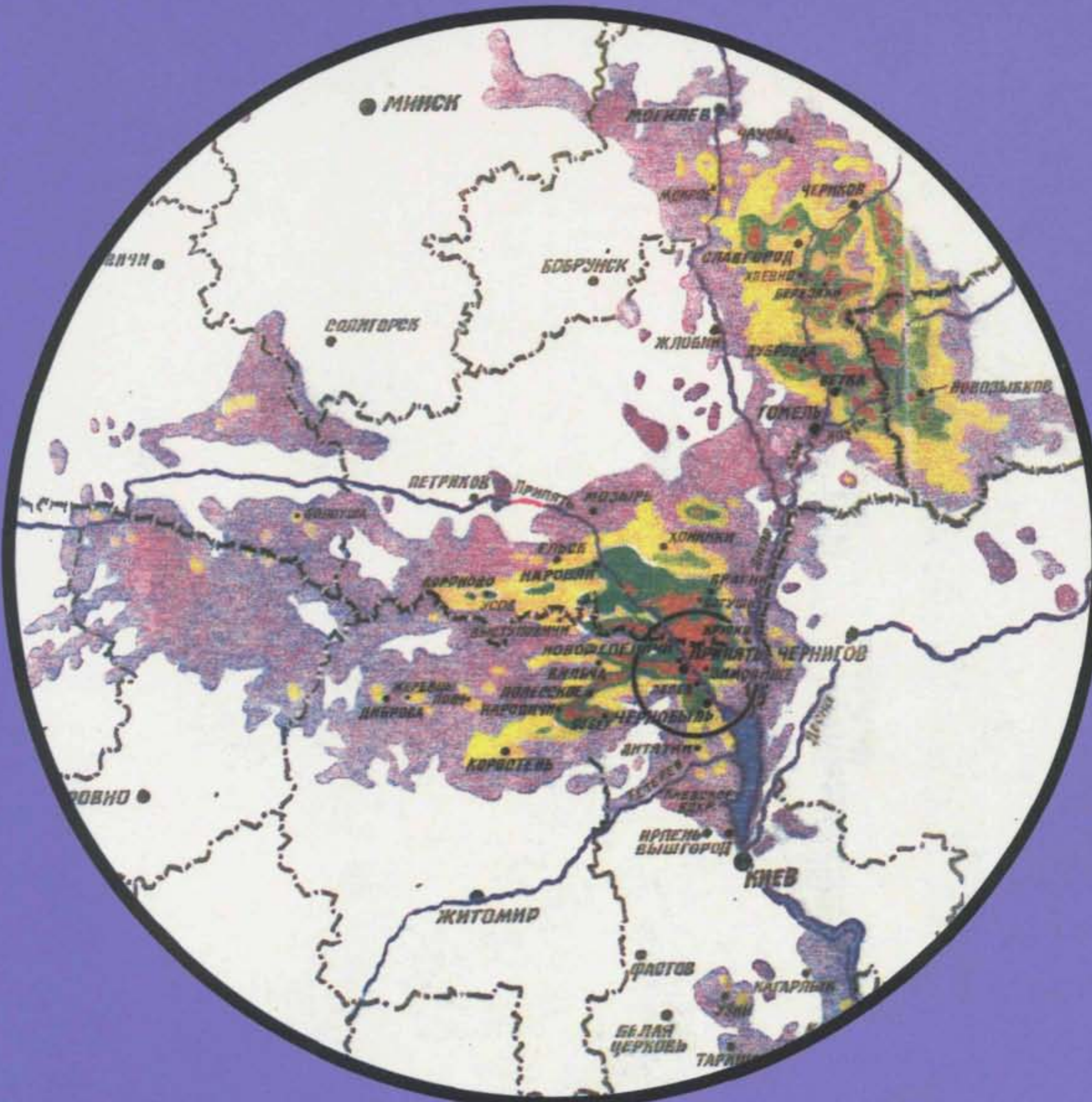
THE INTERNATIONAL CHERNOBYL PROJECT

TECHNICAL REPORT



ASSESSMENT OF RADIOLOGICAL CONSEQUENCES
AND EVALUATION OF PROTECTIVE MEASURES

REPORT BY AN INTERNATIONAL ADVISORY COMMITTEE

THE INTERNATIONAL CHERNOBYL PROJECT

TECHNICAL REPORT

Assessment of Radiological Consequences
and Evaluation of Protective Measures

Report by an International Advisory Committee

ISBN 92–0–129191–4
Printed by the IAEA in Vienna

THE INTERNATIONAL CHERNOBYL PROJECT

TECHNICAL REPORT

Assessment of Radiological Consequences and Evaluation of Protective Measures

Report by an International Advisory Committee

Acknowledgements

The International Advisory Committee wishes to thank the large number of people who were involved in so many different ways in the International Chernobyl Project — the governments, institutions and organizations who donated the time of their staff and the many individuals who gave of their own time for this important work. Gratitude is expressed to the governments and commercial companies which provided equipment and supplies, without which major parts of the work could not have been carried out.

The Service central de protection contre les rayonnements ionisants in France made available a whole body counter van which was essential in the assessment of the whole body burden of radioisotopes of the populations examined. In addition, it provided some 12 000 film badge dosimeters and undertook their analysis.

The United States Environmental Measurements Laboratory in New York made available a large team of experts and the necessary equipment to study in depth the environmental contamination in Novozybkov.

The German Abteilung für Sicherheit und Strahlenschutz of the Forschungszentrum Jülich sent a team with a specialized van to measure 'hot spots' in various areas.

Rad Elec Inc. of the USA supplied several hundred dosimeters for external gamma dose assessments.

The medical field work could not have been accomplished without the help of many individuals, institutes and commercial companies.

The following companies donated essential medical equipment and supplies:

Becton and Dickinson (radioimmunoassay kits), Orangeburg, New York, USA
Coulter Electronics, Hialeah, Florida, USA; Paris, France
Hitachi Medical, Tokyo, Japan
New Mexico State Toxicology Laboratory, USA
Schleicher and Schuell Inc., Keene, New Hampshire, USA
Siemens Medical Systems, Erlangen, Germany

It is impossible to overestimate the value of the assistance and contribution of the many Soviet authorities at the All-Union and Republic levels, and the scientists, experts, technical and administrative staff and members of the public who co-operated with the visiting Project teams. Thanks are also due to the inhabitants and the authorities of, and to the physicians, nurses and other staff of hospitals and clinics in, the settlements visited who helped the Project medical field teams in their work.

A considerable debt of gratitude is due to the IAEA Secretariat, who overcame the many difficulties inherent in an effort of such complexity.

Finally, apologies are due to anyone who may have been missed from these acknowledgements. We are sincerely grateful to all those who contributed.

A comprehensive list of participants in the International Chernobyl Project is included at the end of the Technical Report.

Preface by the Chairman of the International Advisory Committee

It was my privilege to act as Chairman of the International Advisory Committee (IAC), which was composed of prominent experts in different fields. They were called together by the various participating organizations of the United Nations system and the Commission of the European Communities. The IAC approved the work plan for the International Chernobyl Project described in this Technical Report and monitored its implementation. The aims of the Project were to examine assessments of the radiological and health situation in areas of the USSR affected by the Chernobyl accident and to evaluate measures to protect the population.

The task assigned to the IAC was a formidable one. There were unavoidable constraints on the time, manpower and funds available for the assignment. The Project was centred on questions of continuing mass relocation of people and sought to provide sound scientific bases for decisions yet to be made.

The Project teams applied their collective expertise and experience to sort facts from misconceptions and radiation effects from effects not related to radiation exposure. They obtained and examined vast quantities of data in their task to understand the present situation and to draw conclusions on the further steps that might be taken to alleviate the consequences of the Chernobyl accident.

The IAC set out to conduct an independent, scientifically authoritative study and to provide a readily understandable report that could assist responsible authorities in deciding how to proceed. Only time will show the significance of our contribution.

My profound thanks go to all those who contributed to this work: the members of the Committee; the consultants; the task leaders; the team leaders and all the experts who participated; the secretariat of the Project; and the many officials of the USSR, the BSSR, the RSFSR and the UkrSSR who gave their time and efforts to assist in the Project.

Itsuzo Shigematsu
Radiation Effects Research Foundation
Hiroshima, Japan

Editorial Note

Parts C to G of this Technical Report contain the findings of the International Chernobyl Project and were prepared by the respective task leaders. Part H presents the conclusions and recommendations of the International Advisory Committee as adopted at its meeting in Vienna in March 1991. Other parts of the text have been compiled by the Secretariat of the Project and the editorial staff of the IAEA. It should be noted that the views expressed in the Report are not necessarily those of nominating governments or organizations.

The use of particular designations of countries or territories does not imply any judgement by the publisher or the individual authors as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.

The mention of names of specific companies or products (whether or not indicated as registered) does not imply any intention to infringe proprietary rights, nor should it be construed as an endorsement or recommendation on the part of the publisher or individual authors.

While great care has been taken to maintain the accuracy of the information presented in the Technical Report, neither the publisher nor the individual authors assume any responsibility for consequences which may arise from its use.

CONTENTS

Part A
Introduction

Contents

1. Preamble

The accident at Unit 4 of Chernobyl nuclear power plant occurred on 26 April 1986. The subsequent months and years saw unprecedented technical and scientific work in the Union of Soviet Socialist Republics (USSR) to identify the composition and measure the amount of radioactive materials released in the accident and to assess and mitigate the consequences of the release. These activities and their results have led to numerous administrative and policy decisions since the accident that have affected and will continue to affect the lives of hundreds of thousands of people, including their health, way of life, agriculture and socioeconomic conditions.

These decisions, which disrupted and indeed redirected the lives of people who were exposed to radioactive materials released in the accident, gave rise to much opposition and anxiety. Because of this, the Government of the USSR requested the International Atomic Energy Agency (IAEA) in October 1989 to organize and co-ordinate an assessment of the guidance given by the Soviet authorities to persons living in radiologically contaminated areas and an evaluation of measures to safeguard the health of the population.

The response to this request called upon the services and assistance of around 200 scientists from 25 countries (including the USSR) and from the Commission of the European Communities (CEC), the Food and Agriculture Organization of the United Nations (FAO), the International Labour Organisation (ILO), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the World Health Organization (WHO) and the IAEA itself.

The project on the Radiological Consequences in the USSR of the Chernobyl Accident: Assessment of Health and Environmental Effects and Evaluation of Protective Measures was termed the International Chernobyl Project (hereinafter referred to as the Project).

This Technical Report explains the organization and implementation of the Project; presents the background scientific information that served as the basis for the Project; describes the technical activities and analyses carried out under the Project; and sets out the conclusions and recommendations resulting from the Project. It is one of three reports, the others being an Overview report and a Brochure for a wider non-technical audience.

2. Background

One of the major consequences of the Chernobyl accident was the surface contamination by radionuclides of large areas of primarily three Republics of the USSR: the Byelorussian Soviet Socialist Republic (BSSR), the Russian Soviet Federated Socialist Republic (RSFSR) and the Ukrainian Soviet Socialist Republic (UkrSSR). The consequent efforts made by the several authorities to measure, monitor and assess the consequences of the accident and the personnel and financial resources allocated to this were probably the greatest ever in response to a man-made environmental disaster.

Although the information available in the scientific literature is not commensurate with the scale of the radiological contamination, a substantial amount of information on the radiological consequences of the accident was presented at an All-Union Conference on the Medical Aspects of the Chernobyl Accident organized by the Ministry of Health of the USSR and the All-Union Scientific Centre of Radiation Medicine of the Academy of Medical Sciences of the USSR, which was held in Kiev from 11 to 13 May 1988 [1]. The short term human, economic and environmental dimensions of the accident were reported at the Conference: 31 deaths; over 100 000 persons evacuated; the evacuation of thousands of head of livestock; and extensive soil and forest contamination.

Additionally, a report on the radiocontamination patterns and possible health consequences of the accident has been published in the open scientific literature [2].

By mid-1989, the longer term consequences of the accident, including the health and welfare of persons living in contaminated areas outside the early evacuation zone, were becoming a matter of increasing concern. Although there were radiation protection criteria governing relocation policies from 1986 to 1989, more long term guidance was required. In order to provide this guidance on radiological matters, the USSR National Committee on Radiological Protection (NCRP) ultimately proposed a 'safe living concept' and recommended a policy setting a 70 year exposure limit of 35 rem (350 mSv) which would define the upper limit of radiological conditions under which life could proceed without requiring disruptive countermeasures to provide adequate safety over a lifetime.

This policy on intervention criteria for dealing with the radiological situation was summarized in a document submitted by the Soviet delegation to the thirty-eighth session of UNSCEAR [3]. The policy was discussed at an informal experts meeting arranged by the IAEA Secretariat on 12 May 1989. An unofficial summary of this informal meeting was presented at a symposium in Vienna in November 1989 [4]. This guidance immediately became controversial. Other concepts proposed included a two tier lifetime dose limit concept and a surface contamination concept as a criterion for both relocation and compensation payments.

There were conflict between the governments of the USSR and the Republics and controversy among the public in a climate of fear, anxiety, dissent and protest when the USSR turned to the international community for assistance and guidance.

The Government of the USSR requested assistance from WHO with this problem. WHO sent a team of experts in June 1989 whose conclusions were as follows [5]:

> "The expert group was requested to assess the concept of a lifetime dose of 35 rem [350 mSv] as a limit following the accident. They agreed that this was a conservative value which ensured that the risk to health from this exposure was very small compared with other risks over a lifetime. The value of 35 rem [350 mSv] was based on international assessments of the risks to health from ionizing radiation. These are extensive and well documented long term studies in epidemiology and radiobiology.
>
> "The experts felt that a dose level, and not a ground deposition level, was the appropriate primary limit since it was the sum of all pathways of exposure and could be applied to all circumstances of the accident as they changed. Derived levels could be developed for practical application in specific local conditions, but were not the appropriate criteria for a primary limit. The experts volunteered the view that, had they been requested to set a level for the lifetime dose, they would have chosen a value of the order of two to three times higher than 35 rem [350 mSv].
>
> "It became very clear in the meetings that the public and scientists who were not specialists in radiation protection did not fully understand the principles involved. For example, the difference between the dose limits for the population during normal operation and for design purposes was confused with levels following an accident where intervention may be necessary. These are two separate circumstances where different dose levels are appropriate.
>
> "In addition, scientists who are not well versed in radiation effects have attributed various biological and health effects to radiation exposure. These changes cannot be attributed to radiation exposure, especially when the normal incidence is unknown, and are much more likely to be due to psychological factors and stress. Attributing these effects to radiation not only increases the psychological pressure in the population and provokes additional

stress related health problems, it also undermines confidence in the competence of the radiation specialists. This has in turn led to doubts over the proposed values. Urgent consideration should be given to the institution of an education programme to overcome this mistrust by ensuring that the public and scientists in allied fields can properly appreciate the proposals to protect the population.

"In addition, many scientists perceived a lack of available information. The experts were pleased to note that they had access to all information and that the data were available to Soviet scientists. However, in view of the perception that the data were not freely available, every effort should be made to ensure that information is made available on a routine regular basis, perhaps through the appropriate Academies of Science and Medicine in the Republics.

"Considerable concern was expressed over the possible synergistic effects of radiation and other environmental agents. The experts stated unequivocally that at the dose limit proposed, no synergistic effect could result.

"To ensure that the 35 rem [350 mSv] lifetime dose is not exceeded, extensive dosimetric measurements and calculations will need to be continued for the foreseeable future.

"The experts were convinced that the 35 rem [350 mSv] lifetime dose was the minimum at which to consider relocating people, which remedial action should be based on the local conditions, the costs involved and individual preferences and should not be undertaken at a fixed dose level in all situations.

"The experts noted that the lifetime dose limit included the contribution from contaminated food and that the Soviet standards were similar to the levels adopted by the European Communities for unrestricted trade in food and lower than the WHO Guidelines for contaminated food. It was also noted that the importation and consumption of uncontaminated food, if feasible, could significantly reduce the dose from ingestion. Food processing, filtering and other measures can also reduce the level of food contamination.

"The experts praised the efforts of the people and Soviet scientists in dealing with the tragedy of Chernobyl and its aftermath. The experience gained by the Soviet scientists who dealt with this catastrophe places them in the forefront of nuclear accident management and they have a unique opportunity to assist other countries in the development of their emergency plans. It is hoped that this expertise will be sought by and made available to the appropriate organizations whose programmes are directed towards emergency preparedness."

A team of experts from the League of Red Cross and Red Crescent Societies also went to the USSR in early 1990. Their report indicated the following [6]:

"Following the accident at the Chernobyl nuclear power plant in 1986, approximately 100 000 people were evacuated from a 30 kilometre zone around the plant. In July 1989 it was decided that in areas where the lifetime radioactive dose exceeds 35 rem per person, further evacuations would need to be carried out over the next three years. This could involve relocation of as many as another 100 000 people.

"If radiation dose were the only criterion for relocation, there would be some contaminated areas where life would be possible provided permissible levels of contamination in foodstuffs were not exceeded. However, our overall impression was that in practice, in these agricultural communities, there are too many restrictions to permit an acceptable quality of life under these conditions. Therefore, in accordance with well established principles of radiological protection, the indications for relocation should include consideration of the socioeconomic conditions as well as the radiological situation.

"Among the health problems reported it was felt that many of these, though perceived as radiation effects both by the public and by some doctors, were unrelated to radiation exposure. Little recognition appears to have been given to factors such as improved screening of the population and changed patterns of living and of dietary habits. In particular, psychological stress and anxiety, understandable in the current situation, cause physical symptoms and affect health in a variety of ways. We feel that there is a need for more objective information in order to allay many of the fears of the population.

"The Soviet Red Cross has been active in assisting the victims of the Chernobyl accident and intends to continue providing medical and welfare assistance both to the people who have already been relocated and to those about to be relocated. It is felt that there are a number of ways in which Red Cross workers could provide additional help to the victims of the accident, with some assistance from the League. In brief, these would include: the provision of accurate information to people directly affected by the accident; the use of counselling skills in order to help alleviate many of the psychological problems apparent in much of the population living in the affected areas; and the provision of Geiger counters to Red Cross workers in order to help allay many of the fears of the affected population.

"It is also felt that closer co-operation between scientists, both within and outside the USSR, should be encouraged and that closer links should be established between organizations who have an interest in this field.

"In addition, it is felt that other national societies can better formulate their own disaster preparedness plans in accidents of this type by learning from the experience of the Soviet Red Cross. Finally, it is becoming increasingly evident that many large scale disasters result in much stress related behaviour and it is recommended that the Red Cross movement as a whole explore how it can better respond to the psychological effects of disasters."

3. The Request

In a letter dated 6 December 1989 to the Director General of the IAEA, the Government of the USSR requested that the IAEA initiate and co-ordinate the organization and implementation of "an international experts' assessment of the concept which the USSR has evolved to enable the population to live safely in areas affected by radioactive contamination following the Chernobyl accident, and an evaluation of the effectiveness of the steps taken in these areas to safeguard the health of the population".

From this it is clear that the request had two objectives:

- To examine the assessment of the radiological situation in the contaminated areas;
- To evaluate the criteria that were developed in order to ensure safe living conditions in the affected areas.

Implicit in this was the corollary objective: to advise the Government of the USSR whether additional protective measures, especially life disruptive measures such as relocation, should be implemented in order to ensure safe living conditions for the population still living in contaminated areas.

It is important to understand that the request did not extend to an assessment of the health and welfare of those persons who may have been affected by the accident but were evacuated from the contaminated areas and are no longer living in them. Nor did it extend to an assessment of the health and welfare of the 'liquidators'. (This term is used for the emergency response and recovery workers, including those persons who extinguished the fire and contained the accident at the plant, those who entombed the destroyed reactor, and those who participated in the decontamination and recovery activities to reduce the likelihood of further effects on the environment.)

4. The Response

The response was a proposal for a multinational team to undertake an assessment of the radiological situation in the three affected Soviet Republics — the BSSR, the RSFSR and the UkrSSR. The International Chernobyl Project was therefore organized, with the participation of the CEC, the FAO, the ILO, UNSCEAR, WHO and the WMO.

It was clear that extensive efforts had already been made to assess the consequences of the Chernobyl accident and it would not be necessary for the Project to undertake a totally new, comprehensive assessment. Rather, the task would be to assess the quality and correctness of the existing results. Secondly, to be manageable, the international assessment would have to focus on the key issues of concern to the population and policy makers, namely: the true extent of the contamination; the past, current and future radiation exposure of the population; the actual and potential health effects; and the adequacy of measures being taken to protect the public.

5. The International Chernobyl Project

5.1. Goals and Scope of the Project

The International Chernobyl Project was not intended to have the rigour and comprehensiveness of an elaborate long term research study. Nor was it intended even remotely to duplicate the voluminous previous assessments of the environmental contamination, the radiation exposures of the population and possible health effects due to exposures resulting from the accident. The intention was to have a multidisciplinary group of international experts critically examine the extensive information, address the key issues and put together an understandable description of the situation.

The goals of the Project, in short, were to examine assessments of the radiological and health situation in areas of the USSR affected by the Chernobyl accident and to evaluate measures to protect the population.

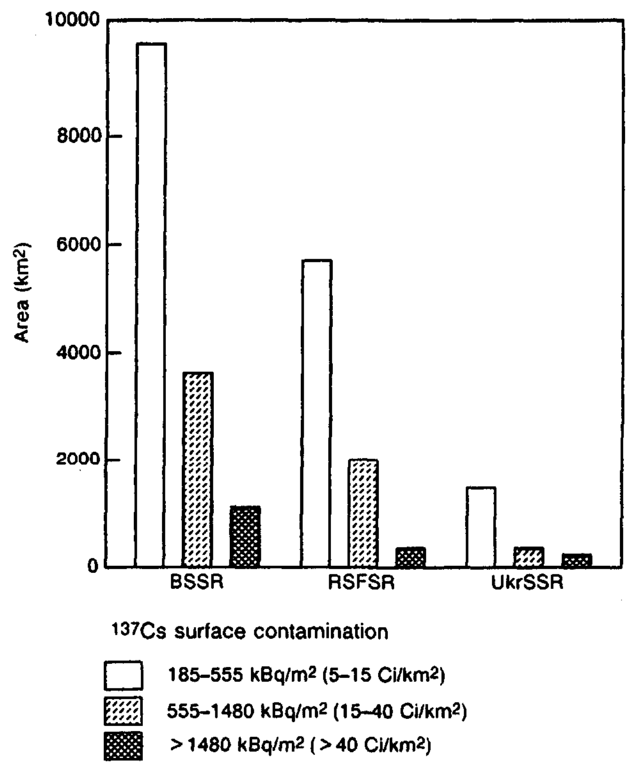


FIG. 1. Geographical framework. The international assessment focused on the approximately 25 000 km^2 in the BSSR, the RSFSR and the UkrSSR officially reported to have a caesium surface contamination level in excess of 5 Ci/km^2 (185 kBq/m^2) and particularly on those areas with a level greater than 40 Ci/km^2 (1480 kBq/m^2). The assessment excluded the prohibited zone (30 km in radius) around the Chernobyl reactor. [Doc. A/45/342 E/1990/102, United Nations Economic and Social Council, Geneva, 9 July 1990.]

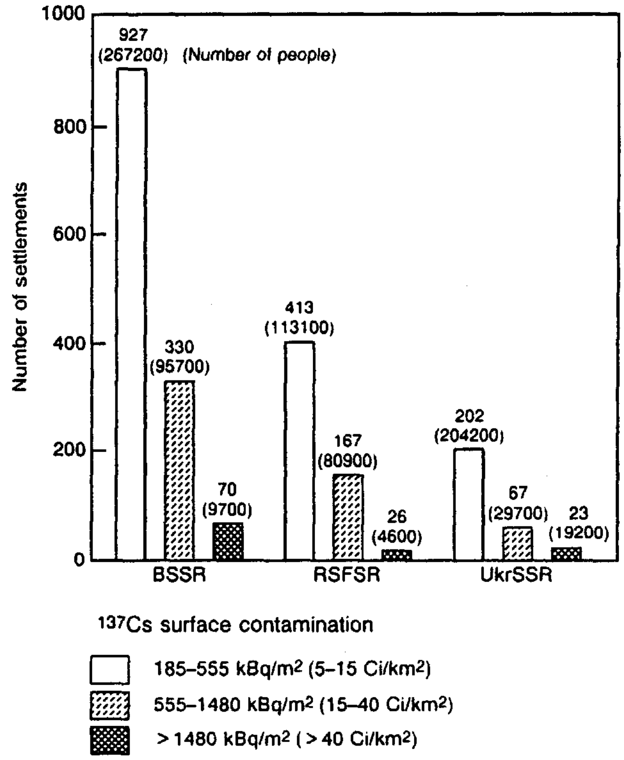


FIG. 2. Demographic framework. The international assessment addressed the radiological consequences for the approximately 825 000 people living in 2225 settlements in the BSSR, the RSFSR and the UkrSSR. It did not include those people who had lived in contaminated areas but had since moved from those areas. Nor did the Project address possible consequences for the so-called 'liquidators', i.e. the recovery workers occupationally exposed at the Chernobyl plant site. [Doc. A/45/342 E/1990/102, United Nations Economic and Social Council, Geneva, 9 July 1990.]

Thirteen districts in the USSR have been officially identified as having a ground level contamination by ^{137}Cs in excess of 1 Ci/km^2 (37 kBq/m^2)[1]. Territories covering approximately 25 000 km^2 are defined as affected areas with ground concentration levels of ^{137}Cs in excess of 5 Ci/km^2 (185 kBq/m^2). Of this total, approximately 14 600 km^2 are in the BSSR, 8100 km^2 in the RSFSR and 2100 km^2 in the UkrSSR. The Project related to these affected areas. It was not in the terms of reference of the Project to investigate the prohibited zone (approximately 30 km in radius) around the

[1] Units of the Système international (SI) d'unités are in general use throughout the world. However, in the USSR old units are still used and the original data were usually presented in the old units. The data in this Technical Report are given in both units.

damaged reactor, except to describe the measures taken to contain the accident in the early post-accident phase. The Project dealt exclusively with the radiological consequences for the people living in affected areas when the assessment began in 1990. From official Soviet reports, this population was approximately 825 000, of whom 45% lived in the BSSR, 24% in the RSFSR and 31% in the UkrSSR (Figs 1 and 2 show the geographical and demographic framework of the Project).

5.2. Preliminary Arrangements

Following the request made by the Government of the USSR to the IAEA for the international assessment, a Preliminary Meeting was held between the appropriate authorities and IAEA representatives to discuss ideas for a project to make the necessary assessments. The meeting was held at the headquarters of the Ministry of Atomic Power and Industry of the USSR in Moscow from 7 to 9 February 1990. It was attended by representatives of the organizations participating in the Project at the request of the three IAEA Member States concerned: the BSSR, the UkrSSR and the USSR.

The participants in the meeting considered a Draft Proposal for the Project prepared by the IAEA Secretariat. The Draft Proposal was well received in general, although additional efforts, specifically on advice pertaining to intervention levels and countermeasures, were requested of the IAEA.

The meeting reached consensus on a number of points:

- The scientific nature of the Project rather than public informational aspects would be emphasized.

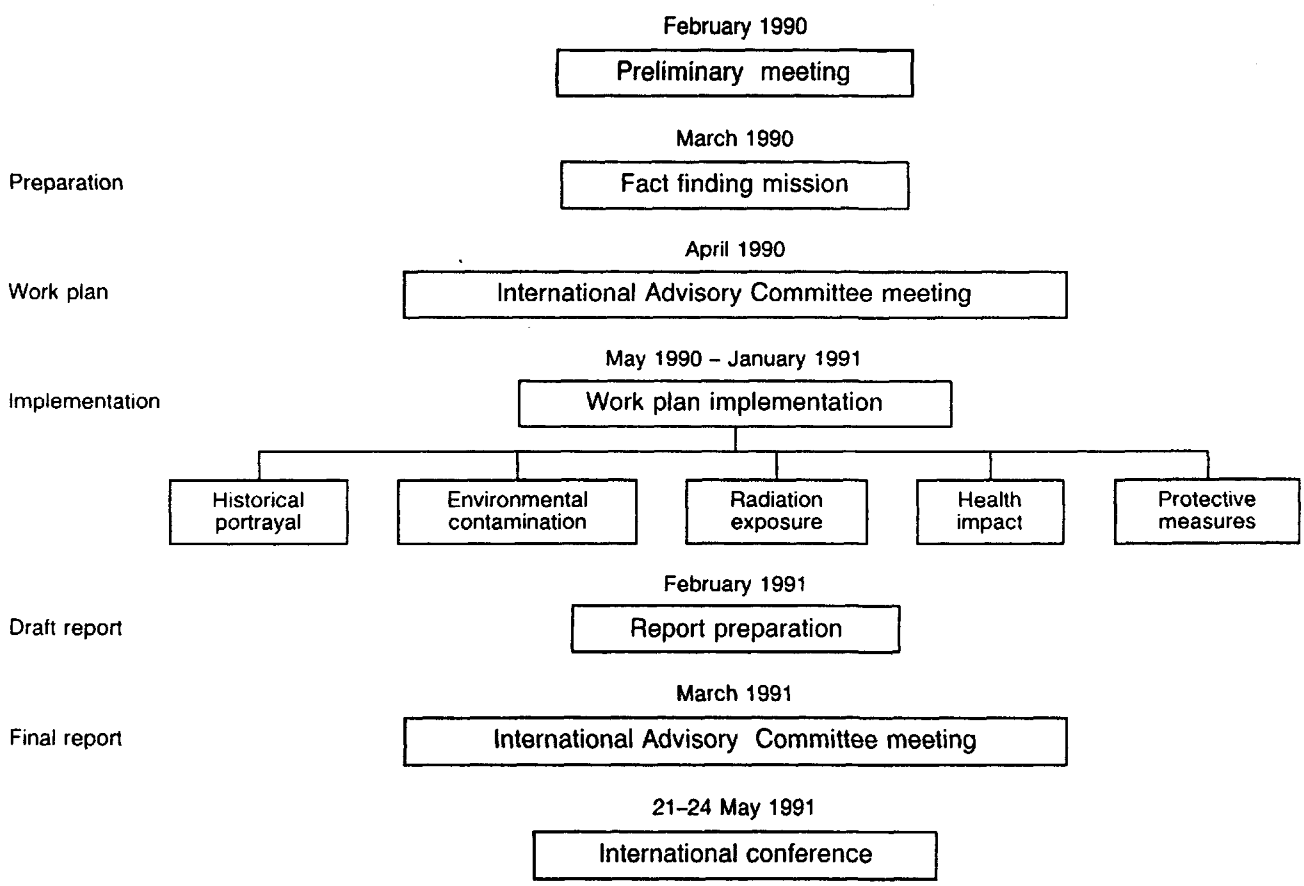


FIG. 3. The International Chernobyl Project. The Project was organized in response to a USSR Government request for an international assessment of the radiological consequences of the Chernobyl accident. The multinational effort was directed by the IAC and included the participation of the CEC, the FAO, the IAEA, the ILO, UNSCEAR, WHO and the WMO. Five tasks defined the Project implementation: the historical portrayal of the events leading to the current radiological situation; the evaluation of the environmental contamination; the evaluation of the radiation exposure of the population; the investigation of public health and possible clinical effects of irradiation; and the evaluation of the protective measures.

- The ultimate objective of the Project was to be the evaluation of the effectiveness of the measures taken in the contaminated areas to safeguard the health of the population; this point was stressed particularly by representatives of the Academy of Medical Sciences of the USSR and the USSR National Commission on Radiation Protection.
- The Project would not be limited to the assessment of doses using standardized transfer factors but rather it would include an evaluation of whether the factors themselves are correct (for example, by direct measurements in contaminated areas).
- The Project would be carried out in distinct phases (see Fig. 3):

  Preparatory fact finding mission: A number of experts, including independent experts and experts from international organizations and the CEC, would undertake a preparatory mission to selected locations in the BSSR, the RSFSR and the UkrSSR.

  International Advisory Committee: An International Advisory Committee (IAC) would be established to develop, approve and monitor a work plan.

  Implementation of the work plan: Teams of international scientific experts would be sent to the BSSR, the RSFSR and the UkrSSR to implement the work plan of the Project.

  Reporting of the results: The several international teams of scientific experts would prepare a Draft Report for consideration by the IAC.

  Approval of the Conclusions: The Draft Report (including conclusions and recommendations) would be reviewed and approved by the IAC.

  Presentations of the Conclusions: The findings, conclusions and recommendations of the Project would be presented to the requesting authorities and to an international conference of experts for scrutiny and discussion. They would thereafter be presented to the public in the BSSR, the RSFSR, the UkrSSR and the USSR.

5.3. Preparatory Fact Finding Mission

Following the agreement reached at the Preliminary Meeting in Moscow, the first phase of the Project was immediately initiated. An international team of experts visited the affected areas in the BSSR, the RSFSR and the UkrSSR on a preparatory mission from 25 to 30 March 1990 to identify major problems that would need to be considered in the assessments carried out under the Project. Participants in the preparatory mission included experts in radiation medicine and radiology, radiation protection, radiation dosimetry, radioecology, food technology and psychology. Some of these experts were representatives of WHO, the FAO and the CEC.

The preparatory mission had three objectives:

- To identify major problems to be addressed in the assessments;
- To recommend the scope and terms of reference for the Project;
- To discuss the Project with the population in the affected areas.

The participants in the preparatory mission visited seven settlements selected by the authorities in the three affected Republics:

- in the BSSR: Bragin, Korma and Veprin;
- in the RSFSR: Novozybkov and Zlynka;
- in the UkrSSR: Ovruch and Polesskoe.

In addition, technical meetings were held in Gomel, BSSR; Kiev, UkrSSR; and in Moscow. These meetings gave the participants an opportunity to make observations in the affected areas, to hear the concerns of the local population, and to begin to understand the type and amount of data that had been collected at the Republican level in the BSSR, the RSFSR and the UkrSSR during the preceding four years.

The general observations made on the preparatory mission can be grouped into the following three categories.

(1) *Publicly available data.* Medical, radiological, environmental and agricultural data were sought during this preparatory mission. Some scientific and technical information related to the Chernobyl accident was already available in the scientific literature. Radiological information had been presented at an All-Union Conference on Medical Aspects of the Chernobyl Accident organized by the Ministry of Health of the USSR and the All-Union Scientific Centre of Radiation Medicine of the Academy of Medical Sciences of the USSR, which was held in Kiev from 11 to 13 May 1988. (The IAEA published the unedited proceedings of the conference [1]. In addition, an article on radiocontamination patterns and possible health consequences of the accident has been published in the scientific literature [2].) Nevertheless, it was apparent that most of the available data had not previously been made available.

(2) *Contamination in inhabited areas.* Previously unreported radiological data were reviewed and assessed, and a more comprehensive understanding of the geographic areas concerned and levels of contamination was gained. Thirteen districts in the three Republics have been identified officially as having levels of contamination due to ^{137}Cs in excess of 1 Ci/km^2 (37 kBq/m^2). As already stated, approximately 25 000 km^2 of territory are

defined as being in affected areas with ground contamination levels due to ^{137}Cs in excess of 5 Ci/km^2 (185 kBq/m^2). Of these areas, approximately 8000 km^2 have ^{137}Cs contamination levels in excess of 15 Ci/km^2 (555 kBq/m^2) and approximately 1700 km^2 have levels in excess of 40 Ci/km^2 (1.48 kBq/m^2).

(3) *Public concerns.* It was in the encounters with the people of the USSR, from the first greeting at the airport in Kiev to the last question in a packed town hall, that the dimensions of the task became clear. Plans for the Project were presented to residents of seven settlements in the three Republics, who were invited to express their feelings and to put questions. The scientists found themselves responding to very human concerns. Large numbers of people, including local government officials, were present at meetings in all seven of the settlements visited. People expressed anxiety about the following:

   (a) Health problems, particularly the health of their children; past and future exposures; and assessments of the radiological consequences of the accident and their effect on living conditions in contaminated areas in the future. These concerns were aggravated by references to a higher incidence of many illnesses as reported in the news media and occasionally by local physicians.
   (b) The adequacy of the Government's proposed measures for limiting radiation exposures over people's lifetimes and those of their children.
   (c) The independence of the Project. These enquiries about the independence of the Project indicated a considerable legacy of mistrust of the authorities, particularly those associated with nuclear programmes, and of scientific and medical personnel. People were concerned that the findings of the study would be vetted by the central authorities in Moscow. Another major concern was the accessibility of the results of the Project. The IAEA report on the radiological accident in Goiânia [7] (in Russian) was provided to the mayors of the settlements in order to show how the results of the Project would be published. The questions asked at the meetings in the seven settlements are listed in Annex II of this Technical Report.

The information obtained, observations made and impressions gained by the participants in the preparatory mission led them to consider and propose two courses of action:

(1) To develop a work plan to provide an operational framework for the technical and scientific assessments that would provide the basis of the response to the request from the USSR;
(2) To take short term actions designed to increase understanding in the medical and environmental fields as soon as possible.

Furthermore, they suggested that the work plan should focus on at least four major activities that should serve as the core of the Project assessment on the validity of the information produced and provided by the Government of the USSR:

- The measurements of environmental contamination;
- The estimates of past, continuing and future radiation exposures of the population;
- The reports of actual health effects and estimated potential health effects;
- The protective measures taken and proposed to safeguard public health.

5.4. The International Advisory Committee

The IAC was established to review the four proposed assessments, to direct the Project and to be solely responsible for its findings and their reporting. The IAC was composed of 19 scientists and physicians selected from universities and scientific institutions, from organizations of the United Nations system and from the CEC. The members represented a range of disciplines that included specialists and social scientists in the fields of clinical medicine, radiation pathology, radiation protection, radiation dose assessment, environmental measurements and analyses, psychology, epidemiology and public health policy.

The chairman of the IAC was Dr. Itsuzo Shigematsu, Director of the Radiation Effects Research Foundation in Hiroshima, Japan. The Committee met from 23 to 27 April 1990 first in Kiev and then in Minsk. After reviewing the preparatory work and the findings of the preparatory mission, and making such modifications as it deemed appropriate, the IAC endorsed the four key areas to be included in the work plan identified earlier and the short term activities. The four key areas then became the basis of the work plan.

The scientific basis for the study was set from the outset to conform with international recommendations of the CEC, the FAO, the IAEA, the International Commission on Radiological Protection (ICRP), the ILO, the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA) and the WHO.

5.5. Implementation

5.5.1. The Work Plan

The work plan adopted called for the investigation of the validity of official methods and findings, and their independent verification through field sampling, laboratory analysis and internationally recognized calculational techniques. An account of the major events since the accident would also be prepared to provide the necessary background for a better understanding of the complexity of the situation and the interrelated nature of the Project's goals.

The work covered five areas or 'tasks':

Task 1: Compilation of an account of the events that led to the present radiological conditions;
Task 2: Evaluation of the official assessments of environmental contamination;
Task 3: Evaluation of the official assessments of radiation exposure;
Task 4: Investigation of public health and possible clinical health effects due to radiation exposure;
Task 5: Evaluation of protective measures.

In the process of developing a work plan to achieve the objectives identified, the IAC was obliged to operate under a number of constraints:

Time elapsed since the accident: The fact that the Project was to commence four years after the accident had occurred precluded any independent evaluation of radiological conditions in the period immediately after the accident. (In this period, conditions were presumably governed by the presence of short lived radioisotopes, the most important of which were the isotopes of iodine.) For this reason, and because of the relative lack of documentation pertaining to the taking of protective measures and their effectiveness, any evaluation of radiological conditions prevailing in this period would of necessity be limited mainly to evaluating the analytical methods that had been employed, using such data as existed.

Time to complete the project: The need for the results of the Project was urgent for all interested parties: the governments of the USSR, the BSSR, the RSFSR and the UkrSSR, the relevant Academies of Sciences, physicians and scientists, and the affected population. The results were awaited with much anxiety and guidance on issues such as the 'safe living concept' was urgently needed. Therefore the goals were to complete any field studies in 1990 and to prepare a Draft Report by January 1991.

Scale: The contaminated areas were large and had hundreds of thousands of inhabitants; consequently, a comprehensive assessment of all the measurements of environmental contamination and of all exposures and their associated health effects was neither feasible nor possible.

Data: There were several limitations to the data provided to the Project: the majority of the supplied data was received in the form of statistics, mainly as averages; in most cases, no error bands were included in the data; very few raw data or detailed contamination maps were submitted, although they were presumed to exist; the data submitted were presented mainly in tabular form and not as computer files, which limited the possibilities of further processing; and most of the data (including names and titles of tables) and methodologies were received in their original Russian language form which required translation and consequently delayed the work.

Resources: The human resources available were dependent upon the generosity of individuals and institutions. The financial resources were provided mainly by the Governments of the BSSR, the UkrSSR and the USSR; these resources were limited.

All of the foregoing limitations combined to preclude any possibility of making independent comprehensive assessments of environmental contamination, exposure and dose estimates, and public health throughout the contaminated areas in the three Republics. Yet to have relied exclusively on information from the extensive assessments made by the several Soviet authorities would be to have forgone the benefits of an independent international assessment.

5.5.2. Short Term Activities

A parallel consideration was the desire of the population living in the contaminated areas for practical advice about how best to cope with the radiological conditions. Project experts concluded that there was a poor understanding on the part of people in the contaminated areas of the scientific principles relating to radiation and its effects (as is indeed generally the case throughout the world) and that this was at the root of many of the medical and social problems observed. Therefore, in addition to the main tasks of the Project, several information exchange activities were carried out in order to raise the level of understanding of the problems in the local scientific community.

Three activities were identified that would be short term, that could be carried out relatively quickly and easily, and that would help to provide some assistance to the medical, scientific and technical communities and to further their knowledge and understanding of radiological issues. The first activity was to provide medical personnel in the BSSR, the RSFSR and the UkrSSR with a more thorough understanding of the effects of exposure to radiation. The second activity was intended to increase the understanding of agricultural countermeasures to mitigate the consequences of the accident and in particular to alleviate problems associated with the transfer of caesium from soil to agricultural products. The third activity was aimed at increasing the understanding of radioecological problems on the part of inhabitants of the contaminated areas.

5.5.3. Implementation of the Work Plan

The Project was carried out by a closely co-ordinated multidisciplinary team of approximately 200 experts from 25 countries (including the USSR) and seven intergovernmental organizations. The experts were organized into five Task Groups, each of which assumed responsibility for reviewing data and carrying out assessments relevant to one of the five tasks identified in the foregoing. From April to December 1990, the experts undertook nearly 50 separate missions to the BSSR, the RSFSR and the UkrSSR. The participating scientists and their affiliations are given in the List of Participants at the end of the Technical Report.

Organizations in many countries volunteered equipment, supplies and computing time which greatly assisted the Project.

Details of the methods used and the implementation of the work plans of the various Task Groups are described in the other parts of the Technical Report. Each Task was carried out by a number of experts who participated in one or more field missions and who were under the general direction of a Task Group leader.

The Project teams, in co-operation with local authorities, selected a number of settlements in the contaminated areas of concern in which to perform the necessary surveys. Some of the settlements were in areas of relatively high soil surface contamination; others were in areas of relatively low soil surface contamination but with the potential for giving rise to high radiation doses. In this Technical Report, these settlements are termed 'surveyed contaminated settlements'.

Settlements outside the contaminated areas of concern were also selected to serve as references for comparative purposes. These settlements are termed 'surveyed control settlements'.

The surveyed contaminated settlements were:

Bragin	Novozybkov
Daleta	Novye Bobovichi
Gden	Ovruch
Gomel	Polesskoe
Khojniki	Rakitnoe
Komarin	Savenki
Korma	Savichi
Kortsevka	Slovechno
Malozhin	Staroe Vasil'kovo
Michul'nya	Starye Bobovichi
Mikulichi	Svyatsk
Milcha	Veprin
Narodichi	Zhatka
Novoe Mesto	Zlynka

The surveyed control settlements were:

Chemer	Surazh
Khodosy	Trokovichi
Kirovsk	Unecha
Krasilovka	

Not all the settlements were investigated in all the Tasks of the Project.

It should be emphasized that the settlements were selected for the study in depth not in order to obtain the worst cases, but in order to obtain independent sampling points, data from which could be compared with existing data. The purpose of the assessment in these settlements was to obtain an indication of the accuracy of the evaluation made by the local authorities and, if possible, to corroborate their results.

A brief summary of the activities of each Task Group follows.

Task 1: Historical Portrayal of Events Leading to the Present Radiological Situation (See Part C)

Project teams visited around 40 institutions in the BSSR, the UkrSSR and the USSR that had participated in the response to the Chernobyl accident and the subsequent actions to mitigate its effects and to assess its consequences. On the basis of information they collected and a review of international literature, the experts prepared an account of the major events leading to the present radiological situation. The issues considered included the accident and its immediate impact on emergency personnel; the measures such as evacuation, decontamination and radioactive waste management that were taken for the protection of public health and the environment; and socioeconomic and political factors. Part C sets the background for the analytical findings of the Project.

Task 2: Examination of Assessments of Environmental Contamination (See Part D)

Within the framework of this Task, technical missions examined the assessments made by the competent authorities of environmental contamination. As part of the work, Task Group members reviewed the officially recorded data on environmental contamination for caesium, strontium and plutonium and evaluated the field sampling techniques, analytical methods and laboratory instrumentation used for the original assessments.

Field work in independently selected settlements supplemented these efforts. The experts took some 2000 measurements of external gamma dose rates in indoor and outdoor locations and collected over 1000 samples of the soil-grass ecosystem and of milk from private and collective farms. A specially equipped van was used to monitor the ground for radioactive 'hot spots' over a 500 km route in and around three towns in the BSSR, the RSFSR and the UkrSSR. The IAEA Laboratory at Seibersdorf in Austria was a major participant in the sample collection and analyses. Independent analyses also were carried out at laboratories in participating countries.

Task 3: Corroboration of Individual and Collective Dose Assessments (See Part E)

One of the major objectives of this Task Group was to examine the original assessments made by the competent authorities of the individual and collective radiation doses to the affected population. Owing to the constraints on time and resources, it would have been impossible for the experts to evaluate the individual doses received by all the inhabitants of the contaminated areas. Instead, a key element of the task was the review of the criteria, methods and input parameters used by the authorities to calculate past, present and future radiation doses to the inhabitants of the contaminated areas.

A second major objective was to monitor independently the external and internal exposures of the population. Monitoring equipment provided by the French Service Central de Protection contre les Rayonnements Ionisants (SCPRI) aided the work. For example, nearly 8000 radiation dosimeters were distributed to inhabitants of selected settlements in both contaminated and non-contaminated areas, and individual monitoring results were recorded. Over a ten week period, Task Group members used a mobile laboratory from SCPRI equipped with four whole body counters to measure internal caesium contamination for some 9000 inhabitants of nine settlements in the BSSR, the RSFSR and the UkrSSR. The results of the individual measurements were validated in France and at the Austrian and IAEA Laboratories at Seibersdorf. This work also included an intercalibration comparison of whole body counting systems in the USSR and in other countries.

Task 4: Investigation of Public Health and Possible Clinical Effects of Radiation Exposure (See Part F)

Initial work was directed towards an assessment of public health in the contaminated areas and towards an understanding of endemic problems, such as goitre and anaemia, which medical authorities had already identified before the Chernobyl accident. An understanding of endemic medical conditions is of importance because reports in the media have attributed certain observed illnesses and congenital malformations to radiation exposures due to the accident. However, such effects would not correlate with available radioepidemiological data from elsewhere, such as those from the 40 year follow-up studies of the survivors of the atomic bombing of Hiroshima and Nagasaki in Japan.

Task Group members met local doctors and examined inhabitants of the contaminated areas and reviewed officially recorded patient data for haematological and immune system disorders, thyroid diseases, cataracts and other factors relevant to both radiation induced and non-radiation-related illnesses. Since medical data from before 1986 are sparse, the experts compared the health status of inhabitants of contaminated areas and inhabitants of non-contaminated areas, the latter serving as a control or reference population.

Nutritional studies were conducted in several settlements to gain insight into lifestyle and dietary habits and how these might affect the health of the population. Task Group members surveyed eating patterns, alcohol and tobacco consumption, and other health related factors, and collected biological and total diet samples from selected families residing in the contaminated areas. Sample analyses for radioactivity, trace elements and heavy metals were conducted at the IAEA Laboratory at Seibersdorf in Austria and at laboratories in participating countries.

Independent medical examinations and clinical analyses of nearly 2300 inhabitants of seven settlements in the contaminated areas and of six control (non-contaminated) settlements were carried out late in 1990 by three Project medical teams. These teams included specialists in thyroid diseases, paediatrics, oncology, haematology, psychiatry and radiology. The examination of children for malignancies, thyroid disorders, anaemia, disorders of the immune system and the clotting system, anxiety, stress and other psychological effects was of primary importance. Haematological, hormonal and chromosomal analyses were carried out at laboratories in six countries.

Task 5: Evaluation of Protective Measures (See Part G)

Task Group members sought in part to promote a better understanding of the complex issues involved in making policy decisions about future protective measures. A series of five decision conferences were conducted by the CEC in the BSSR, the RSFSR and the UkrSSR and with the central authorities of the USSR. Groups of officials from the BSSR, the RSFSR and the UkrSSR and the central authorities of the USSR, together with international experts, investigated quantitative techniques for decision making. The discussions covered not only health and environmental consequences of the accident but also the socioeconomic and political factors relevant to future decisions on protective measures. In the final conference, representatives from the previous conferences evaluated their findings.

Task Group members also evaluated protective measures taken to limit the radiation exposure of the public. The early protective measures included evacuation, sheltering and the administration of stable iodine; possible future protective options include decontamination, agricultural countermeasures, food restrictions and relocation. Pre-1990 protective measures were compared with international guidance available at the time, while the several currently proposed protective measures were analysed in the context of social and economic factors as well as the potential consequences of exposure to radiation.

5.5.4. Implementation of Short Term Activities

In order to respond to the needs of the public and local experts, a series of practical information exchange seminars with the participation of external and local experts were initiated to broaden understanding of how radiation exposures affect the environment and man, how these exposures can be assessed and minimized, and what criteria might be suitable for radiation protection (see Part B).

Medical Seminars

Three-day seminars were held in July 1990 in a number of settlements in each of the three Republics to broaden the knowledge of general practitioners and health administrators. More than 1200 local experts joined the visiting team of four international specialists in discussing the results of long term studies on radiation induced and related illnesses, the ways such illnesses can be diagnosed and treated and the methods that are used to study cancer and other diseases in populations exposed to radiation.

Agricultural Seminars and Investigations

A fact finding mission to the USSR in August 1990 identified the concerns of farmers and farm workers about living and working in a contaminated agricultural environment. At a one-week workshop in Norway in September 1990, agricultural scientists and ministry officials from the three Republics learned about Norwegian techniques for reducing caesium contamination in milk and meat derived from grazing animals and a series of trials using so-called caesium binders were started. During October and November, a series of one-day seminars were held in settlements in the three Republics, with Project experts discussing with some 1300 collective farmers, farm workers, veterinarians and others from the local agricultural community how to use these practical methods and other techniques for soil management in contaminated environments.

Radioecology Seminar

To help local experts better understand the assessment of human radiation exposures following environmental releases of radionuclides, a five-day seminar was held in Kiev in January 1991. More than 200 specialists in radiobiology, radioecology, environmental science and public health from the three affected Republics took part in discussions on such topics as environmental monitoring, the behaviour of radionuclides in the biosphere and the relevance of these nuclides for people.

5.5.5. Participation

The Project was carried out on a completely voluntary basis by a closely co-operating team of some 200 experts associated with research institutes, universities and other organizations in 25 countries and 7 international organizations. The time devoted to the Project was volunteered by governments, institutes, companies or the experts themselves. Nearly 50 missions to the USSR were completed between March 1990 and January 1991. The IAEA Laboratory at Seibersdorf together with 13 laboratories in six countries also participated on a voluntary basis in the collection and analysis of samples. The IAEA Laboratories carried out an intercomparison exercise with participating Soviet laboratories. Governmental authorities and commercial companies in five countries donated equipment and supplies, radiation monitors and computing time to back up the Project work. (See Acknowledgements.)

The Project received the full support of the Government of the USSR and the Republican Governments of the BSSR, the RSFSR and the UkrSSR. Assistance took various forms, including the participation of local scientists in intercomparison exercises, extensive discussions with Project scientists, and assistance in the collection and preparation of field samples and in making medical examinations. Most of the logistical support for the Project was provided by the Ministry of Atomic Power and Industry of the USSR. Open and frank conversations with authorities, scientists and especially local citizens greatly helped the international experts in their understanding of the situation.

5.6. Reporting of the Results

The work of the various Task Groups consisted primarily of the nearly 50 field missions undertaken by teams of specialists. These trips were supplemented, when necessary, by subsequent meetings among the participants to prepare reports on each of the missions. These reports were then submitted by the team leaders to the Task Group leaders. Task Group reports were prepared and submitted by the Task Group leaders to the IAC.

This process culminated in the preparation of three reports:

— a Technical Report
— an Overview report
— a Brochure.

The Technical Report presents all the relevant results from the five Task Groups. It is intended mainly for the scientific community and includes descriptions of the various methods used, interpretation and evaluation of original data from the competent authorities, and compilations and evaluations of data obtained independently by the Task Groups, together with the final conclusions and recommendations of the Project. The Technical Report consists of the following major Parts:

Part C: Historical Portrayal
Part D: Environmental Contamination
Part E: Radiation Exposure of the Population
Part F: Health Impact
Part G: Protective Measures
Part H: Conclusions and Recommendations.

In addition, Part B presents an explanation of radiation and radiation protection issues central to an understanding of the Project as well as a description of activities aimed at achieving a common level of understanding among local and international experts.

The preparation of the draft Technical Report required the collaboration of all the Task Group leaders. This was achieved by first distributing the Task Group reports to all Task Group leaders. A meeting of Task Group leaders chaired by the Chairman of the IAC in December 1990 reviewed the various Task Group reports and sought to achieve coherency and consistency between them. Following the meeting in December 1990, further work was undertaken by the Task Group leaders to finalize their reports, which were then incorporated into the draft Technical Report. The draft Technical Report was distributed to the members of the IAC (see Section 5.7) for review and comment in February 1991.

The Overview report presents a summary of the most important points discussed in the Technical Report together with the conclusions and recommendations. It is intended primarily for decision makers, concerned groups and opinion formers, and also for the public.

Both the Technical Report and the Overview report are issued by the IAEA under the authorship of the IAC.

5.7. Approving the Conclusions: Final IAC Meeting

The IAC, under the chairmanship of Dr. Itsuzo Shigematsu, met in Vienna on 18–22 March 1991 to review and approve the draft Technical Report and the Overview report.

5.8. Presentation of the Conclusions

The work plan envisaged four stages in the presentation of the results of the Project:

- Publication of the Technical Report, the Overview and the Brochure;
- An International Conference on the International Chernobyl Project to be held on 21–24 May 1991 in Vienna;
- Presentation of the results in the BSSR, the RSFSR, the UkrSSR and the USSR;
- Distribution of the Brochure to the public in the contaminated areas.

The International Conference was mainly intended for the presentation of the Project results to a technical audience for discussion. It was open to nominated participants from the Member States of the international and intergovernmental organizations that participated in the Project. In addition, it was open to representatives of the media.

The Technical Report and the Overview are to be presented in the BSSR, the RSFSR, the UkrSSR and the USSR in September 1991. These presentations are for the benefit of decision makers, concerned groups and scientists who have an interest in the Project.

The Brochure is to be presented in open meetings in the contaminated areas in September 1991 to provide the basis for question and answer sessions as well as discussions. It is hoped that these meetings increase understanding of the Project, its aims its accomplishments, and of what its conclusions might mean for the people living in the contaminated areas.

6. Resources

6.1. The BSSR, the RSFSR, the UkrSSR and the USSR

Most of the logistical support for the Project was provided by the Ministry of Atomic Power and Industry of the USSR. A great effort was required in the BSSR, the RSFSR, the UkrSSR and the USSR and a considerable number of personnel had to be allocated to the Project in order that its objectives could be achieved within the extremely tight schedule imposed.

It is impossible to overestimate the support that the Project received in the BSSR, the RSFSR, the UkrSSR and the USSR. The Project could not have been accomplished without the major efforts made by and the support received from the Ministry of Atomic Power and Industry of the USSR, the Governments of the BSSR, the RSFSR and the UkrSSR and the central Soviet Government, local authorities and scientists. Also, the many citizens who spoke freely to the participants in the preparatory mission and the subsequent field missions greatly assisted them in their difficult work.

Specific support included the flights to and from and internal travel within the BSSR, the UkrSSR and the USSR, accommodation, the provision of interpreters and guides, and the assistance of several scientific and technical staff in the field missions and in the intercalibration exercises.

6.2. Participating Experts

The time devoted to the Project by the participating experts was donated by their governments, their organizations, their companies and, in several cases, by the experts themselves. In no case did an expert require to be paid for assisting. The experts' willingness to participate in the Project overcame all obstacles and without them the Project could not have been accomplished. The participating experts are listed at the end of the Technical Report in the List of Participants.

6.3. The IAEA

The IAEA, which was requested by the Government of the USSR to co-ordinate the Project, served as its secretariat.

The resources that the IAEA would need to devote to the Project were underestimated at first. By the time of the International Conference in May 1991, over eight man-years of IAEA staff time had been devoted to the Project. In addition, some unforeseen expenses were encountered in the execution of the Project, such as for travel and purchase of equipment. The IAEA bore all these expenses.

In order to facilitate the field work in the BSSR, the RSFSR and the UkrSSR, an IAEA office was set up in Gomel in the BSSR during the most work intensive period in mid-1990. This office, which was staffed by local personnel, carried out liaison duties with the local authorities, co-ordinated the field visits and served as the central office for the various missions, with word processing and communications facilities at their disposal.

6.4. Other Sources

Many items of equipment were given or loaned to the Project by various institutes and commercial companies. These are mentioned in the Acknowledgements.

References

[1] Medical Aspects of the Chernobyl Accident, IAEA-TECDOC-516, IAEA, Vienna (1989).

[2] ILYIN, L.A., et al., Radiocontamination patterns and possible health consequences of the accident at the Chernobyl nuclear power station, J. Rad. Prot. **10** 13 (1990).

[3] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, The Policy of the USSR National Commission on Radiation Protection on the Substantiation of Temporary Annual Dose Limits for Public Exposure Due to the Chernobyl Accident, UNSCEAR/XXXVIII/10 (internal document of an UNSCEAR Working Group), UNSCEAR, Vienna (1989).

[4] GONZALEZ, A.J., "Recovery operations after the Chernobyl accident: the intervention criteria of the USSR's National Commission on Radiation Protection", Recovery Operations in the Event of a Nuclear Accident or Radiological Emergency (Proc. Symp. Vienna, 1989), IAEA, Vienna (1990) 313-346.

[5] WORLD HEALTH ORGANIZATION, Report on the WHO Mission of Radiation Protection Experts to the USSR, 19-25 June 1989, WHO, Geneva (1989).

[6] LEAGUE OF RED CROSS AND RED CRESCENT SOCIETIES, Report on Assessment Mission to the Areas Affected by the Chernobyl Accident, LORCS, Geneva (1990).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, IAEA, Vienna (1988).

Part B
Broadening Understanding

Contents

1. Introduction

One of the main challenges of the International Chernobyl Project was to achieve a common level of understanding on the expected effects of radiation exposures as well as on international radiation protection principles. This common understanding is a necessary condition for building up a consensus within the scientific and technical communities in the Republics affected and at the All-Union level on the radiological consequences of the Chernobyl accident and on the evaluation of radiation protection measures.

Part B of the Technical Report, therefore, presents basic knowledge on ionizing radiation and its effects on human beings and the environment. It also discusses the internationally agreed radiation protection principles for controlling radiation exposure. Finally, it includes a description of the exchanges of information among local and international specialists carried out under the Project.

The information introduced in Part B has been taken mainly from assessments and recommendations from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU) [1-3].

2. Radiation: Concepts and Quantities

2.1. Ionizing Radiations

The stability of an atom is a result of the balance of the forces within it. Many atoms are unstable. An unstable atom may become stable by releasing energy in various ways, often with the emission of ionizing radiation. Ionizing radiation covers a small part of the electromagnetic and particle radiation spectrum that includes radio waves, microwaves, visible light, ultraviolet and infrared radiation and even electromagnetic waves induced by electric power lines. Radiation of very short wavelength may transfer sufficient energy to an atom to cause an electron to be ejected. This process is termed ionization and radiation able to induce ionization is termed ionizing radiation.

The mass, charge and velocity of a particle or wave form affect the rate at which ionization occurs. Heavy, highly charged particles (such as alpha particles) lose energy rapidly with distance and therefore do not penetrate deeply into matter. Alpha particles (which consist of two protons and two neutrons) do not penetrate the layer of dead cells on the skin surface. Beta particles (electrons from the change of neutrons into protons in the nuclei of radionuclides) may penetrate up to several centimetres into the body. Other types of electromagnetic radiation, such as X radiation and gamma radiation, penetrate well enough to be used for medical diagnostic purposes.

2.2. Radioactivity and Radioactive Decay

An atom of a radioisotope that is unstable attains stability by disintegrating and emitting ionizing radiation. This property is termed radioactivity and such an atom is termed a radionuclide. Radionuclides may emit alpha particles, beta particles, X rays, gamma rays or other types of radiation in radioactive decay. The activity of a substance is defined in terms of the number of disintegrations occurring spontaneously per unit time and its historical unit is the curie (Ci), which is equivalent to 3.7×10^{10} disintegrations per second. This unit has generally been superseded by the Système International (SI) d'Unités unit, the becquerel (Bq), which essentially represents one disintegration per second.

Individual radionuclides decay randomly. The activity of a large number of radionuclides of a given radioisotope decays exponentially with time and the term half-life is used to characterize this decay. The physical half-life of a radionuclide is the time taken for the activity present to be reduced by one half and is a constant for any given radioisotope. Two other concepts are also used: the biological half-life and the effective half-life. The biological half-life is the time taken for an organism to eliminate half its content of a given substance on a strictly biological basis. The effective half-life combines the physical and the biological half-lives. This is the most significant parameter for radioactive substances in the human body. If a given radionuclide has a physical half-life of 24 000 years but its biological half-life is only three hours, the body quickly eliminates the substance.

2.3. Radiation Quantities and Units

2.3.1. Primary Dosimetric Quantities

Absorbed Dose

As radiation passes through air, it can be measured by counting the number of ionized particles it produces. The quantity 'exposure' has been historically defined as the number of electrical charges produced in a unit mass of air and measured in units of röntgens (R). (The international SI unit of exposure is the coulomb per kilogram of air, but this is rarely used in practice.) As radiation penetrates any material, its energy is absorbed and released by the constituent atoms. The absorbed energy per unit mass of material is termed the absorbed dose. The old unit of absorbed dose was the rad, defined as 100 ergs of energy per gram of material. The SI unit is the gray (Gy), one gray being equal to one joule of energy absorbed per kilogram of matter, and equivalent to 100 rads. The effects of radiation on any material, including biological materials such as tissue, depend on the magnitude of the absorbed dose.

Radiation Weighting Factors

Radiation effects, including harm to tissue, are found to depend not only on the absorbed dose, but also on the type and energy of the radiation causing the dose. For radiation protection purposes, these factors are taken into account by weighting the absorbed dose in tissue by a factor related to the effectiveness of the radiation. The weighting factor for this purpose is termed the radiation weighting factor, w_R, and it reflects the type and energy of the radiation incident on the body or, in the case of radiation sources within the body, the radiation emitted by the source (see Table 1).

TABLE 1. Radiation Weighting Factors[a]

Type and energy range		Radiation weighting factor w_R
Photons, all energies (including gamma radiation and X rays)		1
Electrons and muons, all energies[b]		1
Neutrons	< 10 keV	5
	10 keV to 100 keV	10
	100 keV to 2 MeV	20
	2 MeV to 20 MeV	10
	> 20 MeV	5
Protons, other than recoil protons	> 2 MeV	5
Alpha particles, fission fragments, heavy nuclei		20

[a] All values relate to the radiation incident on the body or, for internal sources, the radiation emitted from the source.

[b] Excluding Auger electrons emitted from nuclei bound to deoxyribonucleic acid (DNA).

Equivalent Dose

The absorbed dose weighted by the radiation weighting factors is strictly a dose that is termed equivalent dose in a tissue or organ T, represented by H_T, is given by the expression:

$$H_T = \Sigma_R \cdot w_R \cdot D_{T,R}$$

where $D_{T,R}$ is the mean absorbed dose in the tissue or organ T due to radiation R. The unit of equivalent dose is the joule per kilogram and is termed the sievert (Sv).

Tissue Weighting Factors and Effective Dose

For a given equivalent dose, the likelihood of radiation effects is found also to depend on the tissue or organ irradiated. It is therefore appropriate to define a further quantity, derived from the equivalent dose, to indicate the combined effect of different doses to several different tissues. The factor by which the equivalent dose in a tissue or organ T is multiplied is termed the tissue weighting factor w_T, which represents the relative contribution of that tissue or organ to the total harm (or detriment) resulting from uniform irradiation of the whole body. Tissue weighting factors are given in Table 2. The weighted equivalent dose (a doubly weighted absorbed dose) is termed the effective dose E. The effective dose is thus a measure of the total risk due to any combination of radiations affecting any organs of the body. Generally, effective dose is what is meant when the term dose is used.

The effective dose is thus the weighted sum of the equivalent doses in all the tissues and organs of the body. It is given by the expression:

$$E = \Sigma_T \, w_T \cdot \Sigma_R \, w_R \cdot D_{T,R}$$

TABLE 2. Tissue Weighting Factors[a]

Tissue or organ	Tissue weighting factor w_t
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder[b]	0.05
	1.00

[a] The values of the weighting factors have been developed for a reference population of equal numbers of both sexes and a wide range of ages. In the definition of effective dose, they apply to workers, to the population as a whole, and to both sexes.

[b] For the purposes of calculation, the remainder comprises the following additional tissues and organs: adrenal glands, brain, small intestine, kidney, muscle, pancreas, spleen, thymus and uterus. The list includes organs that are likely to be selectively irradiated. Some of these organs are known to be susceptible to cancer induction. If other tissues and organs are subsequently identified as having a significant risk of induced cancer, they will then be included either with a specific w_t or in the additional list constituting the remainder. The latter may also include other tissues or organs selectively irradiated. In exceptional cases in which a single one of the remaining tissues or organs receives an equivalent dose in excess of the highest dose in any of the twelve organs for which a weighting factor is specified, a weighting factor of 0.025 should be applied to that tissue or organ and a weighting factor of 0.025 to the average dose to the rest of the remainder.

where $D_{T,R}$ is the mean absorbed dose in tissue or organ T delivered by radiation R. The radiation is either that incident on the body or that emitted by a source within the body. The effective dose can also be expressed as the doubly weighted sum of the absorbed dose in all the tissues and organs of the body.

2.3.2. Subsidiary Dosimetric Quantities

Committed Equivalent Dose and Committed Effective Dose

Following an intake to the body of radioactive material, there is a period in which the material gives rise to equivalent doses in the tissues of the body at varying rates. The time integral of the equivalent dose rate is termed the *committed equivalent dose*, $H_T(t)$, where t is the integration time (in years) following the intake. If t is not specified, it is assumed that the value is 50 years for adults and for children the number of years from age at intake to age 70 years. By extension, the *committed effective dose* E(t) to the whole body is similarly defined from the effective dose.

Collective Equivalent Dose and Collective Effective Dose

All the dosimetric quantities already referred to relate to the exposure of an individual. Further quantities in use relate to exposed groups or populations. These quantities take account of the number of people exposed to a source by multiplying the average dose to the exposed group due to the source by the number of individuals in

TABLE 3. Hierarchy of Dose Quantities

Absorbed dose	The amount of radiation energy that is absorbed per kilogram of tissue. It is expressed in grays (Gy).
Equivalent dose	The absorbed dose weighted for the harmfulness of different radiations (by radiation weighting factors) to take into account the different types of radiation and their energies. It is expressed in sieverts (Sv), with submultiples of millisieverts (mSv), microsieverts (μSv), etc. For most practical applications, the radiation weighting factor is unity; that is, the numerical values for absorbed dose and equivalent dose will be equal.
Effective dose	The equivalent dose weighted for the susceptibility to harm of different human tissues. It is a (modified) equivalent dose and is also expressed in sieverts.
Collective effective dose	The effective dose to all the people exposed to a source of radiation. It is expressed in man-sieverts (man-Sv).

Note: In practice, these quantities are expressed as rates (for example, millisieverts per hour, or man-sieverts per year). If the rates are summed over time, the resulting quantity is generally termed the dose commitment. Unless specified, the integration time for a dose commitment is theoretically infinite; for example, the collective effective dose commitment is the sum of all doses received by all individuals (present and future individuals over all time) as a result of a practice or action involving radiation.

the group. The relevant quantities derived are the *collective equivalent dose* S_T, which relates to a specified tissue or organ, and the *collective effective dose* S. If several different groups of people are involved, the total collective quantity is the sum of the collective quantities for each group. The unit for these collective quantities is the man-sievert. These quantities can be thought of as representing the total consequences of the exposure of a population or group, but their use in this way should be limited to situations in which the consequences are actually proportional to both the dosimetric quantity and the number of people exposed. When it is necessary to distinguish between a collective dose and the dose to an individual, the latter is termed the individual dose.

The collective effective dose to a population resulting from the presence of radioactive materials in the environment may be accumulated over long periods of time, encompassing successive generations of individuals. The total collective effective dose to be expected in a given situation is the integral over all time of the collective effective dose rate resulting from (that is, committed by) a single release (or in the case of a continuing operation involving radiation, a unit period of a practice). If the integration is not performed over infinite time, the quantity is described as being truncated at a defined time. If the range of individual doses is large or the time is long, it may be useful to subdivide the collective quantities into elements covering more limited ranges of dose and time. In considering the consequences of a unit period of a practice, it is sometimes convenient to distinguish between the collective effective dose already delivered and the collective effective dose committed over all time.

Dose Commitment

The *dose commitment* ($H_{c,T}$ or E_c) is a calculational tool. It can be assessed for a critical group as well as for the global population. It is defined as the infinite time integral of the per caput dose rate

$$H_T \text{ or } \dot{E}$$

due to a specified event, such as a unit (e.g. one year) of a given practice:

$$H_{c,T} = \int_0^{\infty} \dot{H}_T\,(t)\,dt$$

or

$$E_c = \int_0^{\infty} \dot{E}\,(t)\,dt$$

In the case of an indefinite period of a practice at a constant rate, the maximum annual per caput dose rate $\dot{H}_T$ or $\dot{E}$ in the future for the specified population will be equal to the dose commitment of one year of practice, irrespective of changes in the population size. If the practice is continued only over a limited time period τ, the maximum future annual per caput dose will be equal to the corresponding truncated dose commitment, defined as:

$$H_{c,T}(\tau) = \int_0^{\tau} \dot{H}_T\,(t)\,dt$$

or

$$E_c(\tau) = \int_0^{\tau} \dot{E}\,(t)\,dt$$

See Table 3 for a simplified hierarchy of dose quantities.

3. Radiation in the Living Environment

Section 3 provides a broad perspective on the levels of radiation in the living environment. Throughout history people have lived in a 'radiation environment' (i.e. an environment with radiation as a constituent element): part of the radiation in this environment is natural and part is man-made. Gradually, this 'artificial' man-made radiation has been integrated into the steady radiation environment. Human interaction with this environment and its resulting modifications mean that the radiation environment of today differs from that of yesterday, and it will continue to be transformed in the future.

3.1. The Natural Radiation Environment

Natural sources deliver the highest radiation dose that people normally receive (see Fig. 1). The average annual dose due to natural sources is some 2.4 millisieverts (mSv). Within this statistical average are typical individual doses that range from 1 to 5 mSv a year and in extreme cases, doses to 1 Sv or more.

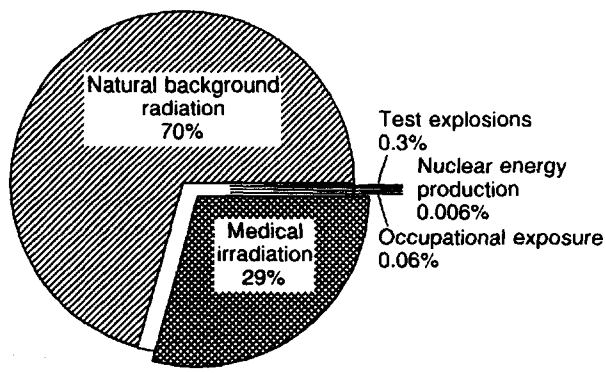


FIG. 1. Sources of radiation exposure: relative contributions to average individual radiation doses. [Source: UNSCEAR [2]]

The two major natural radiation sources are outer space, from which the Earth is irradiated continuously by cosmic radiation; and the Earth's biosphere, which includes radionuclides that have been present, mainly in the Earth's crust, for billions of years. Human irradiation occurs both externally, through exposures to cosmic radiation and to radiation from naturally occurring radioactive materials outside the human body, and internally, through exposure to natural radionuclides biologically present in the human body or incorporated in inhaled air and ingested foodstuffs. Terrestrial radiation is by far the largest natural cause of irradiation, contributing as much as 85% to the average annual dose (see Fig. 2).

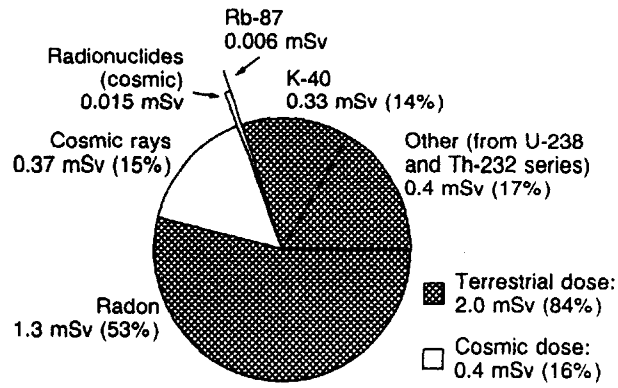


FIG. 2. Estimated annual radiation doses per head from natural sources.

3.1.1. The Cosmic Source

Levels of cosmic radiation are relatively stable at the Earth's surface, but they are affected by the Earth's magnetic field, polar regions receiving more than equatorial regions. More importantly, the level increases greatly with altitude, doubling approximately every 1500 m. Most people live at or close to sea level, so there is little variation around the average dose of 0.37 mSv a year due to cosmic radiation. However, in cities at high altitudes (such as La Paz in Bolivia, Bogota in Colombia and Denver in the USA) the annual doses of cosmic radiation may be much higher than the average level, reaching 1 mSv or more.

3.1.2. Terrestrial Sources

Terrestrial radiation is present at various levels throughout the environment, depending on the activity concentration in such natural materials as rocks, soils, water and air, in food and even in the human body. The most important terrestrial sources are ^{40}K, ^{87}Rb and the two series of radioactive elements arising from the decay of ^{238}U and ^{232}Th. Other radionuclides, such as those in the ^{235}U decay series, make little contribution to total radiation exposure.

The radioactivity in certain rocks and soils is the main source of terrestrial irradiation to people outdoors. Generally, igneous rocks such as granite are more radioactive than sedimentary rocks, with highly radioactive shales and phosphate rocks as notable exceptions. Recent surveys of outdoor external radiation levels in 23 countries, accounting for more than half the world's population, revealed only minor variations. These studies suggest that about 95% of the world's population live in areas where the average annual dose is around 0.4 mSv. Even so, there are well documented examples of areas where people are exposed to exceptionally high levels of terrestrial irradiation. In the coastal areas of Kerala and Tamil Nadu in India, thorium rich monazite sands result in exposure rates that can be up to 1000 times higher than those due to the normal radiation background elsewhere. In Guarapari, Meaipe and Poços de Caldas in Brazil, dose rates can be as much as 100 times the normal level.

Since most people spend most of their time indoors, radiation levels in dwellings are crucial to their exposures. Practically speaking, most indoor terrestrial irradiation can be traced to one all pervasive source: the noble gas radon. (Radon is here used to refer to the nuclides ^{222}Rn and ^{220}Rn and to the chain of their decay products, the so-called radon daughters.)

On average, radon, a naturally occurring, chemically inert radioactive gas created by the decay of ^{238}U, causes slightly more than half (1.3 mSv per annum) the per caput effective dose due to natural background radiation. When radon is inhaled it irradiates the lung and increases the risk of developing lung cancer. This risk increases as the level of radon and the duration of exposure increase. Radon levels in the air vary not only from place to place, but also from season to season, from day to day and, indoors, from hour to hour.

There are several channels for radon entry to buildings, the most important being the underlying or surrounding soils; and also, to a lesser extent, building materials; outdoor air penetrating through openings, gaps and cracks; tap water; and natural gas. Results of indoor surveys have only recently become available and it is likely that exceptionally high radon levels will be recorded for dwellings in many areas that are built on or with materials containing relatively highly radioactive substances.

Internal irradiation by terrestrial sources other than radon is mainly due to the intake of ^{40}K, ^{210}Pb and ^{210}Po. Compared with those of radon exposures, their contribution to the average annual dose level is small. As the intake of ^{40}K is homeostatically controlled in the body, the variability range is low. However, dietary patterns can influence internal exposures to ^{210}Pb and ^{210}Po. For example, these nuclides are concentrated in seafood; and in Japan, where seafood is a preferred food, annual intakes of these radionuclides were found to be five times higher than those in the Federal Republic of Germany and India and ten times higher than those in the USA (Ref. [2], p. 60). An exceptionally large intake of these radionuclides is also known to occur in the extreme northern hemisphere, where reindeer or caribou meat is a staple food for tens of thousands of people. Consumption of the meat of these animals, which graze on lichens that concentrate lead and especially polonium, results in doses to this exposed group that are about ten times higher than the normal level. Lead-210 and ^{210}Po have also been detected in tobacco and in cigarette smoke.

3.2. Altering the Natural Radiation Environment

Four human activities in particular influence the natural radiation environment: the increasing regular and routine use of radiation for medical diagnosis purposes; the atmospheric testing of nuclear weapons; industrial processes that use natural radionuclides; and the generation of electricity by nuclear power.

3.2.1. Medical Uses of Radiation

Medical irradiation is a major source of human radiation doses in addition to the natural environment. The average annual dose due to medical irradiation is between 0.4 and 1 mSv, depending on the method used to estimate doses.

Medical radiation is used largely for diagnostic X ray examinations, including medical and dental radiography, for diagnosis in nuclear medicine by means of internally administered radionuclides, and in radiation therapy[1] for treating cancer and other diseases.

Reliable and detailed information on radiation uses in medical practices is available mainly only for the populations of the developed countries, which amount to less than one quarter of the world's population of over five billion. Sparser data exist for another quarter of the world's population. For more than two and a half billion people, virtually nothing is known about the medical irradiation they undergo, if any.

Medical Diagnostic Radiography

Diagnostic X ray examinations account for nearly 95% of the total doses people receive annually due to medical irradiation. These totals conceal widespread variations in both the absorbed doses due to radiodiagnosis and the extent of its use. For example, on average, there is one X ray machine for every 4000 people in countries with the most comprehensive health care and for every 170 000 people in countries with the least health care. In the first group of countries, on average,

[1] Radiation therapy in the context of this description is unique. Unlike the medical and dental radiological examinations that many people undergo relatively frequently, radiation therapy is generally regarded as highly unusual, remote from daily life and of no influence on the radiation environment. Radiation exposures due to therapeutic medical practices are excluded from further consideration here.

800 X ray examinations are made annually per 1000 people; in many developing countries, there are fewer than 30 examinations annually per 1000 people.

Independently of the extent of use of radiography, individual doses also differ, depending on such factors as the type of examination, the procedure adopted and the efficiency of the equipment. For one thing, the practice of performing mass chest X rays is no longer considered useful in most developed countries, whereas in many developing countries the opposite seems to be the case. In China, for example, more than 75% of all diagnostic radiographical examinations are of the chest. More importantly, while for chest examinations radiographic techniques are still used exclusively or extensively in most developed countries, data for developing countries suggest wide use of fluoroscopic techniques which can result in doses to patients that are 15 times higher than those due to radiography (and even higher doses for the medical staff).

The lack of data on the use of fluoroscopy in many countries gives rise to major uncertainties in conclusions about doses from diagnostic X rays. Another factor affecting dose levels is the performance efficiency of the diagnostic equipment. Significantly, it is estimated that in many countries 30–70% of items of diagnostic X ray equipment are estimated to be malfunctioning.

Dental Radiography

Dental radiography accounts for only 1% of medical exposures, with the dose for individuals averaging 0.04 mSv per examination. This is the most frequent type of diagnostic X ray examination: some 340 million dental X rays are performed each year, mainly in countries with well developed health care systems.

Diagnostic Nuclear Medicine

As a whole, the use of nuclear medical techniques has increased since they were introduced some 30 years ago. In a few cases, such as in the USA, the frequency of the use has declined periodically because of the advent of alternative techniques such as ultrasound. Absorbed doses from diagnostic nuclear medicine represent only 4% of the collective absorbed dose due to all diagnostic medical irradiation. The different types of radionuclide used (for example, ^{131}I or ^{99m}Te) account for the wide range in the average annual doses.

3.2.2. Nuclear Weapons Testing

Between 1945 and 1980, there were more than 400 nuclear explosions in the atmosphere for the purpose of testing nuclear weapons. Atmospheric testing had two peak periods: 1957–1958 and 1961–1962, in each of which there were 128 tests but with the yields for the latter period being about four times higher than those for the earlier peak. These tests released substantial amounts of radioactive material into the environment.

In 1963, the USSR, the United Kingdom and the USA concluded the Partial Test Ban Treaty, undertaking to cease atmospheric testing; subsequent atmospheric tests by France and China were considerably less frequent and smaller in yield. However, underground testing of nuclear weapons continues.

The fallout from atmospheric testing contains several hundred different radionuclides, but only four are of concern to present and future populations: ^{14}C (with a half-life of 5730 years), ^{137}Cs (half-life 30 years), ^{90}Sr (half-life 30 years) and tritium (half-life 12 years). Carbon-14 accounts for some two-thirds of the committed exposures because of the relatively short half-lives of the other radionuclides. A very small contribution from ^{239}Pu, ^{240}Pu and ^{241}Am (0.1%) to the dose rate will occur over thousands of years. Individually, the average annual due to atmospheric testing is 0.01 mSv; however, because of the long lived nuclides yielded, the collective dose commitment due to atmospheric testing is the largest of all those from man-made sources.

3.2.3. Industrial Processes and Natural Radionuclides

Industrial processes, such as geothermal energy production and phosphate mining, bring to the Earth's surface materials with above average concentrations of natural radionuclides. Other processes, such as coal combustion and phosphate fertilizer production, treat materials with average or above average amounts of natural radionuclides, concentrating the radionuclides into one or more products or by-products. The impact of the resultant exposures on the radiation environment has not been significant. However, these exposures are not systematically monitored, and the accelerated growth of many of these processes, particularly energy production, suggest a greater effect in the decades ahead.

Electricity generation from energy sources other than nuclear also may increase human radiation exposures (see Fig. 3). In many countries, coal is a viable energy option for meeting the increasing demand for electricity. In fact, nearly 70% of the 2.7×10^{12} kilograms of coal equivalent produced worldwide in 1981 was used for generating electricity (with 20% for carbonization and 10% for domestic heating and cooking). Coal, like most natural materials, contains natural radionuclides and these are released during combustion. How much radioactive material is released depends on the activity concentration in the coal, the ash content, the combustion temperature, the partitioning between the heavy slag-ash at the bottom of a furnace and the lighter fly-ash, and the

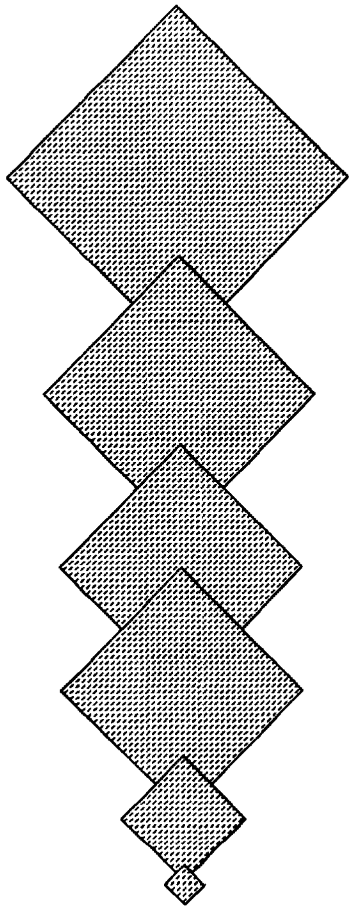


FIG. 3. Estimated collective dose commitments (in man-sieverts per gigawatt-year) due to different means of generating electricity.

efficiency of the emission control devices. There are two different types of coal fired power plants in use: older plants that release about 10% of the fly-ash, and more modern plants equipped with pollution control devices that release only about 0.5% of the fly-ash. On the assumption that two thirds of plants worldwide are older plants, the generation of electrical energy by coal combustion results in a collective dose commitment of 4 man/Sv per gigawatt-year of electricity generated.

Coal combustion gives rise to radiation exposures through other pathways also. Much of the fly-ash collected by emission control devices is used to manufacture cement and concrete for construction, which cause radiation exposures. Waste material is frequently dumped in the vicinity of the power plant, posing potential radiation hazards by resuspension and contamination of surface and underground waters. Assessments of radiation dose due to these practices are lacking.

Geothermal energy is another source of radiation exposure. Although its share in electrical energy production is small, its relative importance is expected to grow. Most of the activity in geothermal fluids derives from the uranium decay chain, specifically from radon. On the basis of measurements of radon in geothermal fluids for several countries, the normalized collective dose commitment is estimated at 2 man/Sv per gigawatt-year of electricity generated.

Peat is burned for energy production in several countries, notably Finland, Ireland and Sweden. Flowing surface and ground waters carry natural radionuclides into peat bogs, where they are eventually absorbed in peat matter. Little information is available on the environmental discharges of natural radionuclides from peat power plants. Assuming that the combustion of 5×10^9 kilograms of peat is needed to generate 1 gigawatt of electrical energy, the normalized collective dose commitment is estimated at 2 man·Sv per gigawatt-year of electricity generated. Over the long term, the storage and disposal of uranium rich peat ash may have the greatest radiological impact.

Both oil and natural gas play a lesser role in radiation exposures from electricity generation worldwide. The collective dose commitments are comparatively low: 0.5 and 0.03 man·Sv per gigawatt-year of electricity generation, respectively.

3.2.4. Radiation and Nuclear Energy

The routine generation of electricity by nuclear means releases radioactive materials into the environment. Additionally, nuclear generation of electricity, like all industrial activities, has the potential for accidents. Since the first commercial nuclear power plant began operation in 1956, the nuclear power industry worldwide had accumulated more than 5000 reactor-years of operation without experiencing any large accidental release of radioactive materials into the environment. However, the accident at Chernobyl took severe accidents out of the hypothetical realm. Given the uneven distribution of exposures, it is questionable whether the average global exposures due to the Chernobyl accident should be compared with those from steady sources, including natural radiation. However, such comparisons may be useful for understanding the impact of the accident in particular (see Subsection 3.2.4.2) and of nuclear energy in general on the radiation environment.

Routine Generation of Nuclear Electricity

Under normal circumstances nuclear electricity generation releases only negligible amounts of radioactive materials into the environment. On average, the annual dose from all practices in the nuclear fuel cycle is only a tiny fraction (less than 0.1%) of that from natural radiation. Exposures due to nuclear energy production occur at all stages of the fuel cycle, and consequent radiation doses are assessed over space and time (see Figs 4 and 5).

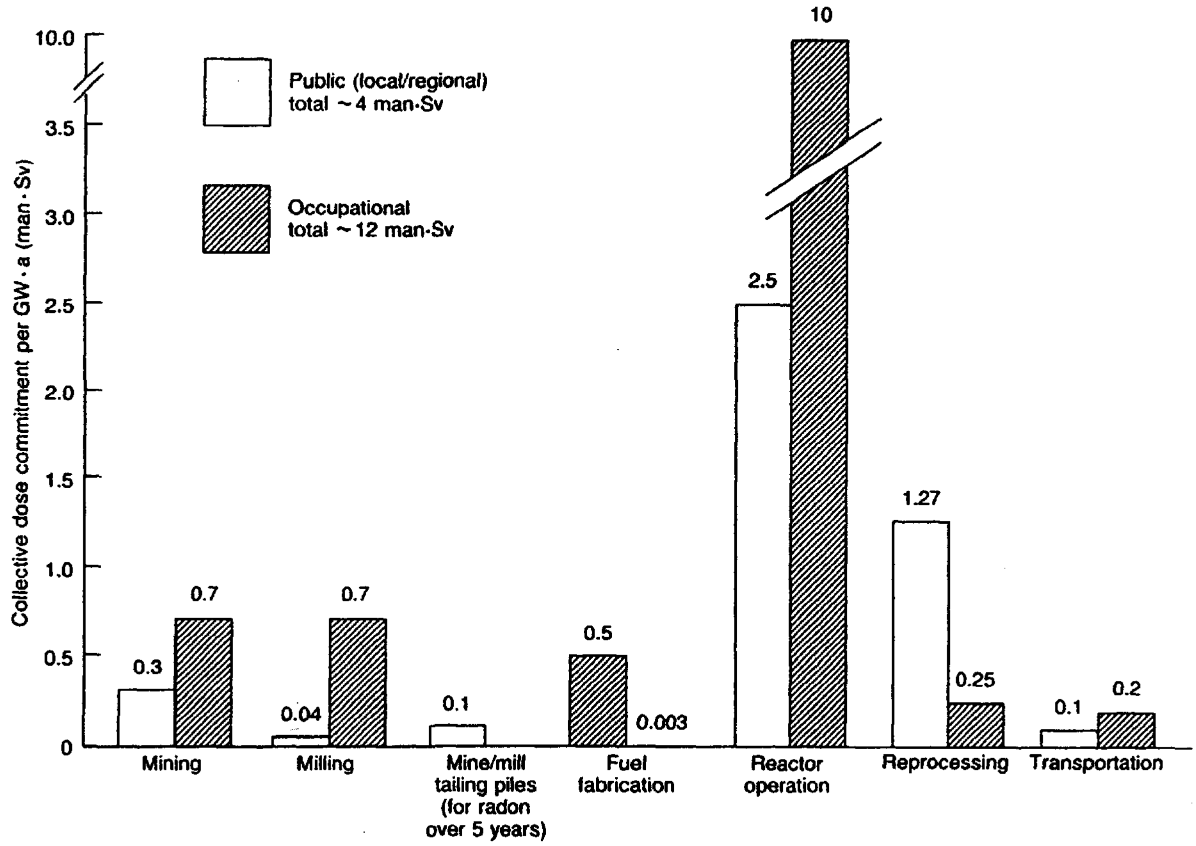


FIG. 4. Estimated collective dose commitments (in man-sieverts per gigawatt-year of electricity generated) over the short term to local and regional populations and to workers due to various stages of the nuclear fuel cycle (normalized).

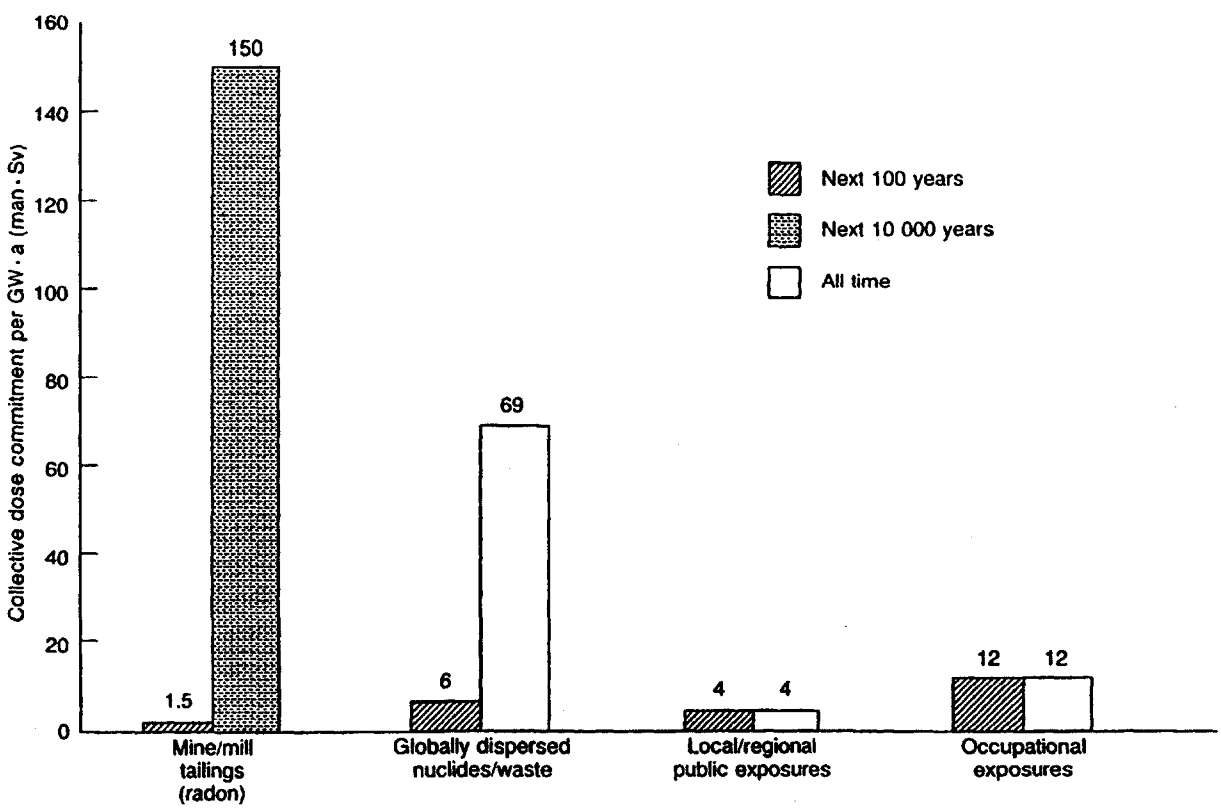


FIG. 5. Estimated collective dose commitments (in man-sieverts per gigawatt-year of electricity generated) over the long term to local and regional populations and to workers due to various stages of the nuclear fuel cycle (normalized).

Uranium mining and milling: Operations at mines give rise to radioactive effluents mainly in the vented air from underground mines or from the pit releases for surface mines. The stockpiles of ore and accumulations of other materials from uranium extraction are responsible for atmospheric releases. The current practice is to store tailings in open uncontained stockpiles or behind engineered dams or dikes with a solid or liquid cover. Radon from mining and milling results in average dose commitments of 0.1 man·Sv per gigawatt-year of electricity generated. Dose commitments to local and regional populations from mining and milling are approximately 0.3 and 0.04 man·Sv per gigawatt-year of electricity generated, respectively.

Nuclear fuel fabrication: Nuclear fuel fabrication gives rise to comparatively minor atmospheric and aquatic discharges. Most uranium compounds are solid and can be easily removed from airborne effluent streams. The collective dose commitment to the public due to nuclear fuel fabrication is 0.003 man·Sv per gigawatt-year of electricity generated.

Reactor operation: Doses to the public due to reactor operations have steadily declined over the past few years, even as electricity generating capacity has increased. This is attributable partly to the comprehensive radiation protection systems at nuclear power plants and partly to increased plant operational efficiency.

Reprocessing: A number of reprocessing plants are operating commercially, including La Hague and Marcoule, both in France, and Sellafield (formerly Windscale) in the United Kingdom. Together, these facilities reprocess only a small percentage of the world's irradiated fuel. The rest is in storage, pending national policy decisions on fuel reprocessing. Long lived nuclides (e.g. ^{14}C, tritium, ^{85}Kr and ^{129}I) in reprocessing effluents are of major concern. Liquid discharges from reprocessing plants are responsible for most of the dose commitment of 1.27 man·Sv per gigawatt-year of electricity generated.

Transport: Exposures to local and regional populations due to the transport of radioactive material in the fuel cycle chain are comparatively low, with a dose commitment of about 0.1 man·Sv per gigawatt-year of electricity generated.

Long term prospects: Fuel cycle operations also give rise to much longer lived radionuclides which remain in the biosphere for thousands of years. On the assumption that these radionuclides deliver doses over a hypothetically infinite time, the dose commitment is 66 man·Sv per gigawatt-year of electricity generated. However, only 10% of this total will be delivered over the next 100 years. Conceptually, radon exposures from mill tailings could become significant in the very long term (e.g. over the next 10 000 years), contributing as much as 150 man·Sv per gigawatt-year of electricity generated.

The Chernobyl Accident: Out of the Hypothetical Realm

Global radiation exposures due to the Chernobyl accident can be assessed on the basis of the extensive information available from the international and national groups that have collected and analysed data on the consequent radioactive fallout. In particular, UNSCEAR, together with the IAEA and the World Health Organization (WHO), assessed the global radiological impact of the accident based on the basis of data from nearly 40 countries.

The findings on the major radionuclides released indicate widespread variations in the estimated doses to the public in countries other than the USSR. The dose commitments from the accident will be delivered mainly over the next 30 years or so, mostly owing to the continuing exposures due to ^{137}Cs. Even the highest regional commitment (nearly 1.2 mSv), recorded for populations in southeastern Europe, represents only a small fraction of the 30 year dose (some 70 mSv) that the populations concerned will receive inevitably over this period due to natural background radiation (see Fig. 6).

The doses received during the first year after the accident are also comparatively small. In Europe, first year doses varied, representing 25–75% of the annual doses due to natural background radiation. Countries in the western part of Europe and in Asia, North Africa and North and Central America were less affected. As expected from previous experience in the measurement of fallout due to the testing of nuclear weapons, the southern hemisphere remained essentially unaffected by contamination (see Fig. 7).

In addition to the assurances in the UNSCEAR reports [1,2] (see Section 1), in January 1988 the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD) published the findings of its evaluation of the radioactive fallout due to the accident recorded in the OECD countries (mainly western European countries). It concludes that "... individuals in the OECD countries are not likely to have been subjected to a radiation dose significantly greater than that received from one year of exposure in the natural radiation background. As a consequence, the lifetime average risk of radiation related harm for the individual members of the public has not been increased to any noticeable extent by the accident; the number of potential health effects (cancers and genetic effects) that can be derived by calculating collective doses will not constitute a detectable addition to natural incidence of similar effects within the population."

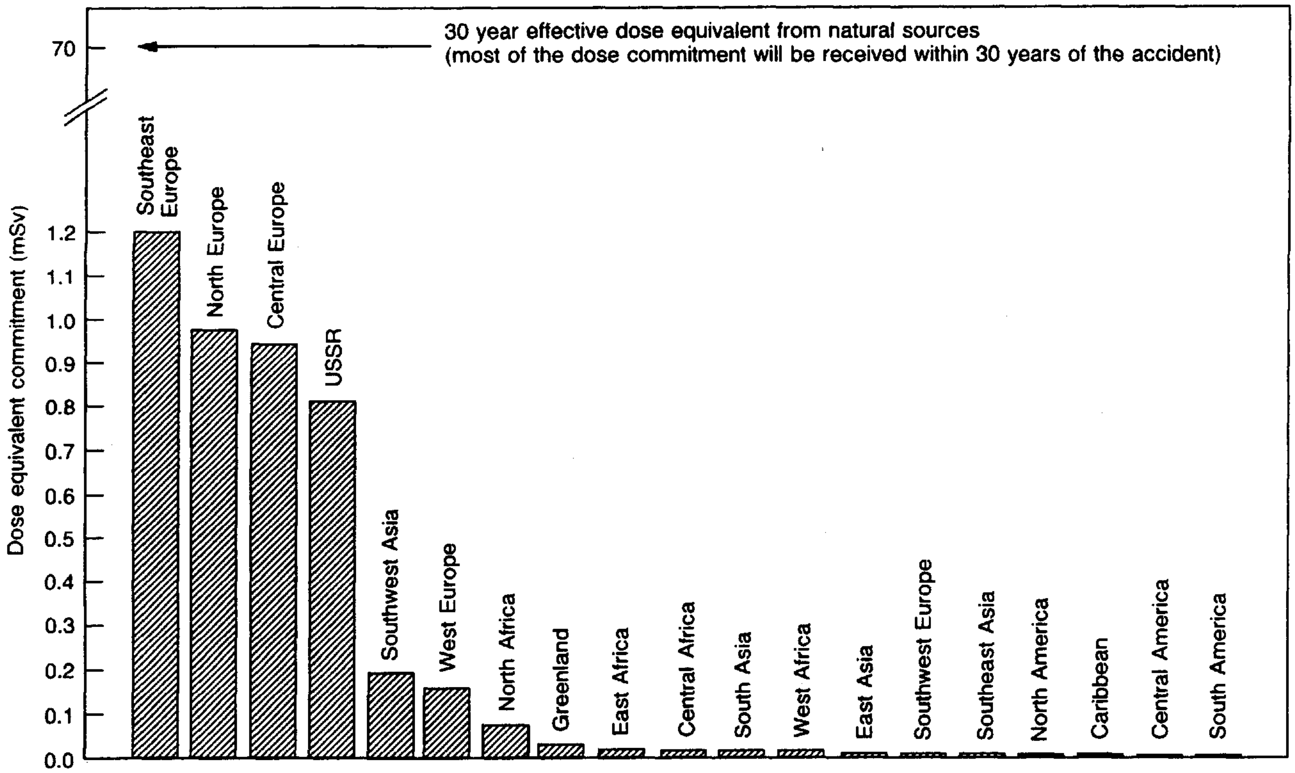


FIG. 6. Regional average dose equivalent commitments due to the Chernobyl accident. [Source: UNSCEAR [2]]

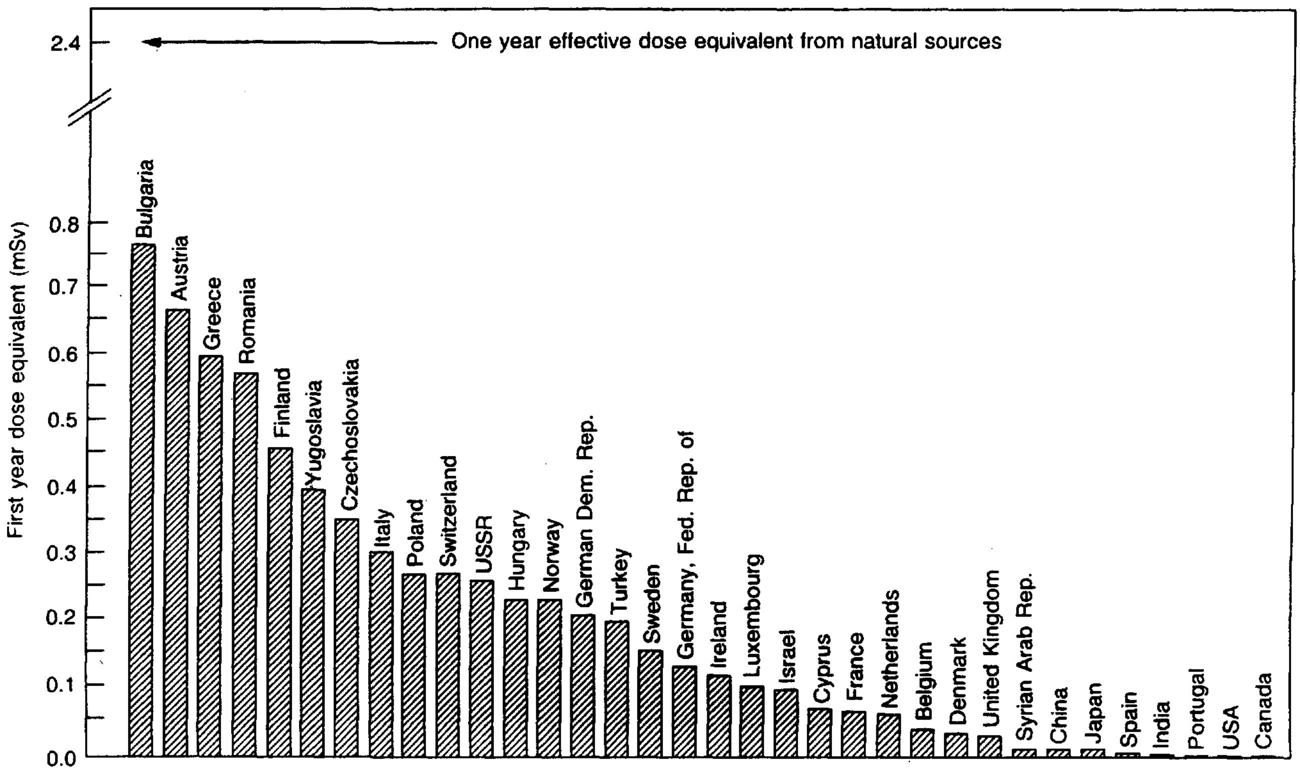


FIG. 7. Country average first year committed dose equivalent commitments due to the Chernobyl accident. [Source: UNSCEAR [2]]

3.3. A Synopsis

From a comparative analysis of radiation in the living environment, a sound factual basis emerges. Under normal conditions, the contribution of nuclear power production to radiation exposure is orders of magnitude lower than the exposure to which an individual is subjected from all other sources. In terms of the collective dose commitment, under normal conditions and excluding the commitment from the very long lived radionuclides, average public exposure due to the production of nuclear generated electricity is equivalent to one additional hour of average exposure to natural background radiation yearly. When these long lived radionuclides (mainly ^{14}C) are included, the committed dose is equivalent to that due to slightly more than one and a half days of natural background radiation yearly.

In the extreme case of the Chernobyl accident, the *global collective dose commitment*, mainly due to ^{137}Cs, to be delivered over the next 30 years corresponds to 21 days of exposure to natural background radiation. (However, individual doses due to the accident were very unevenly distributed.)

The routine worldwide use of radiation for medical diagnosis is a major modifier of the radiation environment. The average annual dose due to this use of medical radiation, particularly diagnostic X ray examinations, is equivalent to 20–45% of the annual average individual dose due to natural background radiation. Collectively, exposures due to medical irradiation are equivalent to 1.4 to 6 months of exposure to natural background radiation yearly. (Medical radiation practices, however, vary widely among the population, with some individuals subject to twice as much exposure from medical irradiation as from natural background radiation.) Moreover, medical irradiation is likely to increase over the next decades if life expectancy increases and medical services reach more of the population in developing countries. By 2000, the collective dose will probably have increased by 50% and by 2025 it may have doubled.

Irradiation due to ^{14}C affects the dose commitment from the atmospheric tests over the past few decades. When the exposure due to this very long lived radionuclide is taken into account, the annual collective dose commitment corresponds to 28 months of exposure to natural background radiation; excluding this, it corresponds to 6 months of exposure to natural background radiation.

4. Release of Radioactive Material to the Environment: Pathways of Human Exposure

The pathways by which man may be exposed following a release of radioactive material to atmosphere are qualitatively well known and their relative importance is understood. If good quantitative data are available for the various processes involved, then accurate assessments of the exposure via each of the pathways are possible.

Following any release of radionuclides to atmosphere, people can be exposed via a number of different routes. As the radioactive cloud is dispersed and transported by the prevailing winds, people are initially exposed to radiation by two principal routes: external irradiation from material in the cloud and internal irradiation following inhalation of radioactive material in the air. Subsequently, the contents of the cloud are gradually depleted during its dispersion as radioactive materials are transferred to the ground and water bodies under dry weather conditions, with precipitation or in fog. People may then be exposed and may continue to be exposed by other routes, the three main ones being: external irradiation from the deposited material itself, the inhalation of any material resuspended into the atmosphere, and the transfer of material through the terrestrial and aquatic environment to food and water, which can give rise to internal irradiation.

Figure 8 illustrates the main pathways leading to radiation exposure of the individual following a release of radioactive materials to the atmosphere. This provides a rather simple picture of the routes of exposure. In reality, of course, each of these pathways has its own additional complexities and these are discussed in more detail in the following sections.

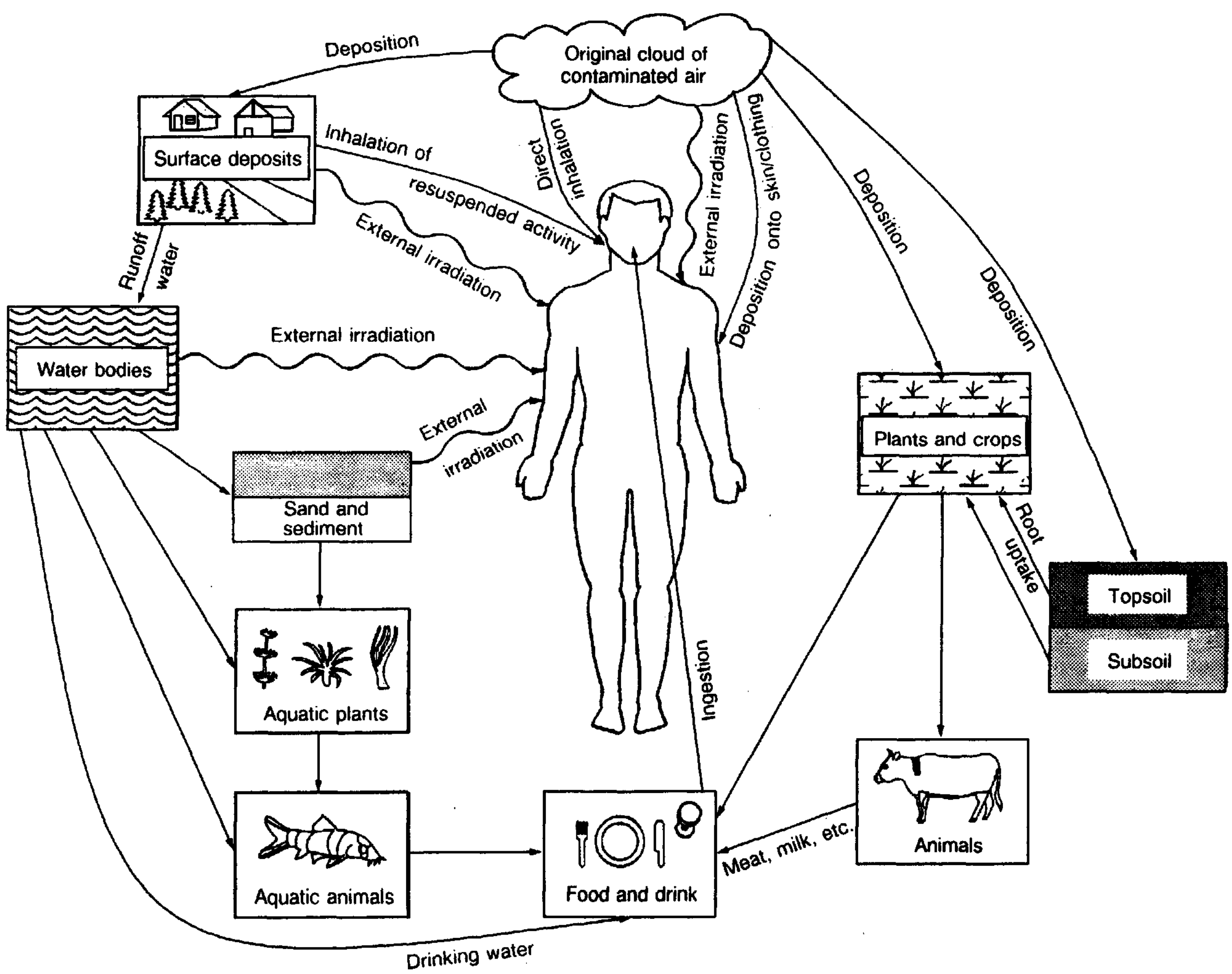


FIG. 8. Main environmental pathways of human radiation exposure.

4.1. Dispersion and Deposition of Radioactive Material

The processes whereby material is dispersed in and deposited from the atmosphere are very complex. Once the radioactive material is released, turbulent eddies in the atmosphere mix the effluent particles and gases within the expanding contaminated plume, which is transported in the wind direction. Both these processes are summarized in the term 'dispersion', which depends on the wind direction, speed and weather stability as well as on the heat content of the plume, features of the terrain and coastal influences.

The dispersing material may then become involved in precipitation formation processes within a cloud, leading to removal by rain-out. Wet deposition may also result from interaction between falling rain drops and dispersing material, referred to as wash-out. Under atmospheric conditions without precipitation, the material may be removed from the plume by gravitational settling and contact with the ground, vegetation or structures in urban areas. These removal processes are referred to collectively as dry deposition. All material except the noble gases is assumed to be removed from the atmosphere by dry and wet deposition processes. Deposition depends on many factors, such as the physico-chemical form of the material, the nature of the underlying surface for dry deposition, and the type and intensity of precipitation for wet deposition.

4.2. External Exposure Pathways

Accidental releases of airborne radioactive material lead to the contamination of air and the ground surface due to atmospheric dispersion and deposition processes. Indeed, external irradiation due to radioactive material deposited on the ground would usually make a significant contribution to both short and long term exposures following a nuclear accident.

In general, external exposure depends on the distribution of the concentration of radionuclides in the passing air and subsequently deposited on the ground, the types and energies of the radiation emitted by each radionuclide, and the transmission of the radiation from the source through different media to the body. In Subsection 4.2.1, general principles common to all the routes of external exposure are described. The subsequent subsections deal with the exposure pathways.

4.2.1. General Principles

As discussed in Subsection 2.2, radioisotopes emit alpha particles, beta particles or photons or some combination of these. Since alpha particles are rapidly absorbed within a few centimetres of air, they do not travel far and even if originating from close to the body do not usually penetrate the outside layers of dead skin. Therefore, alpha radiation is not an external exposure hazard. Beta particles travel several metres in air before being absorbed. Because of this, the beta radiation dose will depend only on the beta emitter concentration local to an individual. Beta radiation also has only a limited range in tissue, a few centimetres at the most, before being completely absorbed, and thus represents a radiation hazard only to those organs situated close to the body surface, in particular the skin. However, photons or gamma rays travel typically hundreds of metres in air and their highly penetrating radiation leads to exposure of all tissues of the body. Thus the gamma radiation dose can depend on the gamma emitter concentration at large distances from an individual. However, the dose distribution within the body is much more uniform than that produced by beta emitters, particularly for higher energy photons. The exposure due to penetrating photons is generally found to be the most significant source of external exposure, although beta irradiation can be a significant component of the skin dose.

In order to assess the distribution of individual doses in the exposed population, it is necessary to take account also of the time spent by different subgroups of the population in different exposure situations (e.g. outdoors, in buildings of different types, in vehicles, etc.) when they are shielded from external irradiation.

4.2.2. External Irradiation due to Radioactive Material in the Passing Cloud

The magnitude of the external exposure due to the radioactive material in the air as it passes over depends on the spatial and temporal distribution of the radioactive material, on the type and energy of the radiation emitted by each radionuclide and on the shielding provided by overlying tissues before absorption within a particular organ of the body.

In addition, the radiation would be attenuated by buildings and transport systems, such that the open area dose would be reduced by a so-called shielding factor, whose possible value ranges from near zero (complete shielding: zero dose) to one (no shielding: open air dose). It has been shown in various studies that, for example, during evacuation the shielding provided by cars and buses may reduce the radiation exposure rate significantly. Also in urban areas there is a shielding effect of neighbouring buildings. Consequently not only the type of building but also the type of settlement would affect the dose.

However, in most types of accidents this pathway is not a major contributor to total radiation dose. This is certainly the case for the Chernobyl accident, and hence the pathway does not warrant such detailed investigation as other more significant routes of exposure.

4.2.3. External Irradiation due to Radioactive Material Deposited onto Surfaces

When assessing the dose due to radioactive materials in a passing plume, all beta and gamma emitting nuclides released must be considered. However, when considering the dose resulting from radioactive materials deposited on the ground, the noble gases and the beta radiation components can be safely neglected. This is because noble gases are not deposited, and because the beta radiation is almost completely absorbed by the rough elements of the ground surface, even for the case of a relatively smooth paved road. Consequently only gamma radiation from deposited radionuclides has to be considered.

Radionuclides are deposited from the cloud by dry and wet deposition processes; these, together with the nature of the surface and shielding provided by any surrounding structure, lead to variation in the resulting external radiation exposure.

Following deposition, the dose rate above the surface will decline due to radioactive decay and the removal of material from the surface by natural weathering processes (e.g. penetration of radioactive material into the soil, and wash-off of already deposited material by rainfall) or mechanical action. There are significant differences in the behaviour of material deposited on soil or agricultural land and that deposited on less permeable urban surfaces, as well as differences in behaviour depending on the physicochemical form of the material, how it is deposited (e.g. wet or dry processes), and the nature of the surface. (During accidents, the external dose to an individual can be reduced by forced decontamination methods, such as the removal or ploughing of soil and the cleaning of buildings and roads. The most important factor leading to dose reduction in urban areas is the shielding by buildings and transport systems. However, the shielding effect of buildings would be reduced if radioactive materials were deposited on internal surfaces, such as walls, floors and ceilings.)

4.2.4. External Irradiation due to Radioactive Material Deposited on Clothes and on the Skin

Individuals in the exposed population around Chernobyl may have been directly contaminated by deposition of radionuclides from the passing cloud onto clothes and the uncovered skin. Contamination of the body surface would have occurred when persons were standing outside in the contaminated cloud or in rain from the passing cloud. Both beta and gamma radiation exposure of the human body resulted.

Due to its low penetration, beta radiation could only have led to radiation doses to the body surface (e.g. skin). Its significance is dependent on the thickness of clothing worn, and on the position of deposited materials in relation to the body organs. Gamma radiation is not significantly attenuated by clothes and a more or less homogeneous radiation field would have resulted. (During accidents, the importance of this exposure pathway depends on the extent and timing of the introduction of protective actions such as changing clothes and washing.)

4.2.5. External Irradiation due to Radioactive Materials in Water

The contamination of water bodies may be caused by direct release, by deposition or by run off processes during or after rainfall. External irradiation from radioactive material in water may be received by individuals swimming, standing by rivers and lakes, or in boats.

4.3. Internal Exposure Pathways

The stages involved in determining the internal irradiation of people following a release to atmosphere are illustrated as follows:

Release
↓
Atmospheric dispersion
↓
Concentration in environmental materials
↓
Intake of radionuclides by man
↓
Internal irradiation

The starting points for the determination of the internal irradiation of people are the concentration of radionuclides in air and the amount deposited on the ground at a particular place. The next stage is to consider the transfer of the radionuclides to environmental materials that are taken into the body, i.e. air, food and water. In some cases this is relatively straightforward, for example in the case of inhalation of radionuclides in air from the passing cloud, but in others the radionuclides may be transferred through various media before being taken into the body (e.g. the soil → grass → cattle → milk → man pathway). Once the concentration of a radionuclide in a given environmental material is known, the amount of that material ingested or inhaled is required so that the intake of the radionuclide of interest by this pathway can be determined. Finally a dosimetric model is required so that the extent of internal irradiation received following the intake of the radionuclide can be determined.

The two important routes by which radionuclides can enter the body are by inhalation and ingestion. Another possible route of intake is across the skin. It is rare for chemicals to be able to transfer across intact skin and the only radioactive material for which this exposure route is normally important is tritiated water. Other materials would only cross the skin through cuts and abrasions and would then only lead to local irradiation of the tissue surrounding the point of entry. The entry of radioactive material through the skin is of minor importance in assessing the consequences of accidental releases and is not considered further.

In the following paragraphs, the main pathways by which radionuclides are inhaled or ingested following a release to atmosphere are considered.

4.3.1. Intake of Radionuclides by Inhalation

Radionuclides in air can be inhaled either directly from the cloud of material as it passes overhead or following the resuspension of radionuclides deposited onto the ground. The former is of interest only during the passage of the cloud and is an important short term exposure pathway following an accidental release. However, resuspension may occur for long periods afterwards.

Direct inhalation of radionuclides in the cloud can be assessed simply by using the predicted concentration in air at a point multiplied by an inhalation rate to determine the intake of the radionuclide. In addition, the radioactive material concentration inside a building is typically lower than that outside, so it is necessary when assessing their inhalation doses to consider the time people spend indoors, whether they have been told to shelter and what protection this provides.

In addition, breathing rate depends on age and size and on whether the individual is engaged in physical activity or resting; it will also vary from person to person, even among persons engaged in similar activities.

Radioactive material deposited on the ground can be resuspended as a result of disturbances caused by wind or human activities, for example digging or ploughing. The extent to which materials are resuspended from surfaces depends on many factors such as the nature and age of the deposit, the physical characteristics of the surface and the strength of the wind. A fine particulate on a dry surface will be resuspended to a greater extent than a deposit on wet ground, particularly if this is on agricultural land. Resuspension due to mechanical disturbance will only affect the individuals in the immediate vicinity and is not significant in assessing the exposure of large groups of people.

Exposure through inhalation of resuspended material normally makes only a small contribution to the overall exposure following releases from thermal reactors, such as the Chernobyl plant. In general, therefore, it can be excluded from the dose assessments. However, it may need to be considered for regions where the deposit contains significant quantities of the actinides (e.g. ^{239}Pu). Here intake by inhalation leads to larger radiation doses than that received following intake by ingestion and where external irradiation is of little concern.

4.3.2. Intake of Radionuclides by Ingestion

Deposited radionuclides may be transferred to both the terrestrial and aquatic food-chains. Freshwater food-chains are normally of secondary importance in determining the consequences of accidental releases of radionuclides to atmosphere. However, in particular circumstances restrictions may need to be placed on water utilization or on the consumption of foods originating in the aquatic environment.

The transfer through terrestrial food-chains is an important exposure pathway when considering both long term health and economic impact. A large number of processes are involved and much depends on the characteristics of the nuclides and the particular environment.

When radionuclides deposit from the atmosphere onto agricultural land, part may be intercepted by the foliage of vegetation and part will land on the soil. Radioactive material is removed from the surface of plants by natural loss processes such as weathering, with a half-life ranging from a few to several tens of days. Part of the surface deposit may be absorbed and transferred to other parts of the plant; this process is known as translocation and is far more significant for some nuclides, notably caesium, than for others, for example plutonium. Interception, retention and translocation are the dominant transfer processes in the first weeks after an accidental deposit, provided this occurs during the growing season.

Radionuclides in the soil may be absorbed through the plant root system and transferred to the edible parts of the plant. The extent to which root uptake occurs depends markedly on the element concerned and its chemical form, together with the soil and plant type. Root uptake is an important plant contamination process in the longer term when direct surface contamination has declined. It is significant, therefore, for longer lived radionuclides (half-lives greater than a few months), notably those of strontium and caesium. Plants may also become contaminated with radionuclides deposited on the soil by resuspension processes or by splashing due to rainfall. Immediately following deposition these routes are insignificant compared with the direct contamination process from atmosphere. In the longer term they are only important for those nuclides that are relatively insoluble in soil and hence which are not taken up to any extent by the roots, e.g. plutonium.

Radionuclides are lost from the system by migration down the soil column and out of the root zone. In some cases, long lived radionuclides in soil may be modified progressively by biochemical changes in soil, and this may alter the extent to which they are absorbed by the plant's root system. The fixation of caesium by clay particles in some soils is a well known example of such a process where root uptake is drastically reduced for some types of soil.

The transfer of radionuclides to animals is another important route that can lead to the exposure of man. The most studied pathway is the pasture—cow—milk pathway. This is important because cows graze a relatively large surface area and hence have a substantial intake of deposited material. The transfer of radionuclides from pasture grass or other fodder crops to various types of livestock and hence to human meat supplies can also be an important exposure pathway, particularly when the livestock graze pasture. The most important route of intake of radionuclides by animals is by the consumption of contaminated grass or fodder. Other possible routes of intake are from contaminated water supplies, by inhalation of radionuclides in the atmosphere and by the inadvertent consumption of contaminated soil. In general, these routes of intake are of less importance than direct ingestion of radionuclides in fodder. Inhalation is only likely to be significant for those nuclides for which only a small fraction of the radioactive material ingested by an animal is transferred across the gut wall. The inadvertent consumption of soil by these animals may become important after deposition has ceased, but only for those radionuclides that are inefficiently taken up from the soil by plant roots.

Another important factor is the removal of radioactive material during food preparation and processing. A significant proportion of material on the surface of crops is removed by preparation processes such as removal of outer leaves and washing, or in processes such as milling and the manufacture of flour from grain. In the dairy industry, the concentration of radionuclides varies significantly between the different final products (e.g. butter produced from contaminated milk contains practically no radiocaesium). Indeed, changing the management of food processing is an important countermeasure for reducing radiation exposure of the population.

The transfer of radionuclides through terrestrial food-chains following an accidental release will be influenced by the prevailing agricultural and food consumption practices, as well as by the physical processes described earlier. These practices can lead to significant variation in the transfer depending on the season of the year when the release occurs. For instance, accidents in the summer growing season when animals may be grazing outdoors would lead to greater contamination of foods than accidents occurring in winter when many fields are fallow and animals are housed indoors. An analysis of the effect of season on the agricultural consequences of accidental releases has indeed shown large variations with the season of year in both the extent to which countermeasures would need to be implemented and in the health effects due to eating locally produced food.

The output of food-chain models is in the form of concentration of radionuclides in the foods of interest, and this has to be multiplied by some form of food intake rate to determine the intake of radionuclides by people.

4.3.3. Internal Dosimetry

Unlike external irradiation, which ends when the source of exposure is removed, internal irradiation is protracted in time after an intake of radioactive materials. Radiation doses to body organs following intake of a radionuclide depend on many factors, including the physical and chemical form of the nuclide, the type of radiation emitted and the metabolism of the individual concerned. Metabolic data and models are required to determine the distribution and retention of the radionuclides in the body. For a given distribution, an assessment is then required of the irradiation of individual organs and tissues, which originates both from the nuclear transformations occurring within the organ itself and from those occurring in surrounding organs. The absorbed dose in both target and source organs depends on the physical properties of the radionuclides as well as on the sizes of and distances between the various organs.

For inhalation, the models used to predict the behaviour of radionuclides entering the body represent the extent to which radioactive material is deposited in different regions of the respiratory system, the length of time it is retained there and how much is transferred to the body fluids for circulation to other organs. Similarly for ingestion, transfer through the gastrointestinal tract is considered together with the extent to which radionuclides cross the walls of the tract to enter the circulatory system. Whether the radionuclides enter the body fluids from the respiratory or the gastrointestinal systems, their subsequent transfer to body organs is generally treated in the same way. Radionuclides will be deposited in various body organs and will also be removed from the body by excretion. The pattern of deposition and removal from various body organs and tissues will vary markedly depending on the element concerned and its physical and chemical forms.

If a radionuclide has radioactive daughters, an allowance has to be made for the absorbed dose contributed by the build-up of daughters produced in the body. In general, there is little evidence to indicate whether the daughters will remain associated with and behave as their parent, or whether they will assume their own metabolic behaviour. With some exceptions (for example the iodine daughters of tellurium) it is usually assumed that any radioactive daughters produced in the body behave metabolically like the parent radionuclide.

There are significant variations in the doses per unit intake by ingestion and inhalation between different individuals related to variations in size and metabolism. In particular, age can have a marked effect on internal dosimetry.

4.3.4. Specific Cases

As a result of the Chernobyl accident, people living in the contaminated areas incorporated radionuclides that were released in the accident, including caesium, iodine, strontium and plutonium. There follows a brief description of specific aspects of the internal exposure due to these radionuclides.

Caesium

Caesium has two radioactive isotopes of biological importance: ^{137}Cs with a half-life of 30 years and ^{134}Cs with a half-life of 2.1 years. ^{137}Cs is likely to be encountered because it is a major fission product of both uranium and plutonium reactor fuels. Caesium-137 has been the subject of many studies of radiobiological and metabolic effects over the last several decades. Caesium and potassium have similar chemical and biochemical behaviours, including their distribution and metabolism in the body. Caesium is soluble in body fluids; upon ingestion it is absorbed rapidly, distributed almost uniformly throughout the body and finally eliminated by the kidneys with an effective half-life in the body of 70 to 110 days. Its biological half-life in children is much shorter, ranging from 12 days in infants to 57 days in older children, and it is shorter in women than in men. The most effective means of removing radioactive caesium from the body on an acute basis is by the oral administration of ferric hexacyanoferrate (Prussian Blue) containing hexacyanoferrate ions, $[Fe(CN)_6]^{4-}$. Usually this method is reserved for high levels of acute ingestion. This therapy was used in the treatment of several patients following the radiological accident in Goiânia, Brazil, in 1988 [4].

Caesium has been studied with regard to its effects during pregnancy in humans. The foetal to maternal plasma concentration ratio is usually about 0.13 and the placenta appears to respond differently to caesium and potassium, with caesium being more inhibited in transfer to the foetus. The effective half-life of caesium in the foetus is approximately 7 days. The whole body is the critical organ and the 50 year committed dose equivalent to the whole body is 8.1 mSv per MBq of activity in that organ. In historical units, this is 0.03 rem per μCi of caesium in the body.

Iodine

About half the 20 radioactive iodine isotopes occur as fission products. The dominant isotope causing internal exposure after a reactor accident in which fresh fission products are released is likely to be ^{131}I; however, short lived isotopes such as ^{132}I, ^{133}I, ^{134}I and ^{135}I, with half-lives from 52 minutes to 7 hours, can contribute significantly to exposure in close proximity to the source of a major release. Iodine-131 has a physical half-life of 8 days and an effective half life in humans of approximately 7.6 days.

Most radioactive iodine released in an accident will be soluble and would be quickly absorbed into the body via inhalation or ingestion or through the skin. Inhaled iodine reaches equilibrium with body fluids in about 30 minutes. Mean values for 24 hour normal thyroid uptake of ^{131}I are usually in the range of 10% to 30% of a total oral dose. Hypothyroidism as well as an increased frequency of occurrence of nodules and cancers may result from large absorbed doses. Preventive actions to reduce exposure to radioactive iodines include control of the food-chain and administration of iodide compounds of either potassium or sodium. This saturates the thyroid with stable iodine and thereby blocks radioactive iodine from the thyroid. If blocking stable iodide is given immediately, it can be almost 100% effective. However, when given six hours after exposure to radioactive iodine, the blocking effect is only up to 50% effective.

The amount of radioactive iodine needed to produce early hypothyroidism in a patient with normal thyroid function is in excess of 5.5×10^9 Bq/kg (150 μCi/g) of estimated thyroid gland weight. Dose equivalent estimates to the thyroid for ^{131}I are 1755 mSv per MBq (6.5 rem per μCi) of ^{131}I in the thyroid.

Radioiodine rapidly and readily crosses the placenta and the human foetal thyroid begins to accumulate iodine in about the 13th week of gestation. Between the 14th and 22nd week of gestation, the percentage uptake of iodine by the thyroid is higher than that in adults, ranging between 55% and 75%.

Strontium-90

Strontium-90 is radiologically the most important radioisotope of strontium. It has a long physical half-life (28 years). Strontium-89 is an indirect fission product of uranium and has a physical half-life of 51 days. Experience suggests that after a single intake by mouth about 25% of strontium will be absorbed into extracellular fluid (after inhalation about one third is absorbed into extracellular fluid) and about half this amount is deposited in bone. Beta particles are emitted by ^{90}Sr and its daughter product and irradiate both calcified bone and adjacent bone marrow. The effective half-life for ^{90}Sr is about 15 years. A number of techniques are available to reduce the amount of radiostrontium that is absorbed, including oral administration of ammonium chloride, aluminium phosphate and/or barium sulphate. Sodium alginates are also used following large acute ingestion. Very few if any of these methods have been used for reduction of absorption on a chronic basis. The committed effective dose equivalent to bone from ^{90}Sr is 8600 mSv per MBq of ^{90}Sr in the bone (32 rem per μCi).

Several studies have been performed on placental transfer of strontium during pregnancy. There does appear to be some discrimination between ^{90}Sr and calcium with a ratio of 1 to 10; nevertheless, strontium can readily cross the placenta.

Plutonium

Plutonium is a metal of the actinide series which oxidizes readily to form plutonium dioxide (PuO_2), a compound most likely to be of concern following a reactor accident. Plutonium-239 is the radioisotope whose radiobiology has caused most concern. It has a physical half-life of about 24 000 years and emits energetic alpha particles that have a range of 24 μm in bone and 40 μm in tissue. Since ^{239}Pu emits mainly alpha particles, it represents a biological hazard only when internally absorbed and deposited. Inhalation is the most common route of internal contamination by plutonium. Deposition patterns and the retention of plutonium in the lungs depend on its physical and chemical properties, including its solubility and particulate size. Relatively insoluble particles have a high degree of retention in the lungs and lymph nodes. The retention half-life in the lungs is between 150 and 1000 days. If plutonium is soluble or becomes soluble, the body distribution is as follows: skeleton 45%, liver 45% and other tissues 10%. The half-life in the body is about 200 years, with retention half-lives of plutonium in the liver and the skeleton assume to be 40 years and 100 years respectively. A number of long term studies relating to accidental exposures to ^{239}Pu have been made and at the present time no statistically significant increase in tumours has been demonstrated. This does not, however, exclude some element of risk from plutonium. The critical organ for soluble plutonium is bone, with an absorbed dose of 8×10^6 mSv per MBq of plutonium in that organ (30 000 rem per μCi of ^{239}Pu in bone). Internal deposition of plutonium has been treated in accidents by utilizing either aerosol or intravenous calcium diamine triamine penta-acetic acid (DTPA). In the relatively few cases to date, there has been some increase in the rate of elimination of plutonium. This method has been reserved for treatment of acute exposure to relatively high levels of plutonium.

5. Health Effects of Radiation

Scientific investigations over almost a century of the complex interaction of radiation with living tissue have helped to define many knowns and to narrow the range of uncertainties in human radiobiology. This understanding comes from extensive in vitro and in vivo animal experiments and from well documented epidemiological studies of the survivors of the atomic bombing of Hiroshima and Nagasaki in 1945 and of other groups exposed to relatively high doses in radiotherapy, in accidents and in some occupational situations. The theoretical basis of radiobiology rests on a model of the interaction of radiation with living matter and an associated set of factors relating the magnitudes of quantities in the model to data on health effects observed for cases of radiation exposure in humans and in experimental animals.

As ionizing radiation passes through human tissue, it can transfer energy and ionize atoms in cellular molecules that are biologically important for the functioning of cells. The process of ionization necessarily changes atoms and molecules, at least transiently.

Once ionization has occurred, the free electron and the ion or free radical that remain may cause chemical reactions. Typically there is recombination. Occasionally, however, the free radicals do not recombine but interact with other molecules in a number of ways. This may cause inactivation of cellular mechanisms or may lead to interaction with genetic material. For most processes of interest, the interaction is only important when genetic material is affected or inactivated, since this controls the structures and functions of the cells of the body.

Ionization by radiation may thus sometimes damage cells. Changes of this type usually occur throughout the lifetime with various causes (radiation exposure being one). Most commonly, the organism is able adequately to repair cellular damage. There is a common misconception that all radiation that is absorbed causes detriment. This is not true; for example, if the ionization and the creation of the free radical affect a single protein within a cell, there would be no functional change, since the cell would simply synthesize another protein. Even

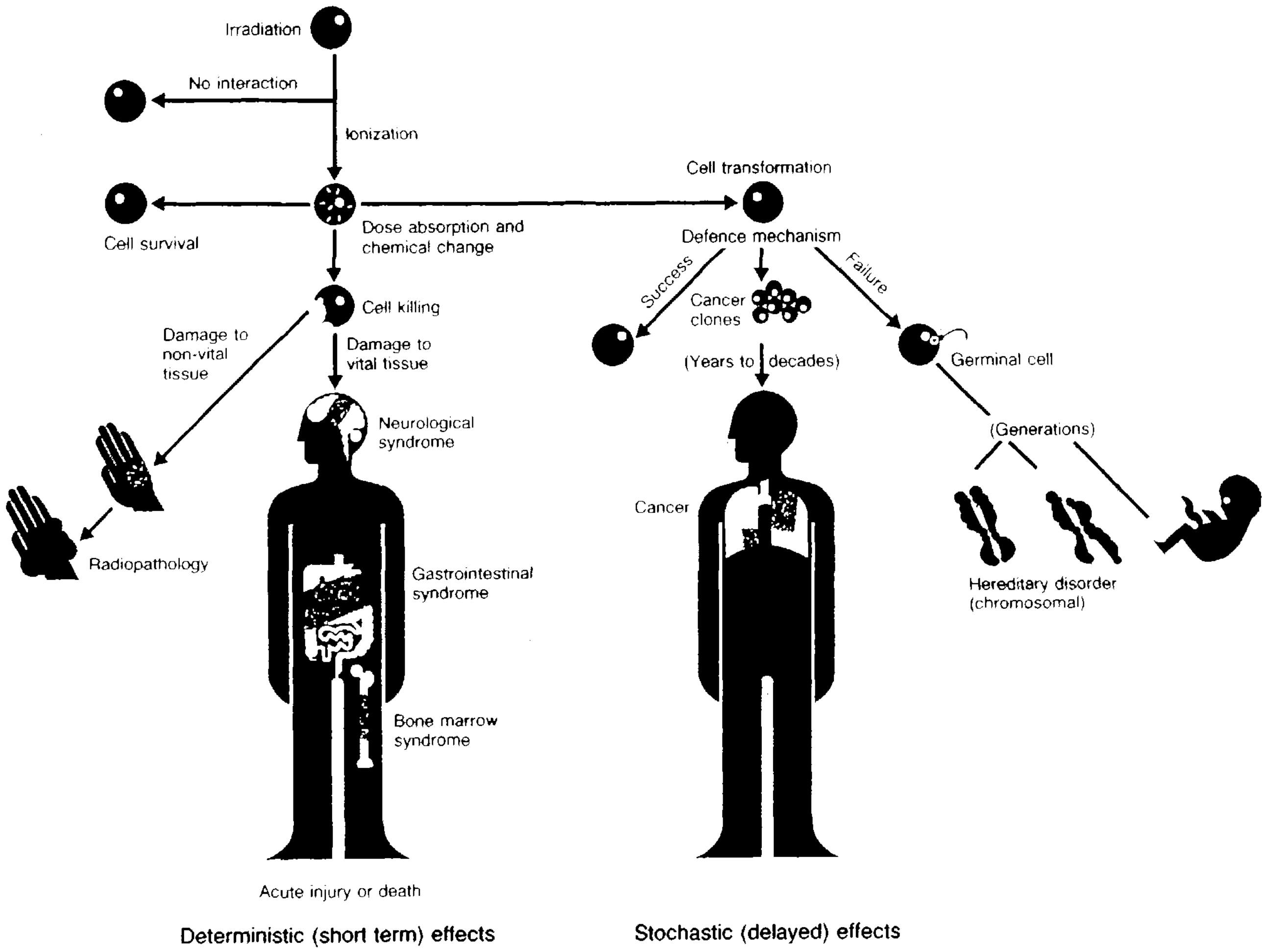


FIG. 9. The effects of radiation on human health.

if the damage affects deoxyribonucleic acid (DNA) or genetic material, it is clear that cells are capable of single stranded DNA repair. This process is somewhat time dependent; thus if a given absorbed radiation dose is spread out over time it is much less effective in producing damage than if the dose is incurred acutely. The reason for this is that if the dose is spread out over time, repair of sublethal cellular damage and also cellular repopulation by means of cell division occur.

If cellular damage does occur and is not adequately repaired, it may prevent the cell from surviving or reproducing, or it may result in a viable but modified cell. The two outcomes have profoundly different implications for the organism as a whole, leading to so called deterministic and stochastic effects (see Fig. 9). Stochastic effects are effects that occur at random, i.e. that are of an aleatory or statistical nature. Somatic effects (i.e. effects in the exposed individual) and prenatal effects in the embryo can be either deterministic or stochastic. Hereditary effects (i.e. effects in the progeny of the exposed individual) are stochastic.

5.1. Deterministic Effects

Cell death is not necessarily life threatening to the human organism, unless a tissue or an organ absorbs a certain threshold dose that is high enough to kill or to impair the reproduction of a significant fraction of vital cells. Most organs and tissues of the body are unaffected by the loss of even substantial number of cells, but if the number lost is very large, there will be observable harm reflecting a loss of tissue function. If killed cells are not replaced, an acute effect will be clinically observed in the organism relatively shortly after irradiation. Although the original effect of cell killing is (at the cell level) stochastic in nature, at the tissue level the effect appears to be of a deterministic nature: the given level of dose determines whether the effects occur or not, and a direct cause–effect relation can be clinically demonstrated for the irradiated individual. The likelihood of effects is zero at doses lower than some threshold dose and increases steeply to certainty (100%) above such a threshold dose, the severity of the harm also increasing

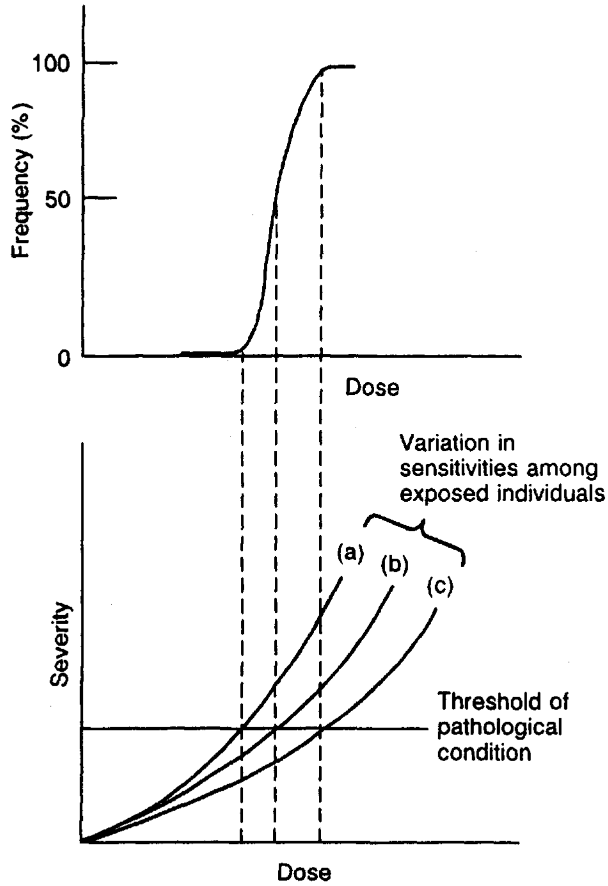


FIG. 10. Typical dose–effect relations for deterministic effects expressed in a population. [Source: ICRP [5]]

with dose. (Deterministic effects were originally termed non-stochastic effects.) (See Fig. 10.)

Not all cells in the body are equally radiosensitive and typically cells that divide rapidly are more radiosensitive than those that divide slowly or not at all. Cells that have high sensitivity to radiation include lymphocytes, immature bone marrow cells and intestinal epithelium. Cells with slightly less sensitivity include those of the lens of the eye and the linings of the stomach, oesophagus, mouth and skin. Cells of intermediate sensitivity are those of the liver, kidneys, lungs, thyroid and fibrous tissue. Mature red blood cells, muscle connective tissue as well as bone, cartilage and nervous tissue all have low sensitivity. The differing radiosensitivity of cells naturally leads to differences in the radiosensitivity of organs. As one might expect, exposure of an individual to absorbed dose levels of about 1 Gy to the whole body might kill only those cells with very high radiosensitivity. As the dose is increased, additional types of cells and organs would be subject to damage and this would alter the clinical presentation of the exposed person.

If the tissue that is damaged is vital, the end result may be death of the individual. If some individuals and exposed groups are already in a state of health approaching the pathological condition, they may reach the condition as a result of exposure to radiation after a smaller loss of cells than would usually be the case. Examples of deterministic effects are erythema or reddening of the skin, bone marrow depression, radiation cataracts and sterility.

The threshold for temporary sterility in men for a single absorbed dose to the testis is about 0.15 Gy and under conditions of prolonged exposure the threshold is about 0.4 Gy per year. Corresponding values for permanent sterility are 3.5 to 6 Gy for acute exposure and 2 Gy per year for prolonged exposure. The threshold for permanent sterility in women is an acute absorbed dose in the range from 2.5 to 6 Gy or a protracted dose over many years of more than about 0.22 Gy per year.

Clinically significant depression of the blood forming bone marrow has a threshold for acute absorbed doses of about 0.5 Gy and for protracted exposure over many years of more than 0.4 Gy per year. The dose which, in the absence of medical care, would result in the death within 60 days due to bone marrow depression of half the individuals in a heterogeneous population that is acutely exposed is about 3 to 5 Gy.

The threshold dose for opacities sufficient to cause impairment of vision,which occurs after some delay, seems to be in the range of 2 to 10 Gy for an acute exposure to X rays or gamma rays. The dose rate threshold for chronic exposure over many years is thought to be somewhat above 0.15 Gy per year.

In summary, there is scientific consensus on the levels of relatively high doses of radiation received over defined time periods that can cause deterministic effects leading to acute radiation injury. Deterministic effects have occurred as a result of the atomic bombing of Hiroshima and Nagasaki and of the hundreds of accidents with radiation sources that have been recorded over the past 40 years. These events have served to confirm the nature of the deterministic effects in significantly overexposed individuals. Death is almost certain for an individual incurring a whole body dose of around 6 Gy or more over a short period. Doses of around 3 Gy may be lethal for around half of those in an irradiated population who receive little or no medical care (the median lethal dose). For healthy persons receiving good medical care, the median lethal dose may be 5 Gy and as high as 9 Gy with very intensive medical treatment. For doses below 1 Gy the likelihood of deterministic effects is practically zero.

5.2. Stochastic Effects

The outcome is very different if the irradiated cell is modified rather than killed. Despite highly effective biological defence mechanisms, the cloning of cells resulting from the reproduction of a modified but viable somatic cell may result, after a prolonged and variable time termed the latency period, in the manifestation of a malignant condition, a somatic cancer.

The probability of a somatic carcinogenesis resulting from radiation is assumed to increase with increments of dose, probably with no threshold of dose below which the probability is zero, and in a way that is roughly proportional to dose, at least for doses well below the thresholds for deterministic effects. The severity of the cancer does not depend on the level of dose. If the damage occurs in a cell whose function is to transmit genetic information to later generations, any resulting effects, which may be of many different kinds and severities, will presumably be expressed in the progeny of the exposed person as a hereditary effect. Somatic carcinogenesis and hereditary effects are termed stochastic effects. In summary, therefore, it is presumed that any transformed cell can become cancerous, reproducing dysfunctionally so as to produce a clone of cells that eventually may become a malignant tumour. If the cell is germinal, the transformation may be hereditarily transmitted.

Years and even decades may be required before the effect of cell transformation could be biostatistically detectable (and epidemiologically demonstrable) as an increase in the incidence of malignancies or of severe hereditary defects in a large population (this does not apply at the individual level). According to the current radiobiological theory, the process leading to a stochastic effect can originate at any dose level, however small, the probability of occurrence of an effect being proportional to the incurred dose. This model is termed the linear, no threshold dose-response relation.

The doses received by members of the public as a result of the Chernobyl accident could produce only stochastic effects such as somatic carcinogenesis and hereditary effects. Prenatal effects can also occur at these dose levels and will be discussed separately.

5.2.1. Somatic Carcinogenesis

Cancer: a Common Disease

In industrialized countries, in which life expectancy averages some 70 years, about 20% of all deaths are attributable to cancer. Radiation is only one of a vast number of chemical, physical and viral agents that may influence cancer development in a not fully understood manner. Cancer incidence varies very widely among regions: industrialization seems to be a relevant factor in higher incidences.

Radioepidemiology: the Statistical Evidence

Most biostatistical evidence for human radiation carcinogenesis relates to individuals who have incurred relatively high doses, most commonly delivered at high dose rates. Efforts to quantify with certainty the incidence of radiation carcinogenesis in human populations receiving relatively low doses are constrained by a whole set of factors, including the natural incidence of cancer, the vast number of carcinogenic agents, the insufficiency of information on the mechanisms of cancer induction, the inescapable exposure to natural background radiation and the extremely small estimated likelihood of cancer induction at low doses. (These problems are to be discussed in more detail in the following.)

Studies of the survivors of the atomic bombings in Japan in 1945 are the most valuable source of information. Since 1947, the Radiation Effects Research Foundation, jointly funded by the governments of Japan and the USA, has closely monitored the medical health patterns of over 100 000 people who received relatively high doses of whole body radiation. Other large population study groups include some 200 000 persons who received high doses of radiation to specific parts of the body for medical treatment of ailments, such as spinal arthritis and cervical cancer. Although lifetime data for these groups are incomplete, data from the follow-up period are extensive. In the case of the survivors of the atomic bombings, it is well into its fifth decade. Study findings for these survivors show a statistically significant increase in the frequency of death due to leukaemia as well as to many solid cancers: in total, they show that in addition to the around 20 000 (20%) of that population who would have been expected to incur cancer, around 1000 incurred cancer that would have been due to doses received as a result of the bombing.

Current Estimates of the Incidence of Radiocarcinogenesis

Recently, UNSCEAR increased its previous (1977) estimates of the lifetime risk of excess cancer deaths for adults exposed to low linear energy transference (LET) radiation at relatively high doses and high dose rates. Among the reasons for the increases in estimated risk are a revised dosimetry for the survivors of the atomic bombing of Hiroshima and Nagasaki, the extended observation period and methodological advances in accounting for different causes of mortality.

While the 1977 UNSCEAR estimate of the incremental risk (that is, above the 'normal' cancer risk of around 20% during lifetime) for an average adult was 2.5% per sievert of dose incurred at relatively high doses and dose rates, the current (1988) UNSCEAR estimates are 4.5% and 7.1% per sievert, depending on whether an additive (A) or a multiplicative (M) model is used for projecting the future incidence of cancer in the atomic bombing survivors (see Fig. 11). (By definition, the additive model estimates the annual risk arising after a latency

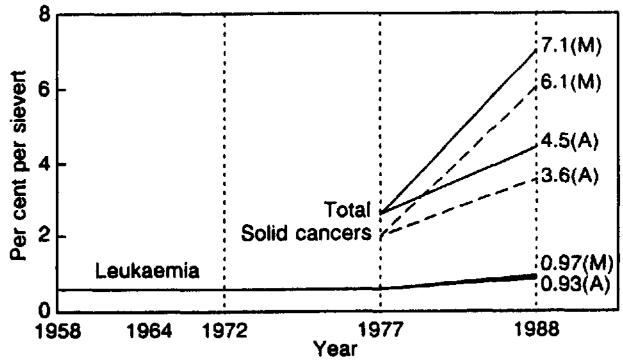


FIG. 11. UNSCEAR risk estimates for radiation induced excess cancer deaths. A: additive model; M: multiplicative model. [Source: UNSCEAR [2]]

period and thereafter remaining constant over time. The multiplicative model estimates the excess risk after latency, given by a constant factor applied to the age dependent incidence of natural cancers in the population.) Figure 12 shows the stylized additive and multiplicative models. Plot (c) shows possible curve shapes under more realistic assumptions. For plot (a), the simple additive model, the excess conditional probability rate (of death due to cancer) after a single radiation dose D is assumed to be proportional to the dose, but only after a minimum latency period and over a plateau period of time. For plot (b), the simple multiplicative model, the excess probability rate is assumed to be proportional also to the background rate of cancer death B(u). These estimates generally apply to doses in the 0.5–1.0 Sv range (although for some cancers and at specific body sites they apply to doses of 0.2–0.5 Sv), usually received at high dose rates.

Uncertainties

There are, however, several significant uncertainties in estimating the incidence of cancer induced by radiation. One is that most of the observations relate to high dose rates, which enhance the biological effects at high doses because more than one ionizing event can then occur in a cell in the relevant period. Thus, according to the radiobiological model in use, the fatal cancer risk factor following exposure to relatively low doses delivered at low dose rates is smaller than the values assessed for high doses at high dose rates; the issue of by how much it is lower seems to remain moot. UNSCEAR's reported correction factor is highly variable, ranging from 2 to 10, and the Committee is studying this important question further. The ICRP judges that this enhancement can be represented by a factor of 2 in the range of doses for which direct observations exist. It therefore applies this factor by reducing the observed probability of stochastic effects when estimating the low dose and low dose rate effects.

The observable information at high doses may be interpreted with some confidence to give estimates of the risks at smaller doses. The extrapolation is not large because the small doses from artificial sources are added to the inescapable doses due to natural background radiation. These latter doses amount to more than 100 mSv in an average lifetime. Statistically significant direct observations in man in homogeneous populations, such as in the studies of the atomic bombing survivors, are available for doses down to about 200 mSv.

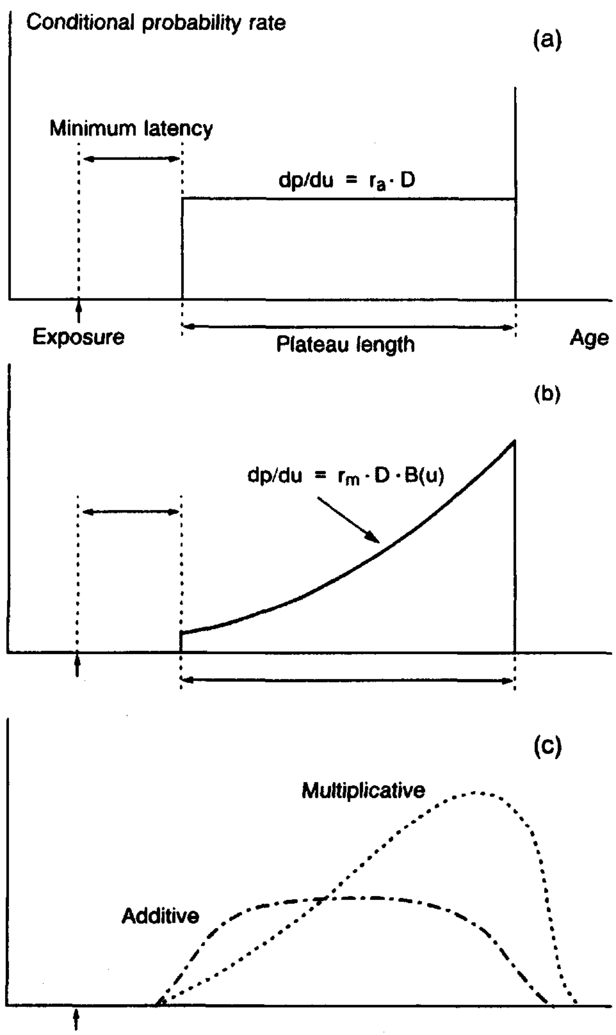


FIG. 12. Illustration of projection models for the probability of death due to cancer following a single radiation dose D. (a) The simple *additive* model: the excess conditional probability rate (of death due to cancer) after a single radiation dose D is assumed to be proportional to the dose D, but only after a minimum latency period and over a 'plateau' period of time. (b) The simple *multiplicative* model: the excess conditional probability rate is assumed to be proportional also to the background rate B(u) of death due to cancer. p: conditional death probability rate; r: unconditional death probability rate; u: age. (c) Possible curves under more realistic assumptions. [Source: ICRP [3]]

A further uncertainty is introduced by the fact that some members of the study populations are still alive, so the ultimate number of fatal cancers attributable to radiation has to be predicted.

Finally, there is an uncertainty in transferring observations for one ethnic population to others. For cancer in individual organs, this uncertainty is considerable, perhaps within a factor of 10, but for the total incidence of all cancers it is much less. It is unlikely that any national population with a high standard of living differs from the typical by more than about 30% in its overall sensitivity to radiation.

In summary, the sources of uncertainty are:

- The factor by which estimates of probability of fatal cancer per unit dose incurred at high doses and dose rates should be reduced for application at low doses and low dose rates.
- The projection of the data for populations, some members of which are still alive, to give the lifetime probability of attributable cancer.
- The utilization of observations on one population to produce estimates for different ethnic populations.

The combined effect of these factors introduces an uncertainty in the risk estimates for carcinogenic effects which may represent an overestimation of the risk by a factor in the region of 3. It is unlikely that the current conclusions underestimate the risk.

There are, therefore, many considerations in the evaluation of the magnitude of the risk of radiation induced cancer. However, for a population receiving high doses at high dose rates, a lifetime fatality probability coefficient for a whole population, including children, is considered to be about 5×10^{-2} per sievert for low doses and low dose rates. In simplistic terms, this means that if in a heterogeneous population each person incurred a dose of 1 Sv, 5% of those persons might die from a radiation induced malignancy. This should be contrasted with the normal spontaneous cancer incidence of about 30% in most developed countries and a probability that death will be due to cancer of about 20%.

Since there is no known threshold for malignant stochastic effects, there might be an increase in the incidence of neoplasms (occurring over the next several decades) for persons living in some regions contaminated as a result of the Chernobyl accident. The magnitude of such increases would be dependent upon the dose received as well as the age at exposure, but it may not be detectable (see Subsection 7.3).

5.2.2. Hereditary Effects

A substantial percentage of the population is born with some type of inherited genetic disorder that will affect these persons during their lifetimes, with or without their knowledge. The hereditary defect may be fairly minor or it may lead to a serious disease or a life impairing condition, such as Down's syndrome and severe mental retardation. Congenital abnormalities and other diseases of complex aetiology comprise the largest groups of inherited defects affecting the well-being of human populations. A hereditary defect can be lethal for the developing organism, with some 40% of spontaneous abortions observed in human populations being due to serious chromosomal disorders.

All told, UNSCEAR estimates the natural incidence of human hereditary defects from all causes at nearly 700 000 cases (as distinct from individuals) in one million live births. The findings of other major studies suggest an even higher number, which would imply that human beings are born with a very high probability of manifesting a hereditary defect of some kind.

While the propensity of radiation to cause hereditary defects has been experimentally demonstrated in highly exposed animals and plants, there is still no epidemiological evidence linking exposures at any dose level to any severe hereditary defect in human populations. Genetic and cytogenetic studies of the nearly 15 000 children born to the atomic bombing survivors in Japan have so far yielded no evidence of a statistically significant increase in severe hereditary defects. Constraints encountered in studying the probability of radiation induced hereditary effects in humans are formidable, because of the need to monitor vast numbers of people in irradiated and control group populations over many generations and because such effects may be indistinguishable from disease conditions due to other causes.

In the absence of useful data on human populations, the only way to evaluate the hereditary risk to humans is to make a number of reasonable assumptions and to use experimentally observed data for other mammals, notably for mice. The following assumptions are usually made: (a) the amount of hereditary damage induced by a given type of radiation is the same in human germ cells as in those of the test species; (b) biological and physical factors affect the magnitude of the damage similarly in the experimental species and in humans; and (c) at low doses and low dose rates of low LET irradiation there exists a linear relationship between the dose and the frequency of occurrence of a severe hereditary defect.

UNSCEAR used two largely independent methods (the doubling dose and the direct method) to estimate the risks to humans of severe hereditary disorders due to radiation induced gene or chromosomal mutations. Essentially, the results are in reasonable agreement, in view of the large uncertainties.

The risk estimates for the doubling dose method are illustrated in Table 4. The estimated mutation risks (grouped to include both gene mutations and chromosomal aberrations) have remained relatively stable over the last decade. While previously UNSCEAR addressed the risks of radiation induced congenital diseases [1], in its recent reports it chose not to provide estimates

TABLE 4. Probability of Severe Hereditary Effects Estimated by the Doubling Dose Method after 1 Gy Low Dose Rate, Low LET Radiation to the Parental Population. The Doubling Dose Assumed is 1 Gy. [Source: Ref. [3]]

	Doubling dose (Gy)	Natural prevalence of genetic disorders (10^{-2})	Radiation induced probability (10^{-2}/Gy)		
			First generation	Second generation	All generations
UNSCEAR 1977 [6]	1	10.51	0.63	—	1.85
UNSCEAR 1982 [7]	1	10.63	0.22	—	~1.50
UNSCEAR 1986 [1] (excluding multifactorial diseases)	1	1.63	0.18	—	1.04
UNSCEAR 1988 [2] (excluding multifactorial diseases)	1	~1.30	~0.18	0.14	~1.20
BEIR 1980 [8]	0.05–2.5	10.70	0.15–0.75	—	0.60–1.10
BEIR 1990 [9] (including congenital abnormalities, excluding common multifactorial diseases)	1	3.6–4.6	0.15–0.40	—	1.15–2.15

[a] BEIR: Committee on the Biological Effects of Ionizing Radiations of the United States National Research Council.

because of persisting uncertainties about the maintenance mechanisms for these disorders in a population and the possible response.

UNSCEAR estimates 1 Sv as the radiation dose required to double the frequency at which severe hereditary disorders appear in the population. Accordingly, irradiation at 1 Sv per generation would induce for one million live births a total of 12 000 cases of gene and chromosomal mutational diseases in equilibrium and 1700 cases over the first generation. The UNSCEAR risk factor for severe hereditary effects of radiation is estimated to be around 0.5% per sievert.

Thus it is difficult to predict what hereditary effects of radiation may be observed in subsequent generations following the first. There have been large and long term studies of the survivors of the atomic bombings in Japan and it does appear that the risk of significant hereditary effects is substantially less than that of radiation induced tumours. The UNSCEAR report in 1986 examined the effect of irradiation at 1 Sv per generation over many generations and estimated that the incidence of severe genetic disease per million live births might be about 12 000 cases. This should be contrasted with the spontaneous occurrence of congenital anomalies alone of about 60 000 per million and about 15 000 additional cases of other genetic abnormalities.

The estimated probabilities of severe hereditary effects of irradiation that were given in the recent ICRP recommendations [3] are shown in Table 4.

5.3. Prenatal Effects

While major strides have been made over the past decades in understanding the effects of radiation at the embryonic and foetal stages of development, the causes, mechanisms and incidence level of detriment following prenatal exposure continues to be uncertain. Observational data for humans apply mainly to the studies of exposures in utero in the atomic bombing of Hiroshima and Nagasaki.

Some years ago, the finding of a dose related increase in the frequency of serious mental retardation in children irradiated in utero in Hiroshima and Nagasaki was reported by the ICRP and UNSCEAR. The number of cases is small, but the data indicate an excess probability of 0.4 at 1 Sv received between 8 and 15 weeks after conception. The results of intelligence quotient (IQ) tests for those children exposed in utero indicate a general downward shift in the distribution of IQ with increasing dose, by a coefficient of about 30 IQ points per sievert of dose incurred in utero between the 8th and the 15th week after conception. A smaller shift is identified for irradiation in utero between the 16th and the 25th weeks after conception.

This downward shift in IQ of 30 points per sievert is consistent with the foregoing observation of an excess probability of serious mental retardation of 0.4 for a dose of 1 Sv. At doses of the order of 0.1 Sv, no effect would be detectable in the general distribution of IQ, but

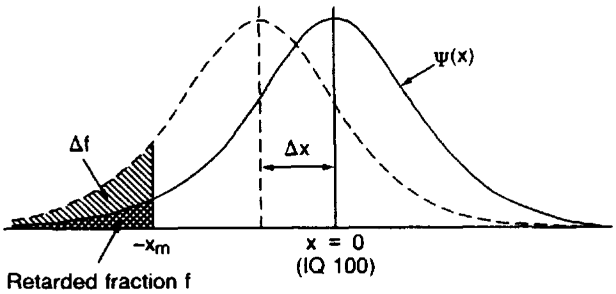


FIG. 13. The shift of the IQ curve due to irradiation in utero. The curve is shifted by 30 IQ units (i.e. 2σ where σ is the standard deviation) per sievert, i.e. $\Delta x = 2H$ where H is the dose equivalent in sieverts and x denotes the number of standard deviations below IQ 100. x_m denotes the number of standard deviations below IQ 100 at which an individual is classified as mentally retarded; thus the fraction f with an IQ below $100 - x_m\sigma$ is classified as mentally retarded. [Source: ICRP [3]]

at somewhat larger doses the effect might be sufficient to show an increase in the numbers classified as seriously mentally retarded. The net result is that the end extreme of serious mental retardation would appear to demonstrate a dose–response threshold, which is indeed observed. The ICRP judges that the phenomenon is deterministic with a threshold related to the minimum shift in IQ that can be measured. It is not therefore taken into account in the definition of detriment used for protection purposes. (Figure 13 shows the schematic representation of the downward shift in IQ following irradiation in utero.)

As for the risks of induction of leukaemia and solid cancers in early childhood, the findings of the study of those exposed in the atomic bombing of Hiroshima and Nagasaki and those of studies of children whose mothers underwent medical irradiation during pregnancy are inconsistent. For the first group, and even for those in the highest risk group who received doses of 0.5 Sv or more in utero, there is no evidence of a significant excess of mortality from childhood leukaemia or cancer. By contrast, studies of children exposed in utero for medical reasons show an excess of tumour and leukaemia cases at a level considerably higher than the natural incidence. However, the study findings of those medically irradiated are widely considered to have confounding and biasing factors. Data are still incomplete on the development of excess cancers late in life for individuals irradiated in utero in the atomic bombings in Japan, although there is some evidence to suggest an increased incidence of cancer for this group.

5.4. Effects of Hot Particles

A controversial subject in relation to the Chernobyl accident is the radiation risk due to 'hot spots' (due to small particles of high specific radioactivity) that it caused. For this reason, the health effect of hot particles are specifically discussed here.

A direct inference of the radiobiological model for carcinogenesis described in Subsection 5.2.1 is that the risk of cancer induction has to be assumed to be broadly proportional to the number of the irradiated viable stem cells in a given organ or tissue. If a given amount of radioactive material is uniformly distributed in the organ or tissue, all the stem cells are irradiated and the risk of cancer induction will therefore be the maximum for the circumstances. But if the same amount is concentrated in some parts of the organ or tissue such that only a fraction of the stem cells are irradiated, the risk of cancer induction will be proportionately lower.

An extreme case of organ or tissues being irradiated non-uniformly occurs when 'hot particles' are incorporated in organs such as the lung or the liver. The average number of stem cells irradiated over the whole tissue is then much less than in the vicinity of the hot particles and the risk of cancer induction is therefore proportionately lower than that due to the same activity uniformly distributed. The actual number of cells irradiated by a hot particle depends on the type of radiation, e.g. it is higher for gamma and beta hot particles than for alpha hot particles. According to the theoretical predictions, therefore, hot particles in organs or tissues can be regarded as posing a smaller risk of cancer induction than the same activity uniformly distributed in those organs or tissues. Experimental studies, particularly for alpha particles in the lung, are in accord with these predictions: generally, high concentrations of radioactive material in hot spots in organs or tissues have been found to be less carcinogenic than the same amount of material spread uniformly and delivering a uniform but lower dose.

Hot particles may create areas of necrosis around them, however, if the cellular dose is sufficiently high to induce cell killing. Dead cells are not available for subsequent cell transformation and therefore do not increase the cancer risk due to hot particles. In case of deposition on the skin, the lesion of concern is ulceration or breakdown with subsequent infection that leads to ulceration. The threshold dose for particles 1 mm in diameter is estimated to be 70 Gy measured over an area of 1.1 mm^2 or about 1 Gy when averaged over 1 cm^2 at a depth of 100–150 μm. However, below 250 Gy the ulcers are transient, lasting less than a week. Erythema over a larger area is detectable at these doses. Other estimates based on the number of beta particles emitted from the source (which is approximately independent of beta energy) suggest threshold values, at least for more severe or more persistent ulceration, of about 10^{10} particles or becquerel-seconds. This emission level corresponds to a dose of about 5 Gy when averaged over 1 cm^2 at 100–150 μm, which is a somewhat higher threshold than those values proposed in the foregoing.

TABLE 5. Summary of Estimates of Probabilities of Effects of Low LET Radiation [Source: Ref. [3]]

Effect	Population	Exposure period	Exposure modes	Probability
Mental effects				
Reduction in IQ	Foetus	8–15 weeks of gestation	High dose, high dose rate	30 IQ points/Sv
Severe mental retardation	Foetus	8–15 weeks of gestation	High dose, high dose rate	40×10^{-2} at 1 Sv
Hereditary effects				
Severe hereditary effects, including multifactorial diseases	Whole population	All generations	Low dose, low dose rate	1.0×10^{-2}/Sv
Cancer				
Fatal cancers (total)	Workers	Lifetime	Low dose, low dose rate	4.0×10^{-2}/Sv
Fatal cancers (total)	General population	Lifetime	Low dose, low dose rate	5.0×10^{-2}/Sv

Many of the experimental studies have concentrated on alpha emitter particles and detailed results have been available mainly in the open scientific literature. The IAEA has initiated a Co-ordinated Research Programme on the issue of hot particles, particularly beta emitter particles, with the participation mainly of laboratories of eastern European countries. Objectives of the programme include fostering the exchange of information already available and extending research on beta emitter particles. It would be expected that the laboratories participating in the programme would confirm the aforementioned conclusions on the lower risk of cancer induction from hot particles than from homogeneously distributed radionuclides.

The corroboration assessments in this report will therefore concentrate not on hot particles but on the contamination that can conceivably be incorporated uniformly in organs and tissues. In the work to corroborate the environmental contamination (see Part D), for instance, not the corpuscular contamination of the environment but rather the average contamination of macroareas and materials has been investigated.

In investigating the doses received, it has been implicitly assumed that the activity is homogeneously distributed in the relevant organs and tissues, which assumption is prudent for radiation protection purposes.

5.5. Summary of Estimated Probabilities of Effects of Irradiation

The estimated probabilities of effects of irradiation that were given in the recent ICRP recommendations [3] are shown in Table 5.

Part B

6. Environmental Effects of Radiation on Species Other than Man

6.1. Introduction

The effects of ionizing radiation can be seen at all levels of biological organization, ranging from the molecular level to ecosystems. Effects at all higher levels of biological organization can be traced to molecular and cellular responses. However, molecular and cellular responses do not necessarily lead to observable effects at the individual, population or ecosystem level. For people, our values are strongly focused upon the individual, as individuals are considered to have great value and importance. In contrast, most other species are viewed and valued more as populations than as identifiable individuals. In general, measurable changes in populations and communities (population assemblages) require rather severe effects at the cellular level for many individual organisms. For the structure of a biotic community to be altered requires a change in component populations, which in turn requires widespread mortality and/or reduced reproduction of individuals. On the other hand, genetic or somatic mutations which can be produced by lower levels of exposure may have little or no impact on population or community performance because of natural selection and convergence of genetic information among adjacent populations.

Many research studies have been directed at acute exposures of the individual organism where pathological responses were observed. The expense and difficulty of doing meaningful study of radiation effects on plant and animal populations and communities in their natural environments preclude the possibility of providing information on a large number of species and community types.

6.2. Effects on Terrestrial Plants

Radiation effects in individual plants express themselves as abnormal shape or appearance, reduced growth or yield, loss of reproductive capacity, wilting and death at high exposures. Among the plant community, characteristics which have been measured in relation to the stress of ionizing radiation are physiognomy (growth form), species composition, species diversity, and vegetation cover and production. Most of the available data on terrestrial plant communities are summarized in Table 6. It can be seen that there is substantial variation in sensitivity among the plant communities. Among the communities studied, the pine forest appears to be the most sensitive, with a threshold total dose of ~3 Gy causing changes in the coefficient of community (see Table 6). It should be noted that in the oak-pine forest, where the pine was again the most sensitive species, the value of the coefficient of community was unaffected at exposure rates <0.5 Gy/d over a period of 18 months. However, measurable change in litter production and leaf fall was observed with exposure rates down to ~20 mGy/d. The other communities listed in Table 6

TABLE 6. Minimum Gamma Ray Exposures and Exposure Rates Observed to Produce Detectable Effects in Terrestrial Plant Communities

Community type	Exposure period (days)	Attribute measured (a)	Minimum exposure rate (Gy/d)	Minimum total exposure (Gy)
Pine forest	8	cc	3.75	3
Oak–pine forest	540	cc	0.5	270
	900	H	0.5	450
	1400	L	0.02	2.9
Deciduous forest	165	B	0.24	40
Tropical forest	34	B	1.18	40
Old fields (abandoned cropland)	17	S,H	0.59	10
	29	cc	12.0	350
	29	B,S,H	5.86	170
	365	cc	0.5	180
	365	H	1.0	360
Meadow vegetation	11	cc	2.27	2.5
Short grass plains	30	cc	4.67	140
	30	H,B	3	90
	420	cc	1.2	500
	420	H	0.4	950
	510	B	1.7	870
Lichen	92	S,B	22	2000
	780	cc,H	3	2340

Note:

cc is the coefficient of community, which measures qualitative changes in species composition;

S is the similarity index, which relates to changes in abundance of individuals within species as well as in the number of species;

H is the diversity index, which measures balance among individuals of different species, as well as the number of species;

B is the biomass index, which is measured as the dry above ground mass of biological tissue per unit ground area;

L is the leaf fall index, which is measured as the dry mass deposited per unit ground area.

are much more resistant; in particular, lichen dominated communities are exceptionally resistant.

The radiation sensitivities of cultivated plants, such as vegetables, grains and fruit trees, are in general similar to those of closely related species that occur naturally. Such radiation sensitivities are predictable to within a factor of perhaps 2 from cellular characteristics, particularly the interphase chromosome volume. Lettuce *(Lactuca sativa)* for example has an LD_{50} (defined as the lethal dose for one half of the irradiated population) of 50 Gy, while barley *(Hordeum vulgare)* and wheat *(Triticum aestivum)* have LD_{50} values of ~20 Gy and ~30 Gy, respectively. LD_{50} values for peach and apple tree buds and seedlings ranged from 32–150 Gy, depending on the stage of leaf development.

The data in the literature also indicate another aspect of the responses of organisms to radiation; the dose rate at which a given response was observed declined with the protraction of the exposure even though the total dose needed to produce the response increased. It would appear that there are unlikely to be any detrimental long term effects on plant communities in which the maximum dose rate is of the order of 10 mGy/d or less.

While a reduction in productivity and an increase in leaf fall may be sensitive indicators of stress in the oak-pine community, there may be little impact on the community structure in the long term. This would be particularly true if only a small part of the community experienced dose rates sufficiently high (~20 mGy/d) to induce this response. However, it must also be remembered that a significant increase in leaf fall (and litter production) could have implications for the ground living invertebrate populations which, while relatively insensitive to the direct effects of radiation, could respond indirectly to the exposure through the change in food supply.

In summary it appears that in the natural environment the most sensitive plants display similar radiation sensitivities to those of mammals.

6.3. Effects on Terrestrial Animals

6.3.1. Mammals

In the case of mammals, most work relevant to populations has involved studies of lethality. The $LD_{50/30}$ values (defined as the lethal dose for one half of the irradiated population over 30 days) ranged from ~5–11 Gy. Direct mortality has been observed in individuals at acute whole body doses down to ~2 Gy. Considerable work has also been done on reproduction, and the majority of results suggests that natality is a more radiosensitive parameter than mortality. Minimum acute doses required to depress reproduction rates may be less than 10% of the doses required to produce direct mortality. Various factors such as competition, hibernation, degree of confinement and temperature can modify mammalian responses to acute radiation, but such modifications appear insufficient to cause significant effects on mortality at acute whole body doses below ~1 Gy.

The basic radiosensitivity of domestic mammals in terms of lethality appears similar to that of the wild mammals. The whole body $LD_{50/60}$ values derived from gamma radiation in the range from 4–7 Gy for sheep, cattle, pigs and horses. One of numerous factors affecting LD_{50} values is dose rate. For example, reported $LD_{50/60}$ values for sheep range from >10 Gy delivered at <10 mGy/h to 2.5 Gy delivered at 6.5 Gy/h.

Species vary greatly in the radiosensitivity of the gonad, but female mice are among the most sensitive. In studies with mice, reproduction was impaired by doses down to 0.2 Gy for females. Male mice were less sensitive, requiring doses of over 3 Gy to impair reproduction. Permanent sterility in female mice was produced by 1 Gy.

With regard to the effects of chronic radiation exposure on animal populations, reproduction was the population attribute most sensitive to damage from chronic irradiation and also the attribute of greatest significance in the ecological context. The long lived species in which reproductive activity was spread over a number of years would be the most sensitive to radiation stress. At 0.1 Gy/d, pigs and donkeys showed some deterioration in a few weeks and died after a few months of continuous exposure. At an exposure rate of 1 mGy/d, no effects were observed. However, in other experiments, chronic exposure of ~4 mGy/d produced measurable declines in the number, mortality and viability of sperm in dogs, while exposure rates <1.2 mGy/d failed to produce sperm count changes in dogs. Under continuing irradiation, animal populations are able to compensate for radiation stress and adjust to new equilibrium states. Higher birth rates may offset higher death rates, or improved late survival may compensate for impaired early survival in populations.

Overall it may be concluded that a dose rate of ~10 mGy/d represents the threshold at which slight effects of radiation become apparent in those attributes, e.g. reproductive capacity, which are of importance for the maintenance of the population.

6.3.2. Birds

In terms of mortality, birds (including domesticated varieties) appear to exhibit $LD_{50/30}$ values in the range of 4.6–30 Gy. Domestic poultry are reported to exhibit an $LD_{50/60}$ of 9 Gy. Irradiation of tree swallow *(Tachycineta bicolor)* and house wren *(Troglodytes aedon)* nestlings immediately after hatching has shown that growth through the nestling stage is unaffected by a total dose of 0.9 Gy but may be slightly depressed at doses >2.6 Gy.

There have been few studies of the effects of acute irradiation on the reproductive capacity of birds, but indications are that birds show radiosensitivity similar to that of mammals. In male weaver finches *(Quelea quelea)*, exposures of ~0.5 and 2 Gy produced no testicular change, but ~4 Gy induced apparent abnormalities. In white leghorn chickens, a dose of 4 Gy reduced egg production for 10 days post-exposure. At higher doses the effects were greater and longer lasting.

Studies of chronic irradiation on bird populations are inherently more difficult because of their mobility, and relatively little work has been done in this area. A few investigators have looked at nesting success of passerine birds in irradiated ecosystems. In these studies, exposure rates of 0.2 Gy/d caused embryonic mortality. In contrast, the breeding success of swallows and wrens exposed to ~0.7–6 mGy/d appeared essentially normal. However, large dose rates (1 Gy/d) reduced hatching success. The minimum chronic exposure level at which effects on reproduction or mortality would become manifest does not seem to be well established.

6.3.3. Reptiles and Amphibians

Literature on reptiles and amphibians suggests that these groups are somewhat less sensitive to acute radiation in regard to lethality than birds and mammals, although there is substantial overlap in sensitivity. A similar comparison for reproduction has not been made, but it is likely that the response for reproduction effects is roughly similar to that of mammals.

6.3.4. Invertebrates

A large number of data are available on the effects of radiation on invertebrates, especially on insects. Insects are, in general, far less sensitive to radiation than vertebrates. Adult insects usually require about 100 times the dose to produce lethality as compared with vertebrates. This difference has generally been ascribed to the fact that there is very little cell division and differentiation in progress in adult insects. Gonadal cells of adult insects do divide, however, and it is found that reproduction can be impaired at much lower doses. Juvenile insect forms are much more sensitive to the lethal effects of radiation, as would be predicted from the high cell turnover rates in these age classes. Many factors have been shown to modify the response of insects to radiation; however, it is very unlikely that species more sensitive than vertebrates to either the lethal or the reproductive effects of radiation will be found.

In order to observe effects on populations, several types of soil invertebrates were counted in an ecosystem with radionuclides. Dose rates that apparently produced reductions in animal numbers were generally quite high ($0.5–10^3$ Gy/d); however, some effects were reported at dose rates on the order of 24 mGy/d. The most sensitive organism observed was the common earthworm, of the family *Lumbricidae.*

With respect to chronic exposures in natural environments, invertebrates appear to be more affected by indirect than by direct effects. Exposure rates that significantly alter vegetation structure or character may not have direct impact on invertebrates. However, these animals exhibit clear responses, both negative and positive, to the vegetative changes.

Genetic effects on insect populations from chronic irradiation are not likely to be more important than effects on fertility. Even severe genetic damage was reparable through succeeding generations.

6.4. Effects on Aquatic Organisms

For many aquatic animals, mortality and induction of histopathological changes occur only after exposure to radiation at high dose rates or in large doses. In general, their early life history stages are more sensitive than their adult stage, and organisms occupying successively higher positions in the phylogenetic tree require progressively lower doses or dose rates to elicit effects. However, it is expected that these responses would be limited to individuals and not populations, unless the area of the marine environment affected by radiation encompasses all or almost all of a species' domain.

The effects of radiation on the mortality rate have been evaluated for most phylogenetic groups of marine organisms. Microorganisms, and other organisms that occupy the lower phylogenetic positions, may require enormous doses to kill them. Bacterial populations continue to form colonies at doses greater than 100 Gy. One of the most resistant observed to date is the ciliate protozoan *Paramecium aurelia*, which is reported to have an LD_{50} of 3000 Gy. Other radioresistant organisms include sponges and hydroids.

The effects of acute radiation have also been determined for a variety of higher invertebrates and fishes. Results of the effects of acute radiation on mortality indicate that the range of lethal levels in adults of different species of fish is from about 3.75 to 100 Gy. The effects of chronic irradiation on mortality of fishes and higher invertebrates have been examined in a few studies. No significant differences were reported in mortality between the salmon *Oncorhynchus tschawytscha* embryos irradiated at about 0.21 mGy/h for approximately 20 days (total dose about 0.1 Gy) and the control salmon embryos. Adults of the blue crab *Callinectes sapidus* subjected to chronic gamma irradiation required dose rates greater than about 290 mGy/h for 70 days to cause death, and juveniles of the clam *Mercenaria mercenaria* exposed to about 0.06 to 370 mGy/h for 14 months exhibited decreases in survival and growth only at the highest dose rate, 160 to 370 mGy/h.

The effects of ionizing radiation on reproductive tissue in fishes have been studied and it was found that counts of primordial germ cells in the chinook salmon *Oncorhynchus tschawytscha* exposed to 2.5 Gy from an X ray source were 10% of the control values. In rainbow trout *Salmo gairdnerii* embryos exposed to a ^{60}Co source for total doses of about 6.0 and 8.0 Gy, sterility, which was induced at the lower dose tested, was detected at all observation periods (60 to 150 days). A reduced egg production rate was observed in adults of the amphipod *Gammarus duebeni* receiving about 2 Gy. However, this was offset by a higher survival of adult females and an increased brood size. Increased embryo mortality was found in the marine polychaete worm *Neanthes arenaceodentata* when mated pairs received doses greater than 0.5 Gy.

The effects of chronic, low level irradiation on germ tissue in fish and invertebrates have been evaluated for a limited number of species. The lowest dose rate at which effects of chronic irradiation exposure on fertility of aquatic invertebrates and fish were demonstrated is about 0.25 mGy/h. With respect to the effects of chronic irradiation on fish embryos, a significant increase in opercular defects of smolt was found at exposures of about 0.3 to 0.5 Gy given at 0.21 mGy/h from the moment of fertilization. There have been few studies on the effects of radiation on the development of invertebrate embryos. Studies on *Physa acuta* gave results similar to those for fish. The lowest observed effect level was an LD_{50} of about 11 Gy for embryos at the four cell stage.

In summary, dose rates between 5 and 100 mGy/d appear to define a critical range in which detrimental effects on fertility are first observed in sensitive organisms. Increased mortality might be expected at sustained dose rates exceeding 240 mGy/d, while reduced reproductive success would be likely at dose rates in the range of 24–240 mGy/d. At lower dose rates there would be minor effects which could be accommodated within the reproductive capacity of the population or eliminated by the process of natural selection. This is of interest because it shows that effect levels in some aquatic animals are comparable to those observed in some mammals, and it indicates that germ cells from some fishes and invertebrates are not more radioresistant than those of mammals.

6.5. Observations in Areas of Elevated Radioactivity Levels

6.5.1. High Natural Background Radiation Areas

There are regions in various countries where the terrestrial radiation dose is substantially high. Animals living in such areas have been investigated for the effects of chronic irradiation. In the studies of a population of the black rat in southern India, a population of invertebrates in Mount Arabia in Georgia (USA) and lizards on the Colorado Plateau (USA), comparisons of the various parameters failed to indicate any significant differences between the populations undergoing elevated radiation exposure rates ranging from two to seven times average levels and those experiencing average background exposure rates. More recent work, however, suggests definite effects on reproduction in female mice maintained in captivity at a site in France where the dose rate from external natural background was measured as ~2 mGy/d. In this study, the number of offspring weaned from the irradiated females was 74% of the comparative number weaned from the control females. In contrast, irradiated male mice produced 1.4 times as many weaned young as did control males. In the same study, rabbit lymphocytes carried an increased number of unstable chromosomal aberrations, such as fragments and dicentrics, when exposed to the enhanced background radiation. These findings, while of considerable interest, do not necessarily imply that populations of mammals receiving comparable dose rates would be perceptibly altered in terms of density or general fitness.

For animals inhabiting areas of high natural radioactivity in the USSR (~1–2 mGy/d), a large number of abnormalities were reported, such as abnormal mitoses, decreased body fat, lower fertility, degeneration and necrotic processes. All of these phenomena helped to explain the reduced fertility, the decrease in the number of animals, and the lower densities of animals in these areas; however, internal doses from incorporated radionuclides and differences in chemical toxicity of the environment were not taken into account.

6.5.2. Contaminated Environments

A number of field studies have been conducted at sites of enhanced environmental radioactivity from anthropogenic sources. A comparison of various biological measurements between two ecologically similar study areas of greatly differing ^{239}Pu levels at Rocky Flats (Colorado, USA) was conducted. Measurements included vegetation structure and biomass; litter mass; arthropod community structure and biomass; and occurrence, population density, biomass, reproduction, organ mass, pathology, and parasite occurrence in a small mammal species. No differences attributable to radiation exposure were found for any of the measurements, even though levels of ^{239}Pu in the upper 3 cm of soil were as high as 1.5×10^7 Bq/m^2.

Populations of the midge *(Chironomus tentans)* and the snail *(Physa heterostropha)* that inhabit White Oak Lake (a radioactive waste retention pond) at the Oak

Ridge National Laboratory, USA, have been the subject of several investigations. In 1960, an increased frequency of chromosomal aberrations was found in the salivary gland chromosomes of *Chironomus* larvae that inhabited White Oak Lake, where they receive a dose of ~2 Gy/a, approximately 1000 times normal background level. However, ten years later when the dose rate had decreased to ~0.1 Gy/a, the frequency of chromosomal aberrations was not significantly different from that in control populations. This decrease in frequency of chromosomal aberrations supported the previous conclusion that chronic irradiation of ~2 Gy/a increased the frequency of chromosomal aberrations in the *Chironomus* population, although there were no apparent additional consequences for the population.

An extensive review of research on ecological effects of nuclear testing at the Pacific proving grounds was provided for rat populations, *Drosophila* cultures, land plants and marine organisms. The effects of the testing programmes could not, in general, be ascribed solely to radiation because of concomitant effects of blast and heat. Furthermore, human exploitation of the resources was altered considerably. Although many significant and complex effects on these ecosystems were observed, the recovery processes following the testing programme were relatively rapid and vigorous. Deleterious effects on marine and terrestrial populations were not persistent, presumably because of the rapid declines in the intensity of radiation and other impacts, the selective elimination of defective genetic information, and the recolonization of damaged areas with healthy individuals from distant locales.

The Chernobyl accident provides an example in which comparatively high levels of radioactivity were found in plants and animals exposed to the fallout. A few months after the accident, lethal effects were visually manifest in pine trees that had received more than 10 Gy (most of it from beta radiation) and pronounced morphological changes were observed in the dose range from 3 to 10 Gy. Other tree species present in the damaged pine area (mainly beech, aspen and oak) suffered practically no damage, and no obvious morphological changes were apparent in herbaceous plants. In Sweden, reindeer were found with levels of ^{137}Cs as high as 1.6×10^4 Bq/kg fresh meat, and fish with levels of up to 4.8×10^4 Bq/kg fresh tissue. The internal dose rate to the fish containing the maximum observed ^{137}Cs level of 4.8×10^4 Bq/kg would be of the order of 0.2 mGy/d. This upper limit dose rate is not likely to produce observable effects on the fish population.

7. Radiation Protection

The use of the term radiation protection is confined to the criteria and approaches adopted to protect human beings against the effect of ionizing radiations. However, it is considered that the standards of environmental control necessary to protect man to the degree currently thought desirable will ensure that other species are also protected.

7.1. The Dose-Response Relationship for Radiation Safety Purposes

Many attempts have been made to incorporate the current knowledge of radiation biology into workable models for radiation safety purposes. One such attempt, in which the overall (deterministic and stochastic) probability of harm is plotted against effective dose in a simplified manner, is shown in Fig. 14.

The figure illustrates the dose-risk relation used for radiation protection purposes. Three regions can be recognized:

- For doses higher than about 5-10 Sv, delivered in a short period of time, practically all irradiated individuals will suffer an acute radiation syndrome and eventually die as a consequence of the irradiation. Therefore, the relation is assumed to approach asymptotically a probability of unity for doses higher than about 5-10 Sv.
- For doses of a significant fraction of 1 Sv, delivered in a short period of time, non-stochastic effects may occur. The dose-risk relation approximates to a sigmoid relation. The exact shape depends on a number of factors, such as the dose rate, which could be relevant for particular scenarios of exposure. For a dose of approximately 3 Sv, the probability of death is about 0.5.
- At dose levels below a fraction of 1 Sv, only stochastic effects occur, the probability of occurrence being directly proportional to the dose level. These include malignancies in the irradiated individual and severe hereditary effects in the succeeding generations of descendants of the irradiated individual. In this range it is assumed that, following any increment of dose, there is a proportional increment in the probability of an effect. The relation of probability of harm to dose is therefore assumed to be linear in this range. For radiation protection purposes, the slope of the line (i.e. the risk factor in this region) is currently taken to be around 5×10^{-2} (5%) per sievert.

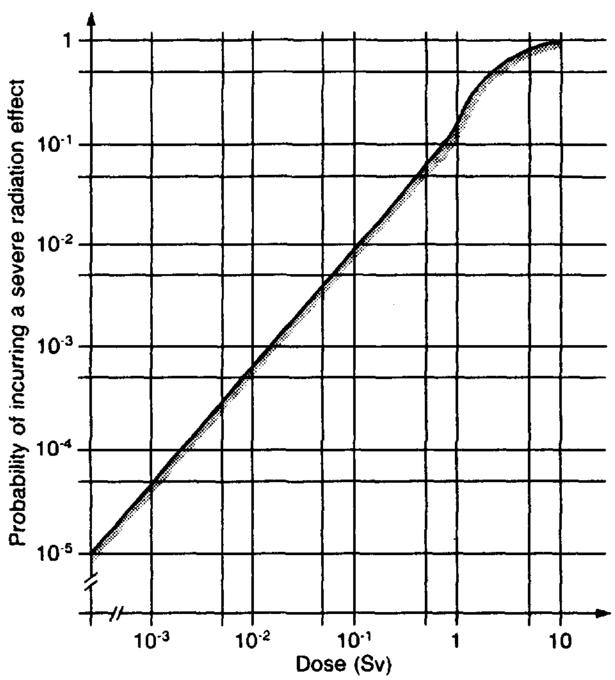


FIG. 14. The dose–risk relation used for radiation protection purposes, showing three distinct regions.

The use of the linear, non-threshold dose–response relation for stochastic effects is much more than a simplistic conservative assumption. It is founded in radiobiology and fits the human data on radiation induced cancer at the low end of the observable range. It has the great advantage for regulatory purposes of allowing separate sources of exposure to be considered separately because the detriment associated with each exposure is independent of the doses due to the others (if the response were non-linear, all doses would have to be considered together as a single entity). The slope of the relation is subject to uncertainties (see Subsection 5.2.1), but there is widespread scientific agreement that the current value of 5% per sievert for a general population is unlikely to be an underestimate of the risk. There are some scientists who claim that the risks are higher and others who consider that the current figures are serious overestimates, but neither view has gained wide acceptance. The radiobiological theory, which supports the linear, non-threshold relation at low dose levels, is conceptually and mathematically simple and plausible, accommodates present scientific knowledge and provides a sound scientific base for future projections.

The advantages mentioned do not alter the fact that the linear, non-threshold dose–response relation is no more and no less than a scientific theory based on mechanisms that fit the available data. As a scientific theory, it is intrinsically subject to invalidation. The lack of observational data on human health effects at very low doses constrains the testing of the theoretical projections for these ranges (this lack of data will probably persist for some time, necessitating a reliance on indirect evidence).

Although a radiation source may deliver a low dose, this dose is not necessarily incurred at a low level in the dose–response relation. Indeed, because of the inescapable exposure to natural background radiation, no human being can sustain zero dose or even receive only very low doses. The exposure to natural background radiation results in a per caput individual dose of about 2.4 mSv per annum, so that by mid-life an average person would have accumulated a dose of the order of 0.1 Sv. (In areas of high natural background radiation, the dose incurred can be orders of magnitude higher than this average.) Doses from specific exposures to man-made sources are additional increments to this accumulated 'natural dose'. (For the body it is immaterial whether a dose received is due to radiation from natural sources or from a given man-made source: the important value is the summed dose.)

If the dose–response relation were so non-linear as to preclude the assumption of proportionality between dose and risk increments, a given dose increment would carry different risks, depending on the dose at which the increment occurred. Thus, in order to control the risk, it would be necessary to know the sequence in which each and every dose contribution was incurred. This would entail a control regime for radiation safety purposes that would be unworkable. Seemingly, even if the relation were shown to be non-linear, regulatory authorities would have no real choice other than to retain the assumption of a linear relation.

7.2. Implications of the Dose–Response Relationship

The relevant implication of the no threshold linear relation is that since it is impossible to achieve zero dose from a given radiation source, it is also impossible to be at zero risk from any source.

The risk may be extremely small but is theoretically quantifiable. Figure 15 shows the extremely small theoretical increase in the total conditional death probability rate (for the population of Sweden in 1986) produced by a dose rate of 5 mSv per year over a lifetime. The change is only shown for the additive projection model. With the multiplicative model the change is smaller for ages below 50 years. At higher ages it is less than 4.5% for females and less than 2.5% for males; these changes are too small to illustrate on the figure.

Moreover, radiation risk at low doses is so small that stochastic radiation effects can be undetectable in most cases. While deterministic effects can be detected (diagnosed) in the exposed individual by clinical methods and can be related to their cause (the absorbed dose), stochastic effects cannot be detected individually, with a

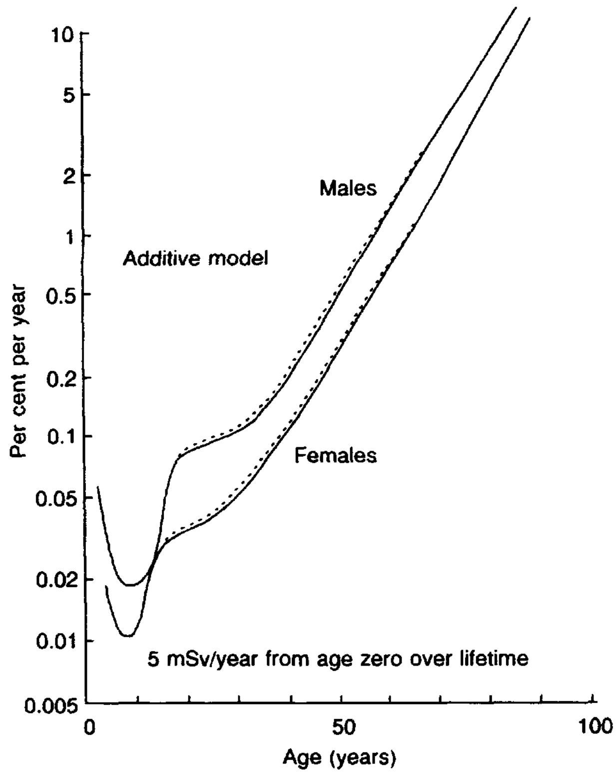


FIG. 15. The change in the total conditional death probability rate (reference: the population of Sweden in 1986) following an exposure of 5 mSv per year from birth over a lifetime. The change is shown for the additive projection model only. With the multiplicative model, the change is smaller for ages below 50 years. At greater ages it is less than 4.5% for females and less than 2.5% for males; these changes are too small to be shown on the figure. [Source: ICRP [3]]

causal relation with the individual's absorbed dose, but only statistically in a population group. And, there is a dose threshold for the epidemiological detectability of stochastic effects, which depends of the number of persons exposed. The epidemiological data need considerable interpretation and studies cannot provide reliable information on the effects of very low doses. This is because cancer and hereditary disorders are naturally common in human populations. The sensitivity of studies of the effects of low doses of radiation on humans is thus very limited. There are two main limitations, one statistical and the other demographic, as follows:

(a) The normal probability that death will be due to cancer of any origin, including cancers due to radiation from natural sources, is about 20%. Thus there is a statistical limitation to radioepidemiological studies that requires very large numbers in both the study group and the control group for any statistical effects of small doses to be observed. For the present estimates of the probability of incurring fatal cancer attributable to radiation, the study and the control groups would each have to contain about 5 million people in order to be able to detect with confidence the effects of an excess dose of 10 Sv.[2]

(b) The demographic limitation is due to unknown differences between the study group and the control group (e.g. due to social conditions, genetic composition, exposure to infections, etc.). Unless the two groups are drawn from a homogeneous population, the effects of doses less than about 0.5 Sv cannot be detected or excluded with confidence.[3]

Under the implication of no zero risk, therefore, the aim is not to seek an idealistic absence of risk but mainly to keep all risks as low as reasonably achievable under the prevailing social and economic conditions; to optimize safety rather than to seek absolute freedom from risk. Thus the relevant safety issue is not whether one could reduce the level of risk further but whether

[2] If two similar populations are being compared, then, to detect with confidence the effect of a higher average radiation dose in one of them, it is necessary to obtain a difference in incidence between them about twice as large as its standard deviation. The difference in the number of fatal cancers is given by (N – C) and its statistical standard deviation by $\sqrt{(N + C)}$, where N is the expected number of cancer deaths in the observed group and C is the expected number in the control group. With 500 people in each group and an expected cancer incidence of 25% in the study group, N would be 125 and C 100. The expected difference would be 25 with a standard deviation of $\sqrt{225}$, or 15. This difference would then be observable with a confidence of about 90%. An incidence of fatal cancer of 25%, i.e. an increase of 5% over the normal probability of 20%, corresponds to an excess dose in the exposed group over that in the control group of about 1 Sv. To detect the effects of 0.1 Sv, the groups would each need to be increased to about 50 000 people, giving a difference (N – C) of 10 250 – 10 000 = 250 with the standard deviation of $\sqrt{20\,250}$, or 142. To observe the effect of a dose of 10 mSv in excess of the natural background would require groups numbering 5 million each.

[3] For geographically separated groups, it is unlikely that confounding factors (such as age distribution, for which corrections can be made, and social conditions, genetic composition, environmental influences and exposure to infections, for all of which the corrections are imprecise or unknown) can be eliminated to the extent that differences of a few per cent can be confidently excluded. That is, if the control group has an incidence of fatal cancer of 20%, the figure for the study group may well be anywhere in the range from 18% to 22%. At current estimates of risk, this precludes the detection of the effects of doses of less than about 0.5 Sv however large the groups may be, unless, as in the studies of the survivors of the atomic bombing of Hiroshima and Nagasaki, the study and control groups are drawn from a single homogeneous population. Conversely, a zero difference in cancer incidence can rarely be used to derive information about doses lower than 0.5 Sv.

one should. In confronting this issue, the safety specialist must make subjective judgements of what are appropriate levels of protection and safety.

7.3. Radiation Safety

Safety is a complex concept. Typically it has been linked to the ideas of protection and security, and used to denote reliability, prudent caution and freedom from danger. Early toxicologists used the concept of safe dose to indicate an amount of harmful substance that was below a level (threshold) above which toxicity could be manifested. Technologists and engineers, on the other hand, generally use the term safety to denote accident prevention. Not surprisingly, these ambiguities have created problems of interpretation of what are the ultimate safety objectives.

In relation to radiation the concept of safety is especially cryptic: historically, the discipline of radiation protection has dealt mainly with the a priori limitation of radiation doses from anticipatable, 'normal' exposures to man-made radiation sources; the discipline of nuclear safety has dealt mainly with the prevention of nuclear accidents and — should they occur — with the mitigation of their consequences by technological means. At the time of the Chernobyl accident, neither discipline had fully developed safety criteria for dealing with the type of de facto situations that would be created by widespread contamination following a catastrophic accident.

Judgements leading to decisions on safety principles for radiation risk are usually made by professional and governmental organizations. Far from being a mechanical operation, the judgemental process in reality reflects cultural perspectives, national traditions, social values and professional attitudes. At least three cultural responses to risk are exhibited by western societies: these may be termed pioneering, regulating and moralizing altitudes. (This discussion is taken from Ref. [10].) These are applicable to the radiation safety community's pattern of response to radiation risk. A pioneering society considers freedom important; it has little concern for risk and in fact is stimulated by risk taking. The regulating society prefers structures and rules; for it, order is most important. For the regulating society, the problem of harmful risks must be solved quantitatively for the sake of order: a value must be clearly set. The moralizing society is strongly motivated by purism, cleanliness and protection. For it, even small risks from any human action are unacceptable, in spite of any derived benefits. Globally, there seems to be a tendency towards the moralizing society, with the associated implications: the pursuit of the 'perfectly safe' technology or the 'absolutely clean' environment.

In making decisions on radiation safety measures, it is a major challenge to establish a healthy equilibrium in which these three cultural approaches interact to promote a rationalized safety. In doing so, it should be recognized that most decisions about human safety are based on an implicit form of balancing benefits against cost and disadvantages, leading to the conclusion that a particular course of action either is, or is not, worthwhile. Decisions on radiation safety are no exception to this rule. Less commonly, it is also generally recognized that the conduct of a protective action should be adjusted to maximize the net benefit to the individual or to society. This is not a simple process because the objectives of the individual and those of society may not coincide. In radiation safety, as in other areas, it is becoming possible to formalize and quantify procedures that help in reaching these decisions. In doing so, attention has to be paid not only to the advantages and disadvantages for society as a whole, but also to the protection of individuals. When benefits and detriments do not have the same distribution throughout the population, there is bound to be some inequity. Serious inequity can be avoided by paying attention to the protection of the interests of individuals.

The Chernobyl accident demonstrated a failure of that plant's nuclear safety measures: the accident was not prevented and its consequences were not limited by the technological features of the plant. Radiation protection specialists had to deal with the radiological consequences of an unanticipated, abnormal situation for which no a priori criteria had been developed.

7.4. Evolution of Radiation Protection

The philosophy of radiation protection has been elaborated by the International Commission on Radiological Protection (ICRP). For over 60 years, the ICRP has issued recommendations on radiation protection, which international organizations, including the CEC, the IAEA, the ILO, the OECD/NEA and WHO, have implemented adaptively. Pioneering radiation protection specialists — influenced by the knowledge of conventional toxicology of the time — presumed the existence of dose thresholds for any biological effects of radiation and, reducing these assumed thresholds by ad hoc 'safety factors', derived the concept of 'safe' dose limits. However, with the growing recognition that any radiation exposure, however small, could be assumed to pose some statistical harm in large populations, protection gradually developed from pragmatic prescriptions of evolving individual related requirements (termed maximum permissible doses) to a sophisticated protection system of individual related and source related requirements (see Subsection 7.6.) intended to constrain, a priori, increases in existing dose levels due to anticipatable, 'normal' exposure caused by the introduction of practices using radiation sources.

Recently, radiation protection specialists have recognized the need to expand the scope of the discipline.

Thus, in the light of the recent concern over, for example, abnormally high radiation exposures due to natural sources in dwellings and post-accident contamination, the need for safety criteria for reducing radiation doses actually incurred in such de facto situations has been recognized. Together these factors have served to emphasize the need for a universal approach to radiation safety for all exposure situations. At the time of the Chernobyl accident, there was no such common approach.

7.5. Basic Aims of Radiation Protection

Since everyone is exposed to radiation from natural and artificial sources, any realistic system of radiological protection must have a clearly defined scope if it is not to apply to the entirety of human activities. It also has to cover, in a consistent way, a very wide range of circumstances or situations.

The basic framework of radiological protection necessarily has to include social as well as scientific judgements. Furthermore, it must be based on current radiobiological knowledge and on the assumption that even small radiation doses may produce deleterious health effects. Radiation protection should therefore be aimed at preventing the occurrence of deterministic effects by keeping doses below the relevant thresholds, and ensuring that all reasonable steps are taken to reduce the probability of stochastic effects. In simple terms, a system of radiological protection (1) should aim to do more good than harm when taking radiation related decisions; (2) should call for radiation protection arrangements that maximize the net benefit to people; and (3) should aim to limit the inequity in the distribution of radiation risks that may arise from a conflict of interest between individuals and society as a whole.

7.6. Source Related and Individual Related Requirements

It is convenient to think of the processes causing human radiation exposures as a network of events and situations. Each part of the network starts from a source. (The term source is used to indicate the source of an exposure, not necessarily a physical source of radiation.) Radiation or radioactive material then passes along environmental pathways (see Section 4), which may be very complex in the natural environment, with some pathways being common to many sources. Eventually, individuals, possibly many individuals, are exposed as a result of a single original source. Since there can be many sources, some individuals will be exposed to radiation from more than one source. For instance, all individuals are exposed to radiation from at least a few natural sources.

Assessments of the effectiveness of protection can be related to the source giving rise to the individual doses, which in such a case is called a source related assessment, or related to the individual dose received by a person from all relevant sources, which is termed an individual related assessment.

Source related assessments make it possible to judge whether all reasonable steps have been taken to reduce the radiation exposures that the source will cause. The source related assessment will take account of the magnitude of individual doses attributable to that source, and of the number of individuals so exposed, but will not consider the additional contributions from other sources. Individual related assessments are intended to determine the total doses to individuals from all relevant sources, in order to determine whether any individual has too high a probability of stochastic effects and whether any individual dose approaches a threshold for deterministic effects.

7.7. Exposure Situations and Safety Criteria

An important step towards coherency in safety matters is the development of consistent criteria for all types of situations posing radiation risks. Two types of situation can be envisaged in forecasting possible scenarios of radiation exposure:

(a) Anticipatable, preplanned situations which can be envisaged when the introduction or modification of a *practice* involving radiation risks is decided. They (i) are expected to give rise to 'normal' exposures that are assumed to occur with certainty (e.g. as a result of planned releases of radioactive materials into the environment) and (ii) may present potential scenarios of exposures of a probabilistic nature (an example being exposures that might occur should an engineering safety system fail). Appropriate engineering protection systems can be planned in advance for restraining the increase in radiation risks expected from these situations.

(b) De facto situations, where the only possible protection measure is some kind of *intervention* to reduce radiation doses. They are unplanned situations, such as 'discovered' exposures to high levels of natural radiation, or exposures occurring following a nuclear accident or a radiological emergency.

In principle, a coherent approach to radiation safety should be applicable to all types of situations involving exposures. In practice, at the time of the Chernobyl accident, a set of consistent and internationally recognized criteria existed only for normal exposure situations, for which the system of dose limitation recommended by the ICRP was widely applied. Criteria for dealing with de facto situations were either excluded from, or only mentioned in passing in, international regulations current at the time. While these regulations recognized implicitly the possibility of unanticipated conditions for which exposures could only be limited by remedial actions, if at all, they did not establish any specific criteria for dealing with such situations. As a result, there were no universal safety criteria for deciding on intervention or remedial actions for dealing with post-accident contamination.

7.8. Practices and Intervention

Following the Chernobyl accident, therefore, new thinking on radiation protection principles evolved. Today's radiation protection philosophy distinguishes between the introduction or modification of a 'practice' and 'intervention' in de facto situations:

Practices are human activities that increase the overall existing exposure to radiation, either by introducing whole new blocks of sources, pathways and individuals, or by modifying the network of pathways from existing sources to man and thus increasing the exposure of individuals or the number of individuals exposed.

Interventions are human activities intended to decrease the already existing radiation exposures by removing the existing sources, modifying pathways or reducing the number of exposed individuals. Typical cases for intervention are old dwellings with high levels of radon or situations such as that following the Chernobyl accident.

In the case of the introduction or modification of a practice, there are the options of accepting the practice, as proposed or with modifications, or of rejecting it outright. Existing practices can be reviewed in the light of new information or changed standards of protection and, at least in principle, can be withdrawn. But these options are not available in the case of a de facto situation, where the only available action to modify the situation is some form of intervention.

The steps needed to restrict the exposure of individuals, either in the control of a practice or by intervention, can be taken by applying actions at any point in the environmental network linking the source to the individuals. The action may be applied to the source, to the environment or to the individual. Actions that can be applied at the source will be the least disruptive. They influence all the pathways and individuals associated with that source. Where available, therefore, controls applied at the source are to be preferred. Actions applied to the environment or to individuals are more obtrusive and may have social disadvantages, not all of which are foreseeable; moreover, their effectiveness will be limited because they apply only to some of the pathways and individuals. After the Chernobyl accident, all possible types of actions were applied to limit the releases from the source, the destroyed reactor, but subsequent measures had to be applied in the environmental network and to the exposed or potentially exposed individuals.

The various types of exposure and the distinction between practices and intervention give rise to different degrees of controllability and thus influence judgements about the reasonableness of the various control procedures. The appropriate radiation protection requirements would depend on whether they are to be applied to a practice (where they are intended to constrain the expected increase in exposure) or to intervention (where they are aimed at reducing existing exposures); however, a system of radiation protection should be intended to be as general as possible, partly for consistency and partly to avoid changes of policy resulting from the demarcation of different situations.

7.9. The System of Radiological Protection

The ICRP is currently recommending a new system of radiological protection which applies to both practices and intervention. For the introduction of practices, the system is basically the same as the historical ICRP dose limitation system and is based on the following general principles:

(a) No practice should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes. This principle is termed the *justification* of a practice.

(b) In relation to any particular source, the magnitude of individual doses, the number of people exposed and the likelihood of incurring exposures where these are not certain to be received should all be kept as low as reasonably achievable, economic and social factors being taken into account. This principle is termed the *optimization* of protection.

(c) The optimization process should be constrained by restrictions on the doses and risks to individuals, so as to limit the inequity likely to result from the inherent economic and social judgements. The overall additional exposure to individuals resulting from the introduction of a practice, therefore, should be subject to overriding individual dose limits aimed at ensuring that no individual is deliberately exposed to radiation risks that are judged to be unacceptable. This principle is termed individual dose *limitation*.

(The principles of the system of radiological protection for practices have been extensively discussed in the literature and incorporated in international and national standards of radiation protection. They will not be discussed further in this Technical Report.)

These basic principles should also apply — in a modified form — to intervention in de facto situations, such as that following the Chernobyl accident, as follows:

— The proposed intervention should be chosen so that the reduction in expected harm is large enough to offset the social effort and consequences, including costs, of the intervention itself. This principle is called the justification of intervention.

— The form, scale and duration of the intervention should be chosen so as to give as large a net social benefit as is reasonably achievable under the prevailing circumstances. This principle is called the optimization of the protective measures.

At some level of projected dose to an individual, some intervention will almost always be justified with the aim of preventing serious deterministic effects. However, *dose limits do not apply in the case of intervention because their use may conflict with the principle of justification by calling for intervention that does more harm than good.*

These are the basic international radiation protection principles that are applicable to the situation that followed the Chernobyl accident and they are now discussed in more detail.

7.10. Principles of Radiological Protection for Intervention

7.10.1. Justification of Intervention

Decisions concerning the adoption of intervention measures that would reduce exposures from the de facto contamination situation that followed the Chernobyl accident required a choice between possible options and should ideally have been carried out in two stages. The first stage is the examination of each option separately in order to identify those options that can be expected to do more good than harm. The second stage is the final selection of the intervention option, which will often require a change from the existing de facto situation to another. The net benefit of the change will then be the relevant feature to be taken into account in the justification of the intervention, rather than the net benefit of each option separately.

The justification of the intervention measure in terms of radiation protection requires that the radiation detriment should be explicitly included in the process of choice. The detriment to be considered should not be confined to that associated with the radiation; it should include other detriments and the social efforts (including costs) of the intervention itself. It should be emphasized that the social cost of intervention is not just the monetary cost, since some protective or remedial actions may entail non-radiological risks or serious social impacts. For example, the removal of people from their homes may not be very expensive, but it may result in considerable anxiety and is sometimes traumatic. In a situation such as that following the Chernobyl accident, the radiation detriment will be a small part of the total detriment.

The justification of intervention thus goes far beyond the scope of radiological protection. It is for these reasons that the use of the term justification should be limited, for radiation protection purposes, to requiring only that the net benefit be positive. The overall justification of intervention is usually a task beyond the responsibility of radiological protection authorities.

7.10.2. Optimization of Protective Measures

Once an intervention option has been justified and adopted, it should be considered how best to use resources in reducing the radiation doses to individuals and the population. The broad aim should be to ensure that the net benefit is maximized. The net benefit is the reduction in radiation detriment less the social detriment caused by the intervention itself. The radiation detriment is reduced by reducing individual doses and/or the number of people exposed. In deciding on the type, scale and duration of the intervention, the benefits must be weighed against the social efforts, including costs. If the next step in reducing the detriment requires a deployment of resources, or causes an increase in the social detriment, that is disproportionate to the resultant reduction in the radiation health detriment, it is not in society's interest for that step to be taken. The protective measures can then be said to have been optimized and the remaining exposures to be as low as reasonably achievable, economic and social factors having been taken into account.

These considerations are complicated by the interaction between the various factors to be included, and the methods for dealing with them are diverse. These methods range from common sense to complex techniques of cost–benefit analysis or multiattribute analysis. All these techniques are aids for deciding when sufficient effort has been applied to the reduction of the radiation detriment. The application of these techniques can be improved by means of *'decision conferences'* for facilitating consensus among those who are responsible for formulating and implementing the policy of intervention (see Part G).

The judgements required in optimizing the protective measures are not purely quantitative; they reflect preferences between detriments of different kinds and between the deployment of resources and the tolerance of health effects. The process of optimizing the protective measures should therefore be carefully structured. It should be applied at the stage of the design of the protective measures following the justification to intervene. It is here that dose reductions are most likely to be achievable in effective ways.

It follows that it is not possible to define quantitative intervention levels for application in all circumstances.

Nevertheless, because some kinds of action may be needed urgently, it is useful to have guidance prepared in advance for possible use following accidents and emergencies.

7.10.3. Individual Limitations

In de facto situations such as after the Chernobyl accident, the sources, the pathways and the exposed individuals are already immutable when decisions on control measure come to be made, and control can be only achieved by intervention. *The dose limits established by radiation protection standards are intended for use in the control of practices and not for intervention. The use of these dose limits, or of any other predetermined limits, as the basis for deciding on intervention might suggest measures that would be out of all proportion to the benefit obtained and would then conflict with the principle of justification.* Although at some level of individual dose, approaching that at which serious deterministic effects would occur, some kind of intervention will become almost mandatory, dose limits must not be used for deciding on the need for or scope of intervention.

It should be emphasized that the dose limits established for the introduction of practices are widely, but erroneously, regarded as: (i) a line of demarcation between 'safe' and 'dangerous' (only if the limits were equal to the threshold dose for deterministic effects would this perception be correct); (ii) the most simple and effective way of keeping exposures low and stimulating improvements; and (iii) the sole measure of the stringency of a system of protection. These misconceptions are, to some extent, strengthened by the incorporation of limits into regulatory instruments. (Causing a limit to be exceeded then becomes an infraction of the rules and sometimes a statutory offence.) Against this background, it is perhaps not surprising that managements, regulatory agencies and governments all improperly set out to apply limits whenever possible, even when the sources in question are partly, or even totally, beyond their control, and when the optimization of protection is the more appropriate course of action. (As may be seen from this Technical Report, the 'limits' applied following the Chernobyl accident are a good example of these misconceptions.)

7.11. De Facto Situations in Which Intervention May Be Needed

The contamination due to the Chernobyl accident is an extreme but by no means unique de facto situation requiring intervention. There are many types of de facto situations in which intervention may be considered. They can be long standing situations that do not call for urgent action, or situations in which serious exposures may result unless immediate action can be taken, which call for prompt decisions. (The Chernobyl accident gave rise to situations of both types.) Such long standing situations are typically exposure to high levels of natural background radiation in general (and to radon in dwellings in particular) and exposure to radioactive residues from previous events (the current contamination due to the Chernobyl accident can be viewed as such a situation). A typical situation calling for prompt decisions is that immediately following an accident (the early phase of the response to the Chernobyl accident is a good example of this).

7.11.1. Long Standing Situations

Radon in Dwellings

Radon in dwellings needs special attention because both the individual doses and the collective doses from radon are higher than those from almost any other source. In many countries, some individual doses due to radon are substantially higher than those that would be permitted due to occupational exposure. If improvements are needed, they have to be achieved by interventions including modifications to the dwellings or to the behaviour of the occupants.

Radioactive Residues from Previous Events

The long term contamination due to the Chernobyl accident is, however, not a unique case of residues from previous events. The most common cause of residues is the burial of long lived materials from early operations such as mining and luminizing with radium compounds. The use of mining spoil as a landfill material, and the subsequent construction of dwellings on sites, has caused substantial problems. Buildings used for radium work have subsequently been put to other purposes, with the radium being discovered only years later. There have been several accidents in which long lived radioactive materials have been dispersed in residential and agricultural areas. The necessary remedial actions vary greatly in complexity and scale. The need for and the extent of remedial action have to be judged by comparing the benefit of the reduction in dose with the detriment of the remedial work, including that due to the doses incurred in the remedial work. No general solutions are possible, but the methods recommended for the optimization of protection can be used to give guidance in each individual case.

7.11.2. Situations Requiring Prompt Decisions

The essential differences between emergencies and other situations calling for intervention are the urgent time-scale on which action is needed and, following most accidents, the fairly short duration for which action has to be continued.

The first step in deciding on the intervention likely to be needed after an accident is to define the type of all likely protective actions and to consider the costs and the expected reductions in individual and collective doses as functions of the scale and duration of each action. A substantial amount of preliminary work on economic and environmental models and on accident forecasting is needed for these assessments.

Because the initial introduction of protective actions on any scale, however small, may have significant costs, it may well be that small scale, short duration intervention is costly without being effective. As the scale and duration are increased, the effectiveness initially increases without a marked increase in costs. Eventually, further increases will fail to achieve increased benefits comparable with their costs and the net benefit again begins to fall. There is then a range of values of the possible intervention level of individual dose averted, within which there is an optimum level. If the net benefit at that optimum is positive, intervention of the defined type, scale and duration will be justified. The initial planning for emergencies should include the choice of intervention levels of dose averted, or a limited range of such intervention levels that are likely to lead to intervention that is justified and reasonably well optimized.

The benefit of a particular protective action within a programme of intervention should be judged on the basis of the reduction in dose achieved or expected by that specific protective action; that is, the dose averted. Thus each protective action has to be considered on its own merits. For example, decisions about the control of individual foodstuffs are independent of decisions about other foodstuffs and of decisions about sheltering or evacuation. In addition, however, the doses that would be incurred via all the relevant pathways of exposure, some subject to protective actions and some not, should be assessed. If the total dose in some individuals is so high as to be unacceptable even in an emergency, the feasibility of additional protective actions influencing the major contributions to the total dose should be urgently reviewed. Doses giving rise to serious deterministic effects or to a high probability of stochastic effects would call for such a review. For this purpose, an intervention level of dose received by all pathways should be chosen at the planning stage.

8. Achieving a Common Level of Understanding among Local and International Experts

8.1. Introduction

An important activity of the International Chernobyl Project was to arrange specialist meetings of international and local experts in medical, agricultural and dose assessment sciences. The principal aim was to seek through these meetings a common level of understanding of the effects of radiation exposure, methods for assessing exposure and reducing it, and appropriate criteria for radiological protection. The need for medical and agricultural seminars was identified and anticipated at the outset of the Project following the international experts' preparatory mission. A radioecology seminar was incorporated later.

Because of the nature of the agricultural problems in the affected areas, the support provided under this part of the Project was extended from the basic aim of fostering exchange of information to assisting in the implementation of positive actions, in addition to actions already taken, for reducing the transfer of radiocaesium into food.

8.2. Medical Seminars for General Practitioners on the Health Effects of Ionizing Radiation

One of the key groups of people to whom the public turn for information and whom they will trust is the medical community. The knowledge of medical personnel in the areas affected by the Chernobyl accident about the effects of radiation exposure was limited. Three-day seminars were thus held in the BSSR, the RSFSR and the UkrSSR as a means of exchanging information on the health effects of ionizing radiation between a visiting team of four experts and local medical personnel from the affected areas.

The main objectives of the seminars were as follows:

— To gain better understanding of the medical problems reported in the affected areas, through presentations and discussions between the invited experts and local medical personnel;

— To familiarize the participants (mostly general practitioners) with the results of long term comprehensive studies on radiation induced and related illnesses and their diagnosis and treatment, as well as the epidemiological methods used in studies of morbidity and mortality in population groups exposed to radiation;
— To review the basic principles of radiation protection with emphasis on problems relating to unanticipated de acto situations.

Visiting experts from Hungary, Japan, Sweden, the USA and the IAEA secretariat, including specialists in clinical oncology, radiobiology, occupational hygiene and radiation protection, supported the seminars with scientific presentations on the subjects covered in Part B of the Technical Report.

The seminars were held in Ovruch, UkrSSR (10–12 July 1990); Gomel, BSSR (14–16 July 1990); and Novozybkov, RSFSR (18–20 July 1990). A total of more than 1200 local doctors and health administrators participated. They included hospital doctors, general practitioners and professional staff of epidemiological centres and local health authorities from affected areas and areas adjacent to those affected.

The IAEA made available 1000 copies of reference material that were distributed at the seminars. Synopses of most of the presentations (in English) were also delivered to local organizing committees.

The programme comprised the following three modules: basic concepts; health effects of radiation exposure; and protection against harmful effects of ionizing radiation. Topics covered included basic facts on radiation and radioactivity — quantities and units; pathways of radiation exposure to man; basic cellular radiobiology; acute radiation syndrome — diagnosis, prognosis and treatment; localized early radiation injuries; effects of radiation on the thyroid gland — prophylaxis, diagnosis and treatment; other effects of radiation exposure; late effects — radiation carcinogenesis; dose-response relations; consequences of in utero exposure; hereditary effects of radiation; epidemiological methods used to study morbidity and mortality in population groups; and basic principles of radiation protection. Considerable time was given over to questions and discussion.

Remarkable interest was shown in the seminars by local medical personnel and the general public. This was reflected in the intensive open discussions, which were evaluated by visiting experts as being at a high professional level. Another indication of the interest shown was the hundreds of questions put by the participants to the visiting specialists (see Annex II). The seminar in Ovruch was tape recorded in order to be able to publish the proceedings. A simultaneous broadcast of the proceedings through loudspeakers attracted a crowd of listeners, and there was substantial coverage of the seminars in central and local media.

In discussions, several participants observed that the information provided at the seminars was valuable and beneficial for background knowledge on the health effects of radiation. They also indicated the relevance of the information to their practices and their daily contact with patients.

8.3. Agricultural Activities

8.3.1. Fact Finding Mission

As a first step in the organization of the agricultural seminars, there was a joint FAO/IAEA fact finding mission to the USSR from 12 to 24 August 1990. The group of four experts from the United Nations Food and Agriculture Organization (FAO), Norway, the United Kingdom and the USA had expertise covering genetics, animal husbandry, soil science, plant uptake and general problems of managing radioactively contaminated agricultural land. The objectives of the mission were to hear the concerns of farmers and farm workers with regard to living and working in a contaminated agricultural environment; to assess the most effective type, level, size and numbers of seminars that could meet their needs for information; and to draft syllabuses for seminars and to recommend suitable lecturers and dates. In addition, the team visited some key agricultural institutes to examine what information was to hand on managing contaminated agricultural environments, formulated recommendations for future work in this field and carried out a preliminary investigation of reports of malformations and mutations in flora and fauna outside the prohibited exclusion zone around the Chernobyl plant.

The team returned with technical information and impressions, much of which have been incorporated into this Technical Report. In particular, the team recommended that the agricultural seminars be organized to give practical advice on improved soil management techniques and on how animals can be fed with hitherto unacceptably contaminated forage by blocking the gut uptake of ^{137}Cs with specific binders. It also suggested that the seminars should give the opportunity to emphasize that positive and economic countermeasures can be effective in relatively high fallout areas, and that they should be given adequate coverage in the media. A workshop on the use of caesium binders was proposed to be held in co-operation with the government of Norway, with attendance by experts from the BSSR, the RSFSR and the UkrSSR, before the seminars took place.

8.3.2. Workshop in Norway on Caesium Binders

A one week workshop was subsequently organized in Norway from 24 to 28 September 1990 for a group of seven agricultural scientists and ministry officials representing the BSSR, the RSFSR and the UkrSSR. The main purpose of the workshop was to exchange scientific, technical and administrative information on and experience in the use of techniques for reducing caesium contamination in milk and meat derived from grazing animals. These techniques employ 'caesium binders', which are additives to fodder, such as bentonite and Prussian Blue (specifically, ammonium hexacyanoferrate (II) (AFCF), containing hexacyanoferrate ions, $[Fe(CN)_6]^{4-}$), which fix free caesium ions in the gut and make them unavailable for absorption through the gut lining and into meat or milk. Adding these caesium binders to animal feed can substantially reduce the levels of caesium radionuclides in the meat and milk (by factors of ten or more), and this was known and understood in the USSR and elsewhere many years before the Chernobyl accident. The technique had not, however, been applied in the USSR as a countermeasure for two reasons: (1) the use of Prussian Blue for this purpose was not licensed by the Ministry of Health, and (2) most of the problems relating to grazing animals occur when they are feeding from natural pasture, and thus when it is difficult to administer any additives. In Norway, methods were developed of administering Prussian Blue to reindeer, goats and sheep contaminated with radiocaesium with minimal interference from or impact on the farming community. These methods include the impregnation of salt licks with Prussian Blue, which in tests with sheep reduced caesium levels in meat by a factor of 2 or 3 simply by passive intake of the salt; and, more importantly, the development of sustained release boli, which after oral administration to cattle deliver Prussian Blue (AFCF) to the rumen over a two to three month period, during which the absorption of caesium into meat and milk is inhibited by a factor of 5 or more.

The team from the BSSR, the RSFSR and the USSR visited and had discussions at the Norwegian Ministry of Agriculture, the National Institute for Radiation Hygiene and the Agricultural University of Norway, as well as visiting farmers and a veterinary control laboratory in the high fallout areas in Norway. They were informed about the general situation in Norway with regard to radioactive contamination of soil, crops, fresh water resources and forests, as well as the activity levels in domestic and wild animals and milk, meat and fish. The Norwegian agricultural specialists informed the visiting team of their research work and results and of the system of environmental and food control. The visiting team was also informed about the national press arrangements and the distribution of information to farmers. Of particular importance was a demonstration of how the caesium binders were used in Norway to reduce caesium levels in the meat and milk of grazing animals. Also of interest to the visiting team were the importance of modern radiological equipment for the in vivo monitoring of animals and the governmental compensation scheme adopted in Norway. The workshop also finalized the programme for the agricultural seminars and proposed a field experiment with Prussian Blue boli in the BSSR, the RSFSR and the UkrSSR before the seminars. In summary, the workshop established close co-operation between the Norwegian scientists and their visiting counterparts dealing with the problems of contaminated animal products.

8.3.3. Agricultural Experiments in the BSSR, the RSFSR and the UkrSSR

Field experiments with the Norwegian Prussian Blue boli were proposed for collective farms in the BSSR, the RSFSR and the UkrSSR. Experiments were set up in Gomel, BSSR; Novozybkov, RSFSR; and Polesskoe, UkrSSR. Groups of cows received one of three treatments, namely a control, administration of two boli of caesium binder, and administration of three boli of caesium binder. Each group consisted of six animals and a feeding regime was selected that would normally have given rise to relatively high radiocaesium values in milk. In Gomel, this proved difficult because, according to local scientists, it was hard to find such contaminated fodder. Also in the UkrSSR, the people from the collective farm were relocated at the end of October 1990, curtailing the experiment. However, an extra experiment with two and four boli per cow was also started at an experimental farm.

The treatment of the animals was followed with interest by large groups of local people, and in the UkrSSR the interest was so great that the treatment of the animals was handed over to local veterinarians after the techniques for administering the boli had been

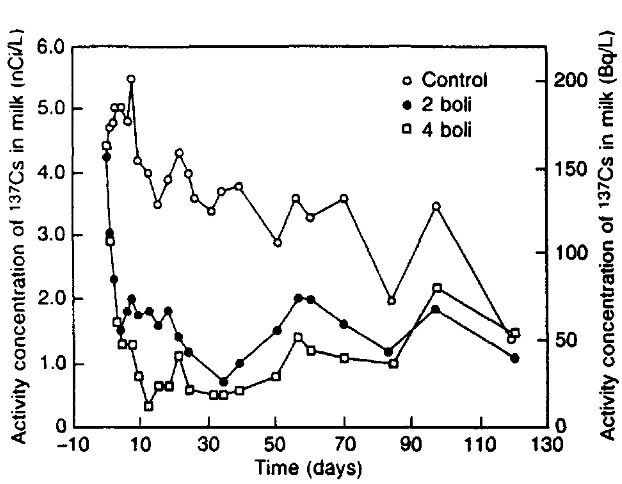


FIG. 16. Results of experiments with boli containing the caesium binder AFCF in the UkrSSR: Plot of activity concentration of ^{137}Cs in milk versus time for three groups of dairy cows, administered no, two and four boli respectively.

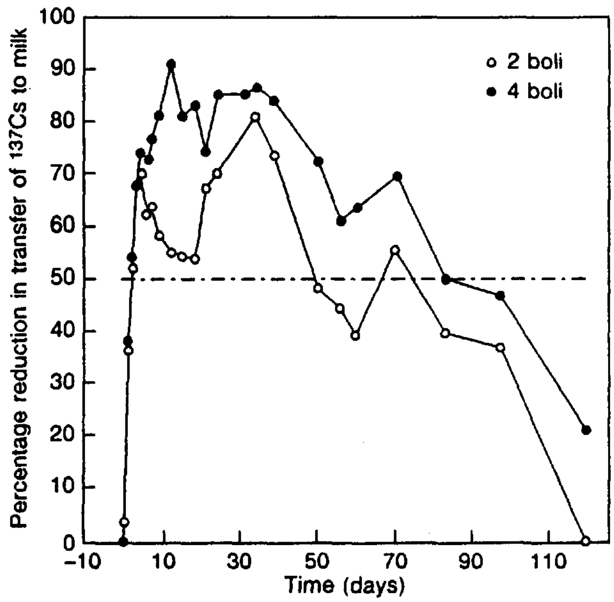


FIG. 17. Results of experiments with boli containing the caesium binder AFCF in the UkrSSR: Plot of percentage reduction in the activity concentration of ^{137}Cs in milk versus time following the administration of two and four boli.

demonstrated. Videos were made of the bolus treatment and of discussions on the use of caesium binders in both the BSSR and the UkrSSR.

Animals were monitored for radiocaesium content in vivo upon administration of the treatments. The radiocaesium levels in milk were subsequently measured approximately weekly by scientists from branches of the All-Union Institute of Agricultural Radiology. Figure 16 shows the activity of ^{137}Cs in milk from three groups of animals, receiving respectively no treatment, two boli and four boli, plotted aginst time. Figure 17 shows the percentage reduction in the transfer of ^{137}Cs to milk effected by the boli: typically a 70% reduction over the first month after treatment with two boli, but maintaining a 50% reduction over the next month also. The reductions achieved for four boli were clearly greater. Comparable results were found for the experiments in the other two Republics. No negative effects were found on the animals' productivity over the period of the experiment.

Secondary problems were also discussed between Professor Hove and the scientists relating to the cows' micromineral shortage (cobalt, zinc, molybdenum), which apparently had been aggravated as a consequence of the treatment of contaminated soils with lime and dolomite. The inclusion of such microelements in Prussian Blue boli might be a way to combine caesium binding with micromineral supplementation.

8.3.4. Agricultural Seminars

A series of seminars on the management of contaminated agricultural areas were held in the BSSR, the RSFSR and the UkrSSR over the period 28 October to 4 November 1990.

The main objectives of the series of seminars were as follows:

— To provide an overall understanding and background knowledge for agricultural managers, administrators, farmers, local authorities and other interested parties of problems pertaining to the management of contaminated agricultural land.
— To give an opportunity for local and visiting experts to exchange information and experience relating to past, current or future research work and studies in the field of management of contaminated agricultural land.
— To review and analyse national and international practices and experience in the methods and the applications of radiocaesium binding for reducing transfer to agricultural products.
— To provide practical advice and recommendations to local authorities, agricultural specialists and farmers on the management of contaminated soils.
— To demonstrate the use of various methods and techniques for the rapid monitoring of radiocaesium in live animals.
— To inform interested parties, including representatives of the press and other media, of relevant developments in the management of contaminated agricultural land.
— To summarize international experience in informing the population on the radioactive contamination of agricultural land.
— To review socioeconomic and psychological problems related to living and working under such conditions.
— To consider and discuss international experience on derived intervention levels in agricultural raw materials and foodstuffs, and their practical application.
— To discuss control systems and ways of utilizing contaminated agricultural products, including processing (cooking, canning, diluting, etc).

The faculty comprised experts from Austria, Norway, the United Kingdom and the IAEA secretariat, whose specialties included soil science, crop management, veterinary science, radioecology, health physics monitoring and radiation protection.

The series of seminars was part theoretical and part practical. The theoretical part was convened in Gomel, BSSR on 28–29 October 1990. The first day was devoted to considering scientific and technological aspects of the objectives noted earlier; the second day concentrated on the practical implementation of the various methods and the necessary administrative effort and support. The audience for the first day comprised approximately 100 people, scientists from all three Republics and the All-Union level; the second day's audience numbered 150 and included in addition administrators, managers and decision makers at various levels, as well as other interested parties (such as representatives of the Green movement and of the press and other media).

The programme for the scientific/technical seminars included reports on the findings of the fact finding mission; comparison of national and international derived intervention levels for food; measurements of fallout radionuclides in soil; management of contaminated soils; soil contamination and uptake by crops and animal fodder; in vivo monitoring of grazing animals; caesium binders; and research in the various countries represented. The preliminary results of the administration of Prussian Blue to cattle in the BSSR were presented. Substantial time was given over to discussion, particularly with respect to the use of caesium binders.

The practical part consisted of three identical seminars held consecutively in Gomel (BSSR), Novozybkov (RSFSR) and Korosten (UkrSSR). The audiences for these seminars comprised collective farmers, farm workers, public health service representatives, veterinarians and others. The numbers of participants at each seminar were 200 (BSSR), 300 (RSFSR) and 800 (UkrSSR).

The programme for the practical seminars included background to the International Project, the results of the fact finding mission; comparison of national and international derived intervention levels for food; use of caesium binders for grazing animals; and methods for reducing radiocaesium levels in the diet through management of food. In the BSSR and the UkrSSR, the video recordings of the experiment on the administration of caesium binders to cattle, which had been made two weeks previously, were shown to the audiences. The programme allowed for questions from the audience. Many of the questions related to the effectiveness and safety of caesium binders, as well as to the safety of living in the affected areas, the 350 mSv lifetime dose concept, intervention levels and general environmental contamination levels in the countries represented by the faculty and general radiation protection matters. Other specific food related questions related to the effectiveness of washing and preparation techniques at reducing radiocaesium levels in various foodstuffs. It seemed to the faculty team at least that basic information about the effectiveness of normal food preparation techniques had not been made widely available, especially in Gomel and Korosten.

The IAEA made available 700 copies of a four page handout, which were distributed at the practical seminars. The handout contained summary information, in Russian, on the management of livestock in contaminated areas (including a discussion on caesium binders and special feeding regimes); management of arable soils (including ploughing, addition of fertilizers and other chemicals and land management); food processing; and foodstuff 'derived intervention levels'. The audiences at the three seminars all wanted copies of the handout. Synopses of most of the scientific/technical presentations (in English) were also made available to the Soviet organizing committees.

8.3.5. Follow-up on Caesium Binders

Currently, Prussian Blue (AFCF) is not licensed in the USSR for use as a caesium binder for grazing animals. The necessary certification comes from the Ministries of Health and of Agriculture. A list of references of work performed on the compound's toxicity, efficiency and other potential problems was made available to the Ministry of Health of the USSR, as well as copies of the documents justifying and permitting its use for this purpose in Norway.

Various forms of Prussian Blue are already manufactured in the USSR, since the chemical has uses as a dyestuff. However, for the purposes of administration to animals as a caesium binder, it is necessary that the chemical meets certain standards of quality and safety. To this end, samples of Prussian Blue (ammonium ferric-hexacyanoferrate (II) or AFCF and potassium ferric-hexacyanoferrate (II)) manufactured in the BSSR,

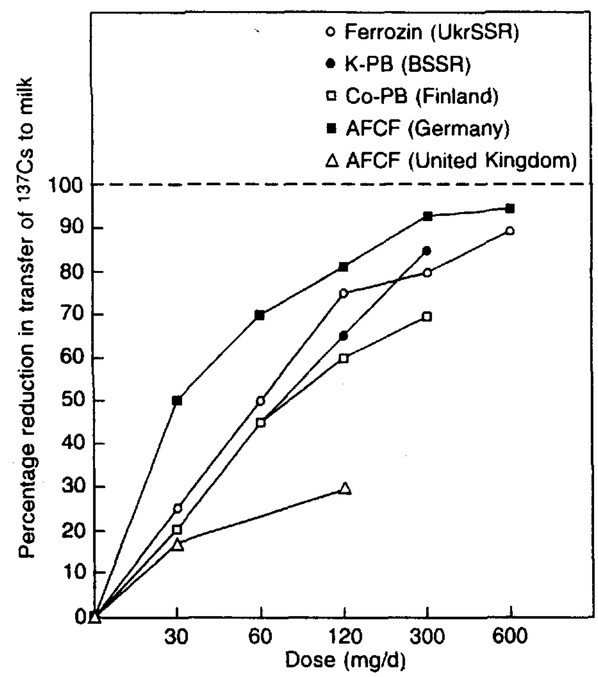


FIG. 18. The efficiency of different types of Prussian Blue: Plot of the percentage reduction in transfer of ^{137}Cs to milk versus dosage.

the RSFSR and the UkrSSR were sent to the Agricultural University of Norway. They were tested for purity, specificity and efficiency at reducing radiocaesium uptake by grazing animals. The efficiency of forms of Prussian Blue produced in the BSSR and the UkrSSR at reducing transfer to goats' milk are presented in Fig. 18, with the percentage reduction in the transfer of ^{137}Cs to milk plotted against the daily dosage of Prussian Blue. Also shown are comparable results for other sources of Prussian Blue. It can be seen that the UkrSSR and BSSR products are comparable with those from other sources, and indeed considerably better than the particular brand from the United Kingdom. The results on purity and specificity are not yet available.

Conditional on the acceptability, in principle, of the technique of administering Prussian Blue to grazing animals, and before a decision on full scale implementation of the method can be taken, it was considered highly desirable to carry out a pilot study in a real farming community. Plans for this study are in hand. It aims to identify problems and provide solutions relating to the implementation of the production and distribution of caesium binders, monitoring of animals and food products and economic/compensation issues; the main conclusion of this study should be to recommend an optimum system of administering the caesium binders and of control.

8.4. Radioecology Seminar: Systematic Assessment of Doses to Persons Following a Release of Radionuclides to the Environment

This seminar was organized later on in the project following a request from the UkrSSR to the IAEA. The main objectives of the seminar were as follows:

- To elucidate the principles of environmental modelling that enable predictions of doses to persons following a release of radionuclides into the environment, with particular emphasis on releases from waste disposal facilities.
- To appreciate the data required to carry out such assessments and to review the methods for obtaining such information.
- To review the behaviour of radiologically significant radionuclides in the biosphere and their relevance to man.
- To facilitate the exchange of scientific and technical information between experts in this field and to stimulate further appreciation of its importance.
- To provide an opportunity for lessons to be learned from the Chernobyl accident with relevance to these subjects.

The seminar took place at the University of Kiev, UkrSSR, on 21-25 January 1991, with lecturers from Canada, Germany, Spain, the United Kingdom and the IAEA secretariat. The lectures covered sources of environmental radioactivity, pathways of exposure, dosimetric concepts, the effects of radiation, environmental measurements, dose assessment modelling, sample collection and processing, quality assurance, parameter determination, reliability of models, sensitivity/uncertainty analysis, validation of models, presentation of results, decision making and case studies of dose assessments in practice. As with the other seminars, considerable time was allowed within the programme for questions from the audience.

The audience consisted of approximately 200 people, with backgrounds in radiobiology, biology, radioecology, environmental science, public health and regulations; they were drawn from the BSSR, the RSFSR and the UkrSSR. The IAEA made available 200 copies of its Safety Series No.77, Principles for Limiting Releases of Radioactive Effluents into the Environment (in Russian), one for each participant. In addition, lecture notes, in English, for most of the presentations were provided by the faculty to the USSR counterparts.

TABLE 7. Summary of Numbers and Professions of Seminar Participants

Name of seminar	Number	Nature of participants
Medical	1200	Local physicians, health administrators, hospital doctors, general practitioners, professional staff of epidemiological centres and health authorities
Agricultural		
Theoretical	150	Agricultural scientists, administrators, managers and decision makers, environmentalists, media representatives
Practical	1300	Collective farmers, farm workers, public service representatives, veterinarians
Radioecology	200	Radioecologists, radiobiologists, environmental scientists, public health and regulatory officials

8.5. Summary and General Conclusions

Table 7 presents information on the numbers and nature of participants in three series of seminars organized as part of the International Chernobyl Project. The seminars proved to be a timely response to prevailing common concerns and continuing great demand for accurate technical information relating to the consequences of the Chernobyl accident in the affected areas. The seminars were welcomed and appreciated as making considerable progress in establishing a common level of understanding of the problems involved.

The seminars were given a high profile by the Soviet press and media, and the willingness of the international experts to answer questions openly and frankly was considered to be of great importance. The large numbers of questions and the discussion support this statement. Questions invariably returned to health matters and concepts of 'safe living', as well as covering more technical issues relevant to each seminar.

There is a continuing need for international follow-up assistance in this respect. This should be continued in association with or by WHO and the FAO within existing agreements on co-operation. In the agricultural sphere, a practical programme of co- operation with regard to the utilization of caesium binders in grazing animals has already been instigated.

Finally, not only did the seminars make considerable progress in achieving their stated objectives, but direct contacts between faculty members and senior representatives from some of the major research institutes in the USSR were established, aimed at future co-operation and exchange of information pertinent to the subject of the seminars.

References

[1] UNITED NATIONS, Genetic and Somatic Effects of Ionizing Radiation (Report to the General Assembly), Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), EEE.86.IX.9, UN, New York (1986).

[2] UNITED NATIONS, Sources, Effects and Risks of Ionizing Radiation (Report to the General Assembly), Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), E.8IX.7, UN, New York (1988).

[3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection, Publication 60, Pergamon Press, Oxford and New York (1991).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, IAEA, Vienna (1988).

[5] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Non-stochastic Effects of Ionizing Radiation, Publication 41, Pergamon Press, Oxford and New York (1984).

[6] UNITED NATIONS, Sources and Effects of Ionizing Radiation (Report to the General Assembly), Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), E.77.IX.1, UN, New York (1977).

[7] UNITED NATIONS, Ionizing Radiation: Sources and Biological Effects (Report to the General Assembly), Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), E.82.IX.8, UN, New York (1982).

[8] COMMITTEE ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATIONS, NATIONAL RESEARCH COUNCIL, The Effects on Populations of Exposure to Low Levels of Ionizing Radiation (BEIR-III), National Academy Press, Washington, DC (1980).

[9] COMMITTEE ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATIONS, NATIONAL RESEARCH COUNCIL, Health Effects of Exposure to Low Levels of Ionizing Radiation (BEIR-V), National Academy Press, Washington, DC (1990).

[10] PRÊTRE, S., "A compromise regarding the three different cultural responses to the 'de minimis' question", Rules for Exemption from Regulatory Control, (Proc. Workshop Washington, DC, 1988) NUREG/CP-0101, United States Nuclear Regulatory Commission, Washington, DC (1989).

Part C
Historical Portrayal

Contents

1. Introduction

Part C is a historical account of the events following the Chernobyl accident which led to the environmental contamination and consequent radiological hazards. The primary intent is to provide the necessary historical background for the sections of the Report that address the questions of exposure pathways, doses to people and possible health effects and the issue of protective actions. Human aspects of the period of disruption following the accident are also described.

Sources used in preparing this account include the many articles, documents and books on the Chernobyl accident and its consequences and interviews conducted by the various international teams that have visited the USSR under this Project with many people who lived through the disaster as well as with numerous officials from various institutes and government bodies. The historical account is unavoidably incomplete. Only the various authorities and organizations, the scientists and the public in the USSR who were involved would be able to prepare a complete history of events.

The account is intended to be factual, but areas of policy and policy implementation by authorities of the USSR, the BSSR, the RSFSR and the UkrSSR have also been examined from a historical perspective. Interpretations of the events must take into account the emergency that confronted those who had to deal with the accident, which was unprecedented in its size and its repercussions. The report is in no way intended to express or to imply judgements based on hindsight or to detract from the courage of those who acted to save the lives of others and those who had to take difficult decisions on the basis of limited information.

2. The Accident and Emergency Measures at the Site

2.1. The Explosion

At the time of the accident, in the early hours of Saturday 26 April 1986, there were nearly 200 employees at the Chernobyl nuclear power plant engaged in the normal operation of Units 1, 2 and 3 and the experiment at Unit 4 that was to lead to the devastating explosion. The cause of the explosion is well summarized in Refs [1, 2]. A further 300 people were working on a night shift to construct two further reactors (Units 5 and 6) about a kilometre away (Fig. 1).

At around 01:24 Moscow time, two explosions in quick succession blew the roof off the Unit 4 reactor building, sending concrete, graphite and debris flying and leaving a gaping hole exposing the reactor core to the outside air [1–5]. Smoke and fumes rose over 1 km into the air, together with a large amount of uranium fuel, transuranics and fission products from the reactor core, including essentially all the noble gases. The heavier material fell out near the site, but lighter particles drifted to the west and north of the plant in a radioactive cloud that contaminated the surface wherever it touched down. The lightest material was carried up by the heat of the explosion to over 1 km in altitude and was blown to the northwest [1–5].

Fires broke out on the roof of the adjoining turbine hall. There were also fires inside the Unit 4 building, together with clouds of steam and dust [3, 4]. The graphite, which constituted a major part of the core, was ignited by the heat and the explosion. A plant employee

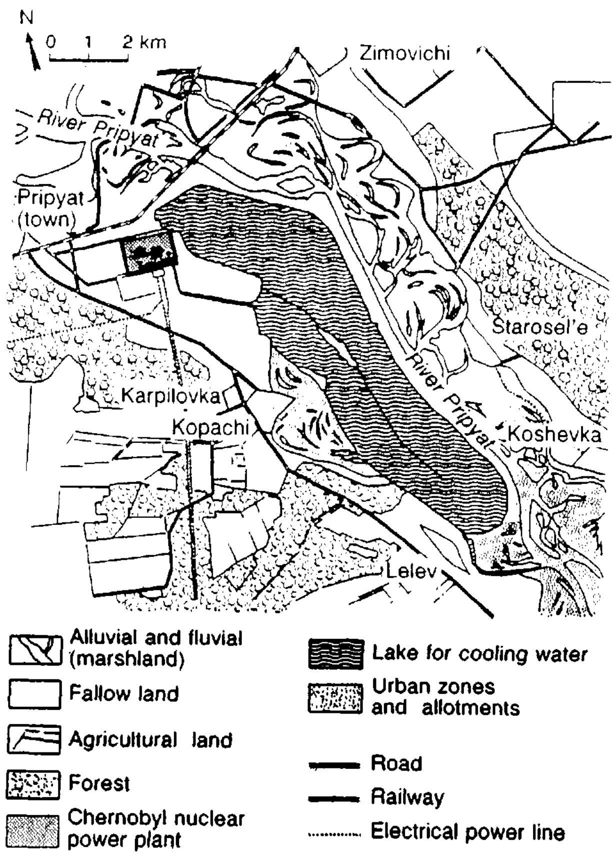


FIG. 1. Map of the immediate surroundings of the Chernobyl nuclear power plant. [Source: Ref. [18]]

working above the reactor was killed instantly in the explosion; his body could not be recovered. Another, crushed by debris and badly burned, was rescued within minutes but died of his injuries a few hours later [3-5].

2.2. Fire-Fighting

Alarms went to fire units in the region [1, 4, 5]. Within minutes, the plant firemen arrived, followed quickly by other squads from around Pripyat. Pripyat was the nearest settlement, at just 3 km from the site, and housed most of the power plant's personnel. Other fire units from further away began to arrive within half an hour. The Pripyat fire team seems to have had no special training in fighting fires at a nuclear reactor and involving radioactive materials [4]. Some firemen set to work, with the help of plant staff, to fight the fires in the turbine hall and the Unit 4 building. Others climbed onto the roofs of the Unit 3 building and the turbine hall to fight fires. Hot lumps of burning graphite from the exploded core were carried by hand from the roof and thrown down.

In the Unit 4 control room, despite the fact that all normal means of monitoring critical core parameters had been lost, it seems that it was not initially clear to the operating staff that the core itself had been destroyed. An explosion in the core had not been considered possible by nuclear experts in the USSR [6, 7]. Even when rescue workers had entered the Unit 4 building and reported that the core had been destroyed, their initial reports seem not to have been credited by the operating crew for several hours [3, 4, 7, 8]. Thus, the operators continued to seek ways to direct more water into the Unit 4 reactor building to combat the fire, and contaminated water flowed down below the core to lower floors that connected with the other units [2, 7].

By dawn on the Saturday, the more than 100 firemen had succeeded in putting out the roof fires, and by about 05:00 all but the graphite fire in the core had been extinguished [2, 3]. These courageous actions by the early fire-fighters and plant personnel resulted in many injuries, but they were essential to preventing the spread of fire to the other units and to preventing a hydrogen explosion or fire that might have ignited the oil in the turbines [2, 3, 5]. Many firemen stayed on the alert on the premises for several hours after the fire was out, which resulted in a number of radiation exposures [3, 7].

Radiation levels were so high in the damaged part of the plant and just outside it that monitoring equipment in the plant could not measure them [3, 8]. Available portable radiation meters went off scale and systematic monitoring became impossible. It seems that many of those who entered the buildings to rescue others, fight fires, perform critical operations or assess damage did not appreciate the radiation risk. The levels in some accessible places are now said to have exceeded 100 Gy/h [3, 9]. As a result of this lack of awareness, as well as the urgent need to fight the fires, no measures were taken to reduce exposure and doses to the emergency personnel. The plant personnel and firemen had no personal dosimeters to measure their radiation doses. As a result, many firemen from the plant and others who fought the fires were seriously irradiated. Some exposures exceeded 10 Gy. Within an hour the first of many cases of acute radiation syndrome (ARS) became evident. There were 132 emergency workers affected by high levels of radiation in the first 12 hours following the accident [2]. (See Appendix of Annex G of Ref. [10].)

2.3. Emergency Medical Response

The plant personnel and auxiliary and emergency staff present at the site in the immediate vicinity of the accident zone were subjected to the combined effect of radiation from several sources: short term external gamma-beta radiation from a gas emission cloud, external gamma-beta radiation of decreasing intensity from fragments of the damaged reactor core scattered over the site, inhalation of gases and aerosol dust particles containing a mixture of radionuclides and deposition of these particles on the skin and mucous membranes during the generation of large amounts of steam and dust. The most significant factors were the general external and relatively uniform whole body gamma irradiation and the beta irradiation of skin surfaces. The basic clinical picture was of a distinctive ARS caused by gamma irradiation of the whole body and by beta irradiation of extensive areas of the skin surface.

Small squads of medical personnel and emergency teams provided first aid and comfort to affected individuals during the first three to six hours after the accident [3, 9]. They evacuated some of the victims to medical units, administered antiemetic and symptomatic drugs, and distributed potassium iodide (KI) tablets. KI tablets were also given to some operating staff to lessen their accumulation of radioiodine from the contaminated air that had penetrated the other three units through connecting corridors and the ventilation system [3]. During the day of the accident, those who had assisted in the emergency response were urged to undergo medical examinations. The 132 persons suspected from suffering acute radiation induced injuries in the first hours were hospitalized in Pripyat.

After about 12 hours, a specialized emergency team arrived at the site. Within 36 hours this team examined more than 350 persons in an on-site medical unit and made about 1000 blood tests, each person having two or three tests. (See Appendix of Annex G of Ref. [10].)

As a result, during the first 3 days after the accident, a total of 299 persons suspected of suffering from ARS were sent either to a specialized treatment centre in Moscow or to hospitals in Kiev. Over the subsequent few days, about 200 additional persons were admitted to these hospitals for examination. Patients were monitored for contamination and, if necessary, underwent decontamination measures. Blood and urine samples were taken and tested for the presence of radionuclides. Measurements of radioactive iodine concentrations in the thyroids of the emergency workers were made in situ on about four to six occasions during the first six to ten days. In addition, whole body counting was performed at measuring clinics with a scintillation counter or a semiconductor detector [9]. (See Appendix of Annex G of Ref. [10].)

The total number of those persons who had been present at the reactor site on 26 April and who subsequently showed clinical effects due to radiation exposure or burns was finally 203, of whom 115 were treated beginning on the second day after the accident at the specialized treatment centre in Moscow. (See Appendix of Annex G of Ref. [10].) Twelve patients with clearly defined clinical patterns of second degree ARS and one person with fourth degree ARS were also treated at hospitals in Kiev (see Tables 1 and 2). By November 1986, the total number of individuals in treatment had increased from 203 to 237, with the addition of other persons suffering from first degree ARS. By then, there were 31 persons suffering from first degree ARS in the Moscow specialized treatment centre and 109 in Kiev (see Appendix of Annex G of Ref. [10]). Twenty-eight of the ARS victims died. Sixteen were still under treatment in Moscow in 1988.

TABLE 1. Degrees of Acute Radiation Syndrome (ARS): Distribution of Patients with ARS Treated at the Specialized Treatment Centre

Degree of severity of ARS	Number of patients	Number of deaths
I Slight	31	—
II Intermediate	43	1
III Severe	21	7
IV Extremely severe	20	20

Source: Appendix of Annex G of Ref. [10].

TABLE 2. Symptoms of ARS: Prognostic Groups According to Severity of Bone Marrow Syndrome

Degree of severity of bone marrow syndrome		Dose (Gy)
I	Slight	1–2
II	Intermediate	2–4
III	Severe	4–6
IV	Extremely severe	>6

Source: Appendix of Annex G of Ref. [10].

2.4. Moscow Alerted and Governmental Commission Formed

Signals from the Chernobyl plant were transmitted automatically, in the first moments of the accident, to the central emergency centre in the Ministry of Atomic Power and Industry in Moscow. They indicated that there had been a serious event involving a nuclear reactor, explosion, fire and radiation. In accordance with national emergency plans, the duty officer immediately informed those on his call list, each of whom took action

TABLE 3. Radionuclides Released [2]

Radionuclide	Half-life (d)	Core inventory[a] (Bq)	Percentage released (%)
Kr-85	3930	3.3×10^{16}	~100
Xe-133	5.27	1.7×10^{18}	~100
I-131	8.05	1.3×10^{18}	20
Te-132	3.25	3.2×10^{17}	15
Cs-134	750	1.9×10^{17}	10
Cs-137	1.1×10^4	2.9×10^{17}	13
Mo-99	2.8	4.8×10^{18}	2.3
Zr-95	65.5	4.4×10^{18}	3.2
Ru-103	39.5	4.1×10^{18}	2.9
Ru-106	368	2.0×10^{18}	2.9
Ba-140	12.8	2.9×10^{18}	5.6
Ce-141	32.5	4.4×10^{18}	2.3
Ce-144	284	3.2×10^{18}	2.8
Sr-89	53	2.0×10^{18}	4.0
Sr-90	1.02×10^4	2.0×10^{17}	4.0
Np-139	2.35	1.4×10^{17}	3
Pu-238	3.15×10^4	1.0×10^{15}	3
Pu-239	8.9×10^6	8.5×10^{14}	3
Pu-240	2.4×10^6	1.2×10^{15}	3
Pu-241	4800	1.7×10^{17}	3
Cm-242	164	2.6×10^{16}	3

[a] Decay corrected to 6 May 1986 and calculated as prescribed by the Soviet experts.

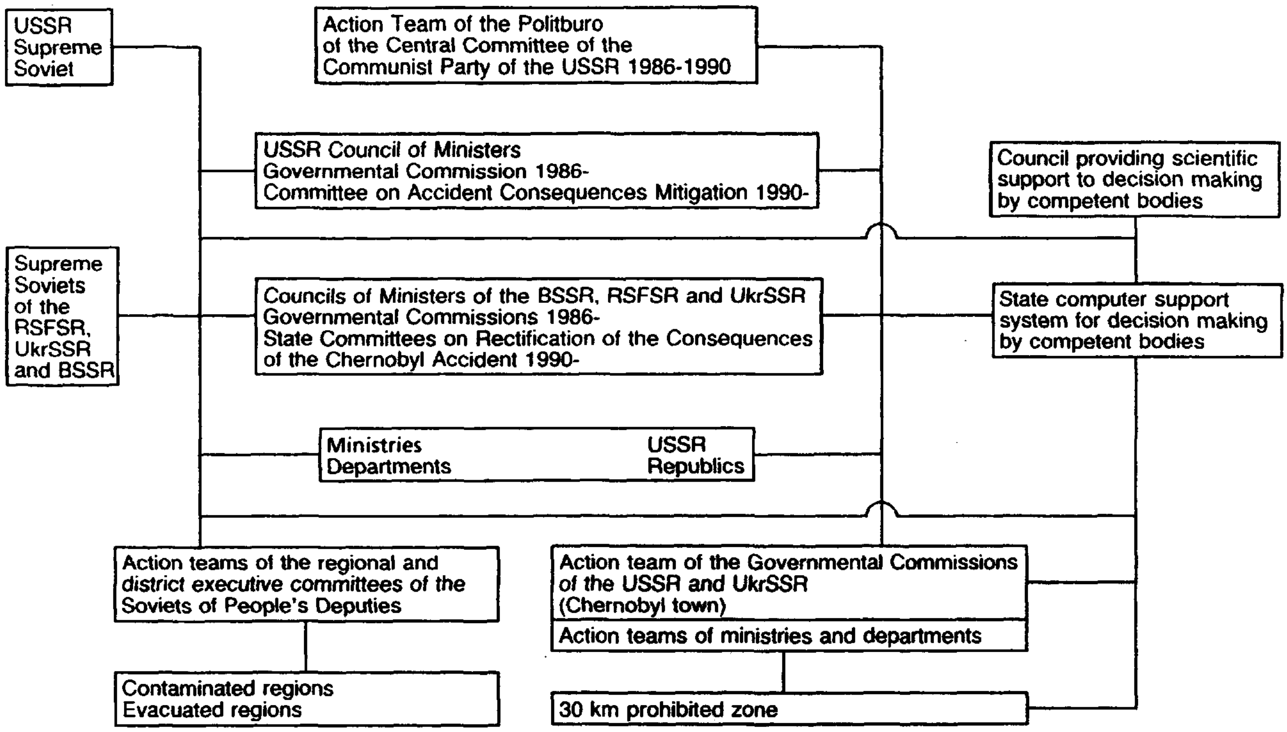


FIG. 2. Control structure of the Soviet effort to overcome the effects of the Chernobyl accident.

according to written instructions. Officials went immediately to the emergency centre in Moscow to analyse incoming information. Initial telephone communications with the plant indicated (erroneously) that the core was still intact and the event was still controllable [3, 5, 7, 11].

Officials of the Ministry of Atomic Power and Industry in Moscow decided within hours that the fires and injuries warranted sending a team of specialists to the site. As analysis of the accumulating information continued, even though the full magnitude of the accident had not yet been appreciated, it was decided that the indications were serious enough to justify sending officials from key ministries and agencies — including the military — to direct follow-up operations at the plant. Later, on Saturday morning, top Ministry and Communist Party officials were called together as a Governmental Commission with the co-ordinating authority for the 'liquidation' of the accident's consequences and also the authority to mobilize the resources needed to deal with the accident [3, 5, 7, 9] (see Table 3 and Fig. 2).

The first group of government specialists arrived at the Chernobyl plant early on Saturday afternoon, 26 April, and surveyed the site to assess the damage. Aerial reconnaissance with Civil Defence helicopters provided the first clear visual evidence of the major damage to the Unit 4 reactor. Highly radioactive graphite blocks on the ground outside Unit 4 attested to the core's explosive destruction [3].

2.5. Emergency Response

The Civil Defence forces apparently received information about the accident at 03:35 on 26 April from the Civil Defence headquarters [3, 8]. The Chief of Staff of the All-Union Civil Defence authorized forces to go to Chernobyl and also put on the alert the entire Civil Defence forces of the UkrSSR, including military and non-military units. All had to go to Pripyat, in accordance with the official plan for protecting the plant personnel and the surrounding population. This plan had been prepared several years earlier.

The Deputy Chief of Staff of the All-Union Civil Defence forces left Moscow by plane with the first specialists and stayed in Chernobyl until 7 May. He was not a member of the Governmental Commission, but was charged with reporting information and measurements and preparing for the evacuation of Pripyat [3, 4]. After radiation data had been obtained from the site, no immediate protective measures were taken for the plant and site workers.

Unit 3, which adjoins the destroyed Unit 4, had been shut down at around 05:00 on 26 April [2], but, because of links between its cooling system and that of the destroyed Unit 4, the Unit 3 operating crew had problems keeping the core cooled. Units 1 and 2 were not shut down until 01:13 and 02:13 respectively on Sunday 27 April, about 24 hours after the explosion. However, personnel from Units 1 and 2 remained on the site after this time at the plant manager's instruction [8]. They were not asked to leave the site until the following day. Contamination inside these units had also spread through the ventilation system, which, together with the water feeding and flooding problem, led to difficulties in shutting them down [2, 3, 7, 11].

Among the first actions of the Governmental Commission was to request the Chemical Defence forces to carry out the first radiological assessment and Soviet Air Force helicopters to assist in extinguishing the fire in the core [3, 8]. The first measurements showed neutron emissions, indicating continuing nuclear reactions. Valerij Legasov, Deputy Director of the I.V. Kurchatov Institute of Atomic Energy in Moscow, was charged with checking the source and intensity of the emissions and investigating how to prevent a further criticality excursion [7]. The Governmental Commission also considered how to stop the raging graphite fire, and submitted their ideas to the I.V. Kurchatov Institute of Atomic Energy and specialists of the Ministry of Atomic Power and Industry of the USSR in Moscow [7].

The last Governmental Commission members arrived in Pripyat at about 20:00 on Saturday evening. Technical specialists identified the key requirements for containing the accident and preventing further radioactive releases. These were [5, 7, 8]:

(1) Extinguishing the graphite fire to reduce the radioactive aerosol emissions, which were rising in a plume of smoke and had led to widespread contamination;
(2) Ensuring that the core was not and could not go critical, which could have resulted in intense heat and/or meltdown of the core and possible further releases of radioactive materials;
(3) Cooling and covering the core to prevent further releases; and
(4) Ensuring that the other units on the site were kept safe.

The Governmental Commission set priorities and assigned specialists to assess the problems and to report back with recommendations.

After shutdown, Units 1, 2 and 3 were brought into a deep subcritical state by inserting all their control and protection rods into the core and loading 20 additional absorbers into Units 1 and 2. Two hundred additional absorber rods were introduced and the flux was continuously monitored. To remove residual heat, all technical channels and the multiple forced circulation circuit were left filled with water. Residual heat was dissipated by natural circulation. The water temperature in the core was maintained at 20–80°C and the temperature of the graphite was maintained at 30–90°C [1].

V. Legasov notes that he arrived in Pripyat at around 14:00 on 26 April [7, 8]. Civil Defence authorities specified possible shelters for the population, organized the distribution of KI tablets to the population, and proposed to the town executive committee that it inform the population by radio of the danger due to radiation. However, this was not done at this time [7, 8]. Decisions about protective measures were within the purview of the plant management, which in fact did not recognize the magnitude of the accident and its potential radiological consequences [3, 4, 7].

The plant management did not have the authority or the resources to manage the response to an emergency on this scale, and the Governmental Commission itself had to appraise the situation and take action. Part of the problem was the lack of prior planning for an accident with such a large and prolonged release of radioactive materials. During the first few days, for example, while the Governmental Commission was in Pripyat, there were no respiratory masks and no individual dosimeters available to its members [7, 8].

The plant itself had no automatic means of performing external environment dosimetry, which could have indicated that there was radioactive contamination for several kilometres around the site. It was necessary to bring in a large number of people and a great deal of equipment, including helicopters, to make such measurements. Many of the first officials of the Governmental Commission present were themselves later hospitalized for medical tests [3, 8]. High levels of radiation forced the Commission to move its headquarters from highly contaminated Pripyat to the somewhat less contaminated settlement of Chernobyl, 17 km south-southeast of the plant and 20 km southeast of Pripyat, on 4 May.

There were by then thousands of people working on the site; it was necessary to provide them with equipment, motor fuel and food, and all this had to be organized. To co-ordinate this, the Deputy President of the Council of Ministers of the USSR, Silaev, replaced Cherbinya on 4 May as President of the Governmental Commission and created a centre for the management of operations. Under a Civil Defence Chief of Staff as director, the centre included a specialist on military transmissions, teams of chemical dosimetrists, a commander of the Chemical Defence force units and the new management of the Chernobyl plant [7, 8].

2.6. Limiting Further Damage to the Core

Once it became clear that the core had been destroyed and was open to the atmosphere, the Governmental Commission decided to stop the use of water to fight the fire in the core's remains. Instead, the Commission decided to cover the reactor crater with heat absorbent and filtering materials [2–4, 7, 8]. Helicopters were rigged to drop 5000 tonnes of boron, dolomite, sand, clay and lead onto the core between 27 April and 10 May. The mix of materials was chosen for specific purposes: boron to absorb neutrons and to prevent the reactor from becoming critical again; lead to absorb heat and melt into gaps to act as shielding; sand to filter out radioactive particles; and dolomite to give off carbon dioxide in order to reduce the flow of oxygen to the graphite fire. Air Force pilots flew thousands of dangerous missions over the core to perform this task.

On around 1 May, the temperature of the core started to rise, probably as a result of heat from the decay of fission products inside the covered reactor, giving rise to fears of a further meltdown. Officials of the Governmental Commission decided to pump liquid nitrogen into the space beneath the reactor [2, 4, 5, 7]. Miners were brought in to drill holes in several places so that large quantities of nitrogen could be piped in to help cool the core. By 6 May, the temperature in the vault began to decrease, for reasons that remain unclear. It may have been due to the effects of the boron and sand, or simply a fortuitous result of graphite burnout or further melting of the fuel into a safer configuration.

At this time, one major fear was that, despite all the efforts to control the fire, the hot core would melt through the bottom of the reactor and react with the water in the spaces below, causing another explosion and further releases. Volunteers therefore went down into the water of the pressure suppression pools to open valves so that emergency coolant stored on the first level below the core could be pumped out to a cooling pond. Under difficult working conditions and in a radioactive environment, a volunteer squad of military firemen managed to rig up temporary piping to pump out the water that had filled the normally dry second level [2–5].

In the days following the accident, in order to provide a safer environment from which to command operations, workers dug an underground bunker under a site building at a distance of 600 m from Unit 4, which served as a control outpost for the co-ordination of site operations. This work was performed by the army and coal miners from Tula and the Donets basin, who worked on three hour shifts day and night to avoid serious individual exposures. After this bunker had been built, the command team decided to install a concrete slab underneath the damaged reactor in order to prevent further interactions between the core and compartments below the core which might still have contained water. Miners and subway constructors dug a tunnel from underneath Unit 3 so that a massive cooling plate might be installed below the foundations of Unit 4 should it be needed. The tunnel was 168 m long and 1.8 m in diameter. Four hundred persons worked continuously and completed the tunnel in 15 days, on 24 June. This permitted the installation of a monolithic reinforced concrete slab under Unit 4 [2, 11].

The explosions had destroyed all built-in means for monitoring critical parameters in the reactor: core neutron flux and temperature, radiation and radioactive emissions. Alternative ways had to be found to measure them in order to guide follow-up actions [2, 4, 12]. Army troops, trained for radiological warfare, installed radiation meters at a number of locations on the site from which readings could be telemetered to a central point. Instruments were also suspended from helicopters hovering above the core to measure emissions. Later, monitors were mounted at fixed points around the destroyed unit. All these activities resulted in radiation exposures to the emergency workers, both civilian and military [3, 7, 13, 14].

No reactions producing neutrons could be measured externally, and this was a sign that the reactor was no longer critical (i.e. that fission had stopped); however, other approaches were necessary to confirm this finding. In mid-May, one group of workers managed to find a way into the lowest level, by then pumped dry, beneath the remains of the Unit 4 core and to install instruments to measure the temperature and heat flux. Days later, a second group broke through a wall to rig radiation and neutron measuring instruments against the ceiling of the area immediately below the core. Measurements with these instruments suggested that the core was not critical and that further criticality was unlikely [2, 4, 5, 12].

Various types of sensors were installed on Unit 4, and contamination of the area around the core was plotted to determine which areas still contained significant accumulations of fuel. The surviving structural elements of the building were also analysed. By early May, measurements were being made from above from helicopters. By August, special sensors (diagnostic buoys) could be placed on the break in the core in the region of the upper reactor plate and around the periphery of the break. These sensors measured gamma radiation, conductive and convective heat fluxes, air temperature and the speed of air movement in vertical and horizontal directions [2, 12].

Nine diagnostic buoys were installed from helicopters. Thermocouples and gamma sensors were installed in tubes in the space around the core. Readings showed a radiation field of 10 to 10^3 Gy/h, confirming the presence of fuel. Four more buoys were installed on the break by building cranes at the end of September and, with improved access to various sections of the destroyed reactor, the number of measurement points increased. These measurements made it possible to evaluate the quantity of nuclear fuel remaining in the reactor building, and they were later supplemented by evidence from plugs drilled from the damaged fuel in the remains of the core. Analysts then considered that they had a very good knowledge of the distribution of the fuel in the core, and they ruled out the possibility of any future criticality [12].

The measurements in the building also agree with data on radioactive releases and deposits on and around the site. These indicate that approximately 96% of the total fuel inventory remains in the reactor and/or on the premises of Unit 4. Research results and data from these measurements similarly indicate the effectiveness of the natural air flow ventilation system under the reactor (in the area of the pressure suppression pool) and the forced extraction ventilation with release to the atmosphere through a special filter system via the exhaust stack on top of the reactor building. To make this ventilation system possible, it was necessary to ensure free access of air to the fuel mass as well as to remove the heated air passing through the reactor vault [2, 12].

2.7. Releases and Transport

Radioactive materials were released from the reactor to the atmosphere over the first ten days following the accident before the releases could be contained. The heat from the fire increased the release rates of radioiodine (^{131}I, ^{133}I), a substantial fraction of the volatile metallic elements, including radiocaesium (^{134}Cs, ^{137}Cs), and somewhat lesser fractions of other radionuclides normally found in the fuel of a reactor that has been operating for several years [2].

The current best estimate for the source term (the activity of the total emissions), based on research in the USSR and collaboration with other countries, is 1.9×10^{18} Bq (50×10^6 Ci), excluding the noble gases. The activity of the caesium released in both gaseous and aerosol forms is now evaluated at 74×10^{15} Bq (2×10^6 Ci). Iodine with an estimated activity of 370×10^{15} Bq (10×10^6 Ci) was also released; some experts consider that twice this amount was released.

The releases did not occur in a single large event. On the contrary, only 25% of the materials released were emitted during the first day of the accident; most of the rest was emitted over the next nine days (Fig. 3). The estimated percentages of the inventories of various radionuclides that were released are shown in Table 3 [2, 10]. The release rate curve may be divided into four stages:

(1) The initial release was on the first day of the accident. During this stage the physical discharge of radioactive materials was the result of the explosion in the reactor and the subsequent heating by the fire and the core.

(2) In the five days that followed, the release rate declined to a minimum approximately six times lower that the initial release rate. In this stage, the release rate decreased owing to the measures taken to fight the graphite fire and to the cooling of the reactor. These measures, which consisted of dropping about 5000 t of boron carbide, dolomite, clay and lead onto the core from helicopters, led to the filtration of the radioactive substances released from the core. At this stage, finely dispersed fuel escaped from the reactor directly with the flow of hot air and with fumes from the burning graphite.

(3) A period of four days then followed during which the release rate increased again to about 70% of the initial release rate. Initially, an escape of volatile components, especially iodine, was observed; subsequently, the radionuclide composition resembled that in spent fuel. These phenomena were due to heating of the fuel in the core to a temperature above 2000°C, as a result of residual heat release and insulation by the materials dropped onto the core.

(4) A sudden drop in the release rate to less than 1% of the initial rate occurred ten days after the accident and there was a continuing decline in the release rate thereafter. This final stage, starting on 6 May, was characterized by a rapid decrease in the emission of fission products and a gradual termination of discharges. These phenomena were the consequence of the special measures taken, which caused the fission products to be incorporated into compounds that were chemically more stable [2, 10].

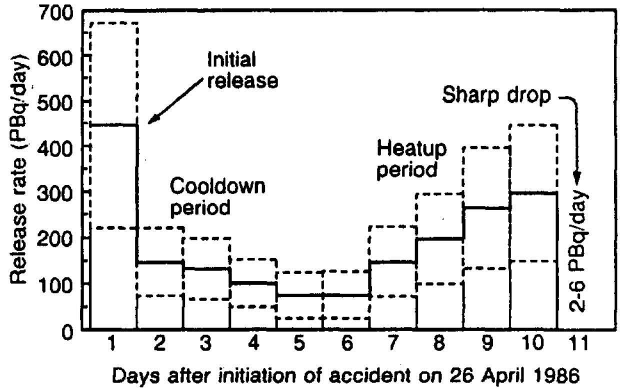


FIG. 3. Rate of release of radioactive material from the core after the accident. [Source: Ref. [2]]

On the basis of radiation measurements and analysis of samples taken within a 30 km radius of the plant and throughout the USSR, it was estimated that materials with an activity in the range of 1–2 $\times 10^{18}$ Bq (25–50 $\times 10^6$ Ci) had been released from the fuel during the accident. These figures do not include the releases of the noble gases xenon and krypton, which are thought to have been released completely from the fuel. Up to 20% of the volatile radionuclides iodine, caesium and tellurium and 2–6% of other more stable radionuclides such as barium, strontium, plutonium and cerium that were present in the core were estimated to have been released [1, 2, 15]. The estimate of the ^{137}Cs release agrees with the amount calculated from estimated deposition in the northern hemisphere, if the wide uncertainties associated with both estimates are taken into account [16,17].

By 7 May 1986, a map of radiation levels over the European territory of the USSR had been completed from the data collected by aircraft. The main boundaries of the areas of radioactive contamination were identified, in addition to the main contaminated areas around the plant and in the Mogilev and Gomel regions in the

BSSR and in the Bryansk region of the RSFSR. The air measurements and the ground measurements showed that during the first four to five days after the accident the radioactive materials spread far away, to various distances depending on the meteorological situation. A short term increase of radiation levels (10 to 100 times the natural background) due to short lived radionuclides was detected by the radiological measurement network of the USSR State Committee on Hydrometeorology within a significant part of the European territory of the USSR (the Moldavian SSR, the Sumskaya, Poltavskaya, Rovenskaya, Voroshilovgradskaya, Krimskaya, Donetskaya, Vyunitskaya, Cherkasskaya, Kirovogradskaya, Odesskaya, Brestskaya, Grodnenskaya, Minskaya, Tul'skaya, Kaluzhskaya, Orlovskaya, Lipetskaya, Kurskaya, Leningradskaya, Voronezhskaya, Smolenskaya, Gor'kovskaya, Rostovskaya, Tambovskaya and Penzenskaya districts, the Caucasus Black Sea coast, Kol'skij peninsula and Baltic Sea areas) and even in Alma-Ata, Ural'sk, Khabarovsk, Vladivostok and the central Atlantic. The first maps of the ^{137}Cs, ^{90}Sr and Pu contamination densities on the territories of the BSSR, the RSFSR and the UkrSSR were established by the USSR State Committee on Hydrometeorology in June 1986 and more detailed ones in July 1986. Percentages of the core inventory deposited at various distances from the plant were estimated to be:

On-site:	0.3–0.5%
Within 20 km:	1.5–2.0%
Beyond 20 km:	1.0–1.5%

On the first day, 26 April 1986, the distribution of radionuclides by altitude in the atmosphere directly above the plant was: 20% above 1800 m; 60% between 1800 m and 1200 m and 20% between 1200 m and 600 m. By the following day, the maximum height reached by emitted radionuclides was 1200 m, although the bulk of the material did not exceed 600 m. After the first two days, the plume did not exceed 600 m in height, as indicated by air sampling. From 27 April 1986 up until the end of the releases from the damaged reactor, the Institute of Hydrometeorology prepared daily factual and forecast data regarding the trajectories of the air mass transfers from the accident area at various altitudes. Specialists of the Institute of Experimental Meteorology used computer codes and meteorological information to prepare expeditions into the areas with higher probabilities of radioactive contamination. This allowed the sequences of detailed exploration in contaminated territories to be optimized. This information was transmitted to the local authorities and to the Ministries of Health and of Agriculture. The Institute of Hydrometeorology was able to use the subsequent measurements of deposition to back-calculate the radioactive releases day by day, and its assessment is still credited in broad terms internationally [18].

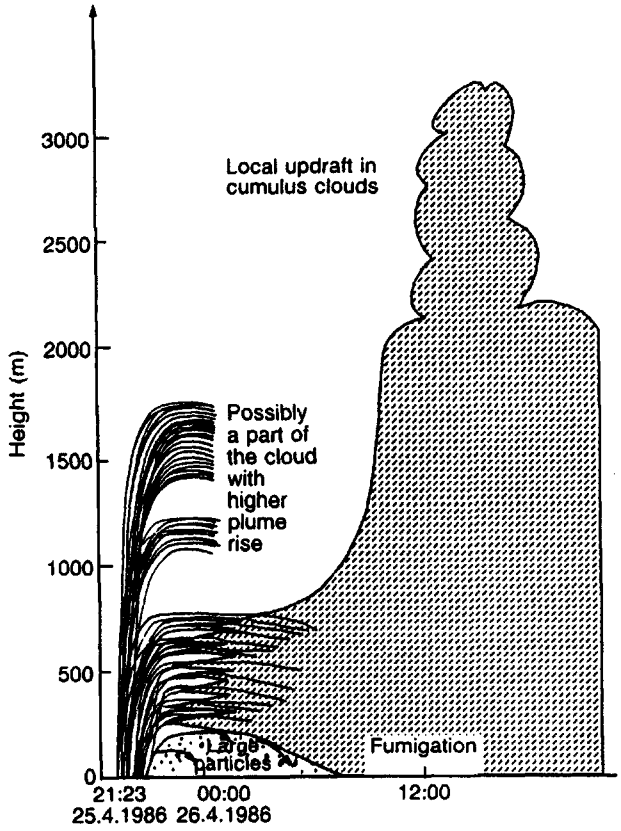


FIG. 4. Movement of the radioactive plume.

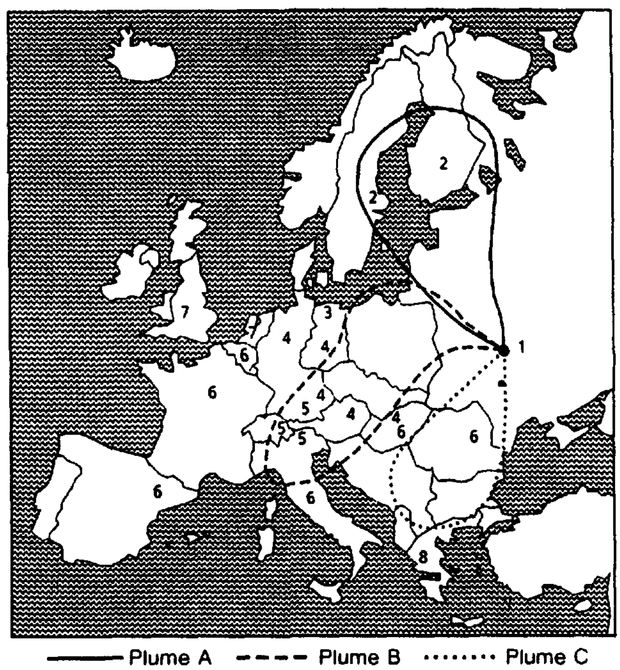


FIG. 5. Descriptive plume behaviour and reported initial arrival times of detectable activity in air. Plumes A, B and C correspond to air mass movements originating from Chernobyl on 26 April, 27–28 April and 29–30 April, respectively. The numbers 1 to 8 indicate initial arrival times: 1 (26 April), 2 (27 April), 3 (28 April), 4 (29 April), 5 (30 April), 6 (1 May), 7 (2 May), 8 (3 May). [Source: Ref. [10]]

At the time of the accident, surface winds were light and variable, but at 1500 m altitude the winds were 8–10 m/s from the southeast (Fig. 4). The initial explosions and heat from the fire carried some of the radioactive materials to this height, from where they were transported by the jet stream flow over the western parts of the USSR towards Finland and Sweden. Radioactive materials were first detected outside the USSR in Sweden on 27 April. They took some 36 hours to travel 1200 km, at an average wind speed of about 10 m/s [19].

The volatile elements iodine and caesium were detected at greater altitudes (6–9 km), with traces also in the lower stratosphere. The refractory elements, such as cerium, zirconium, neptunium and strontium, were for the most part of significance only in local deposition within the USSR.

Changing meteorological conditions, with winds in differing directions at different altitudes and continuing releases over a ten day period, resulted in a very complex dispersion pattern. The plumes of contaminated air spread over Europe (Fig. 5). News of the accident was broadcast on Moscow television on the evening of Monday 28 April. Part of the plume at lower altitude then moved southward towards Poland and the German Democratic Republic. Other eastern and central European countries became affected on 29 and 30 April. Airborne radioactive materials entered northeast Italy on 30 April. Central and southern Italy had first evidence of the plume's passage the following day. Switzerland also reported its passage on 30 April. The generally northward flow of air across western Europe then brought detectable radioactive contamination to eastern France, Belgium and the Netherlands on 1 May, and to the United Kingdom on 2 May. Contaminated air reached northern Greece on 2 May and the southern part on 3 May. Airborne contamination was also reported in Israel, Kuwait and Turkey in early May [17, 19].

The radioactive contamination was spread throughout the northern hemisphere by long range atmospheric transport. Reported initial arrival times were: Japan: 2 May; China: 4 May; India: 5 May; Canada/USA: 5–6 May. The simultaneous arrival of contamination at both western and eastern sites in Canada and the USA suggests a large scale vertical and horizontal mixing over wide areas. No airborne contamination from the Chernobyl plant was reported in the southern hemisphere.

2.8. Protection of the Rivers and the Kiev Reservoir

Immediately after the accident, one of the most critical issues was the potential danger from contamination of the water system. From the first days after the accident, studies of water contamination were started by the USSR State Committee on Hydrometeorology. Monitoring of radionuclide concentrations in the River Pripyat and River Dnepr areas showed that their contamination resulted from fallout during the transfer of contaminated air masses. After the decay of airborne contaminants, a sharp decrease in the concentration was observed.

In the very first days after the accident, estimates were made of the total quantities of radioactive products in water locations due to the fallout and projected concentrations if rainfall were to bring radioactive products from the contaminated ground into the water system. The calculations made around 5–7 May showed that in the event of intensive rainfall in the vicinity of the River Pripyat, the most critical radioactive isotope, ^{90}Sr, would not exceed the limits set by the regulations for drinking water, provided that no further release from the plant occurred. Later measurements confirmed this forecast.

Because of the heavy fallout in the immediate vicinity of the reactor, the nature of the soils in the area and the direct connection through the nearby cooling pond to Kiev's principal reservoir on the River Dnepr north of Kiev, a good deal of effort was made to slow the movement of long lived radionuclides (such as ^{137}Cs and ^{90}Sr) through groundwater or surface water. Three major elements were involved. First, 140 dams and dikes were built to limit runoff from the site area into the cooling pond and the adjacent River Pripyat, a tributary of the Dnepr. Second, a series of silt traps were scoured from the bottoms of the rivers, the pond and the reservoir. Third, an 8 km long barrier, 30–35 m deep, was built in the ground around the plant down to the impermeable clay layer to control the flow of radioactive water towards the Dnepr. An extensive system for monitoring the condition of the structure and determining its effect on the radiation levels on the site and beyond was incorporated. The barrier was completed before the spring floods in 1987. Appropriate actions were taken against clouds to prevent and inhibit the rainfall over the contaminated area of the Chernobyl plant and to limit the transport of radionuclides by rainwater into waterways (the River Pripyat and the Kiev reservoir). The actions were carried out from aircraft by meteorological laboratories of the USSR State Committee on Hydrometeorology after they had performed the surveys of the main contaminated areas. They were performed in two time intervals, 10 May to 15 June 1986, and 15 September to 20 October 1986. The work consisted in freezing clean clouds at distances of between 100 and 30 km from the plant in directions from which the wind was blowing.

The barrier dams and dikes were successful in impeding the flow of water into the rivers and the reservoir, but had the unexpected effect of causing the water table in the area around the plant to rise to only 2 m. When the barrier was constructed, experts believed they had to protect the water system, which serves 40 million people, from contamination. Even low levels of contamination, they believed, could have led to panic among the population [9].

2.9. Construction of the 'Sarcophagus'

In the period following the accident, specialists began considering how they might isolate the reactor building itself, which continued to cause high levels of radiation. A number of approaches were considered to contain the destroyed unit and to prevent further emissions, and work even began on some. One approach considered was the construction of a one piece hat-like structure, to be lifted by helicopter and lowered over the reactor. Parts were delivered to an assembly area in the settlement of Chernobyl, but trial runs with helicopters showed the concept to be unfeasible and it was abandoned.

Finally, on the basis of radiation measurements and the determination of the status of the fuel in the core, as well as an analysis of the remaining structure of the reactor building, engineers designed a structural covering with a span of 55 m that used the remaining walls and the top of the building as supports. Outer protective walls were built along the perimeter; inner concrete partition walls were built in the turbine hall between Units 3 and 4; a metal partition wall was installed in the turbine hall between Units 2 and 3; and a protective steel roof over the turbine hall completed the structure. The outer structure of the sarcophagus was therefore to be shaped by a number of buttressing elements rising in echeloned tiers, the dimensions and forms of which were determined in part by the features of the structure they enclose as well as the contaminated debris that could not be moved. The surface layer of soil in the area adjacent to Unit 4 was removed to local disposal sites. This area was then covered with concrete and asphalt and the surface levelled for self-propelled cranes and other machinery [2, 12].

Design work and construction on the encasement of Unit 4 proceeded quickly, allowing Unit 4 to be enclosed inside its concrete and steel shell by mid-November 1986. In order to check and diagnose the condition of the structure, the temperature is measured in the space under the cover over the central hall and on the upper surface of the cover over the reactor vault, as well as in the components of the lower baseplate and the surface of the covering over the pressure suppression pool. In order to refine data on the location and intensity of heat sources, the heat flux is measured continuously at accessible points of the areas under the reactor and on the upper surface of the destroyed core. Gamma radiation is monitored in all maintenance areas of the plant, at most of the other accessible locations in the Unit 4 building and also in the space under the covering and on the upper surface of the destroyed core. The concentrations of hydrogen, carbon monoxide and water in the air are also monitored continuously.

In order to detect any chain reaction in the damaged fuel, neutron sensors have been installed, and the ventilation exhaust is monitored for the presence of shorter lived iodine isotopes. To prevent any possibility of a fission chain reaction in the reactor vault, a liquid neutron absorber was introduced. Vibroacoustic sensors were also installed to monitor the mechanical stability of the fuel mass and the structural elements of the sarcophagus by recording any acceleration, velocity and vibration caused by shifts of major components. A set of computers monitor these sensors.

Analysis of experimental data on gamma dose rates one year after the accident indicated that the fuel is in a stable condition. The gamma dose rate is falling as the fuel decays, according to authorities in the USSR. Authorities asserted in 1987 that, upon completion of the work on the sarcophagus, the destroyed unit ceased to be a source of increased release of radioactive aerosols, either through the ventilation system or by wind erosion.

2.10. Restarting Units 1, 2 and 3

One of the most important decisions made by the Governmental Commission was to give a high priority to restarting the other three reactors at Chernobyl (Units 1, 2 and 3) without waiting for further radioactive decay of contaminants. Two reasons have been given for this decision. First, without these reactors there was a huge deficit of electric power, which was compounded by the loss of power due to the retrofitting of other RBMK reactors in order to correct deficiencies made evident by the accident. Second, officials wanted to show the population that they could restore normalcy and deal adequately with the consequences of the accident [1, 12].

This required a major effort to decontaminate the plant site and the surrounding area and to design, manufacture and install additional safety features. Decontamination was done with special solutions. Liquid spray and steam cleaning methods were used when possible, and polymer coatings were used in areas where dry decontamination was necessary. Many items of equipment were decontaminated manually with cloths soaked in decontaminating solutions. Remote controlled equipment was brought in and used where feasible, but it was generally necessary to perform the tasks manually.

People wearing protective clothing had to scoop up radioactive debris, sometimes by hand, and each worker had a limited time to carry out these tasks without exceeding dose limits. Cleaning the fine deposits that were everywhere was a tedious, manpower intensive chore. Wastes created were collected in temporary repositories within the 30 km zone. The effectiveness of the decontamination work was checked by the direct measurement of gamma dose rates. These rigorous methods at the site brought levels down to within regulation ranges, although the process continued in a limited number of areas [12]. Decontamination of Units 1 and 2 was completed by October 1986, and that of Unit 3 in 1987.

Restarting of Units 1 and 2 was carried out in accordance with regulations governing the startup of new plants. Item by item testing of systems, including equipment serviceability, instrumentation, shielding, displays and other normal checking, was all done as if the plants had never operated. Special attention was paid to operator training and the responsiveness of systems and mechanisms to signals from the emergency protection devices. Full documentation was prepared on each system, as well as general documentation on the readiness of the equipment, systems, technical procedures and staff, prior to restarting the units [12].

In view of the radioactive contamination in the area, it was also necessary to provide special accommodation for the staff. Shifts were organized on a tour of duty system. During tours of duty, the operating and service staff lived in a settlement located beyond the 30 km prohibited zone. For the first year of operation, service staff spent their free days in Kiev and Chernigov, where accommodation was provided for them. The length of a working day for operating staff was 12 hours (from 08:00 to 20:00 and from 20:00 to 08:00); for service staff and all other workers at the plant, as well as those who continued to live in the 30 km prohibited zone, it was ten hours (09:00 to 19:00). Tours of duty for operating staff were five days on with seven days off. For others, both tours of duty and rest periods were of 15 days.

The intensive and expensive efforts to get Units 1 and 2 back on line by the end of 1986 and Unit 3 by 1987 were successful. However, the manpower intensive approach to speedy completion of the work may have increased collective doses [14].

2.11. Emergency Accident Workers and Liquidators

In June 1986, the dose limits normally used for emergency workers were 0.25 Sv (25 rem). At the beginning of the work on the site, most of those called in did not have personal dosimeters, notably most of the military and Civil Defence 'liquidators'. These workers were monitored on a group or area basis, with judgement providing a basis for deciding how much time an individual could spend on a given task or in a given area. In total (up until the end of 1989), several hundred thousand such workers had to be brought in to ensure that no one would exceed the dose limits by a significant amount. Officials acknowledge that, while 0.25 Sv (25 rem) was the limit, many may have received higher doses in the first few days [14].

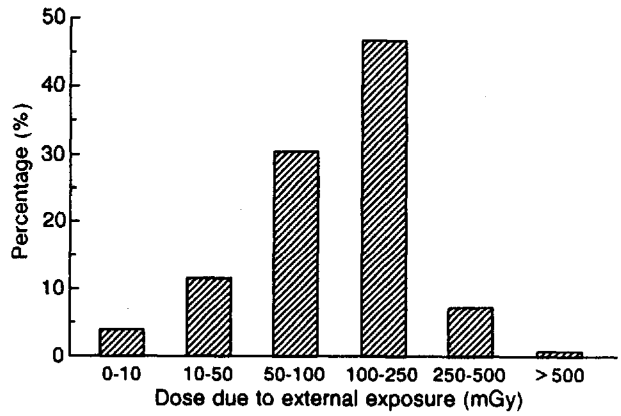


FIG. 6. Distribution of doses due to external exposure for emergency response workers.

Special procedures minimized the spread of radioactive contamination from the heavily contaminated inner zone. Transfers between clothes changing stations inside and outside the zone were effected by buses classified as too contaminated for use outside the zone. Vehicles were monitored and washed, if necessary, at the crossing points. Temporary housing was provided in and near Ivankov, 60 km to the south.

Nearly one third of the emergency accident workers were exposed to external radiation with doses ranging from 0.1 Gy to 0.25 Gy; about 10% of doses were higher than 0.25 Gy [13] (see Fig. 6).

2.12. Current Status of the Chernobyl Plant

The Chernobyl plant is once again operating but with only three reactors. A number of changes have been introduced in these reactors, as for all RBMK reactors in the USSR [2, 12]:

- The positive void coefficient has been decreased by a factor of six, partially as a result of increasing the enrichment of the fuel from 2.0 to 2.4%. Since the reactors have on-line refuelling, however, this is only about half accomplished, and will not be finished until 1992. A total of 81 fuel channels have been changed to absorbers.
- The response time of protective systems has been halved.
- Autonomous protective systems have been installed which are faster by a factor of 12.
- The time required to introduce emergency control rods has been reduced and is now less than 2 s.
- Systems have been installed at Unit 1 to continuously monitor the operating status of the equipment and pipes (for ageing, corrosion, etc.) in the primary circuit.

The modifications to the reactor, including increasing the fuel enrichment and the additional control rods, have resulted in a reduction by about 8% in the economic efficiency of operation. In addition to the six hardware fixes, all the documentation has been revised, including emergency procedures; the personnel have been retested, and training has been increased at the Smolensk training centre, which has a full scale RBMK simulator.

The USSR has, in addition, developed a programme for a second stage for improving the safety of all its reactors. This includes:

— improvement of quality control on metal parts;
— improved reliability of equipment, especially for emergency power;
— design of localizing equipment for leaks;
— installation of auxiliary systems for bringing in additional cooling water to a damaged plant.

This phase has not yet been put into effect, however.

Two projects are under way on Unit 4. One is to confirm the safety of the unit by means of 40 drilled 'buoy' holes inside the reactor vessel; the second is to study the stability of certain major construction elements inside the sarcophagus. Specialists are certain that a chain reaction cannot occur in the remaining material [14].

After the accident, most of the irradiated fuel (96.5%) remained in the destroyed part of Unit 4. This fuel contains 398 kg of ^{239}Pu, 167 kg of ^{240}Pu and substantial quantities of transuranic elements. Of the accumulated inventory of caesium isotopes, 70% are also contained within the unit. Examinations carried out since 1987 have shown that in the lower parts of the building (those compartments containing pressure suppression pools, steam distribution corridors and the room beneath the reactor hall) about 105–165 t of nuclear fuel are concentrated. This mass of material consists very largely of substances resembling lava, consisting mainly of SiO_2, the fuel content by weight varying from 2 to 18%. The fuel burnup is 9–13.5 MW·d/kg of uranium. The calculations made from mass, geometry, physical and chemical characteristics of lava masses and the measurements made confirm the subcritical state. Thus, a self-sustaining fission reaction is not possible.

Because of the difficult conditions under which the sarcophagus was built, it was not possible to seal it hermetically from the environment. It has holes in the upper part of the structure and in the roof. The holes are being monitored for radioactive emissions, however, and under present conditions the sarcophagus may be left as it is for as long as 10 years without undue risk of releases of radioactive materials. Nevertheless, dust and radioactive materials could emerge if there were a major shifting of material inside due to rusting or the failure of major structural elements. Such an occurrence would be a threat only to the personnel on the site, however, and would not result in contamination beyond the prohibited zone. Plastic materials have been inserted through 'buoy' holes drilled in the walls in order to suppress radioactive dust. The annual release of radioactive fission products does not exceed about 11 GBq/a (0.3 Ci/a). On the asphalt yard just outside the sarcophagus (within 20 m of the outer wall) the dose received is about 50 mR/h (12.9 $\mu C \cdot kg^{-1} \cdot h^{-1}$)[14].

The USSR authorities are planning to build a second sarcophagus, which would be hermetically sealed, over the first. This structure would afford complete environmental protection against radiation. It would also allow access to the remaining fuel mass for sampling and analysis and perhaps for dismantling the inner parts of the damaged reactor.

Decontamination work continues on Units 1, 2 and 3. The work was a continuous learning process. While radioactivity levels have generally been brought down to normal, there are still problems with the radiation background at one level in these buildings. Further decontamination is difficult because radioactive material and dust are lodged in cracks in the concrete. The floors inside the Chernobyl plant building are covered with thick plastic. The control room of Unit 4 is dark and instrument panels are covered with plastic sheets. The room itself does not show any signs of damage due to the accident.

2.13. Waste Disposal

The cleanup work at the plant, in the surroundings and in the evacuated areas inside the 30 km prohibited zone, created an enormous amount of solid waste. All the disposal sites currently in use for waste from Chernobyl are classed as for 'temporary storage'. This is probably the most significant, and most underreported, aspect of the consequences of the accident. The managers of the cleanup phase needed to dispose of heavy equipment, helicopters, buildings, soil, trucks, furniture and every artefact of daily life from a town and a large industrial complex. In addition, the equipment used to dispose of all this had to be disposed of itself, following partial decontamination. All this waste is now buried or stored on two sites inside the 30 km prohibited zone. Final storage and disposal, code-named 'Project Vector', will attempt to deal with the wastes in a permanent manner, and it is hoped that this programme can be implemented in 1992. Research is now being conducted on how to reduce the volume of waste [14].

The largest waste site, Buryakovka, for low level wastes, is located about 5 km from the plant, and is situated on relatively high ground. The Buryakovka site is about 1 km wide by 1.5 km long. Until this year it was used to store wastes of up to 5 R/h (1290 $\mu C \cdot kg^{-1} \cdot h^{-1}$). Now the low level wastes stored do not exceed 1 R/h (258 $\mu C \cdot kg^{-1} \cdot h^{-1}$). Heavy equipment such as trucks,

Slavutich: A New Town

The plant personnel now live in a newly built town, Slavutich, which is about 60 km east of the power plant. A railway connects the new town and the plant.

Construction of Slavutich commenced at the beginning of 1987, as a place to house those working at the Chernobyl plant. Great effort went into designing and building a town that would attract qualified workers to the area. The design work for the town was completed in three months at the Kiev Institute of Experimental Design. The design philosophy was to divide the town into eight sectors representing major Republics of the USSR. Each sector is named after the capital of that Republic. Each sector was designed in co-operation with designers from the Republic and then constructed by workers from the Republic. The intention was to make an All-Union city in order to commemorate the support of all the Republics in alleviating the effects of the Chernobyl accident.

By 1 September 1990 the town had 23 000 inhabitants, including 8000 children. Twenty-six nationalities are represented. The city is growing rapidly, and additional infrastructure has to be added for the large apartment buildings now being built on the outskirts of the town for couples, pensioners and families with children. The city's planners are becoming aware of things they overlooked in the original design. For example, they did not foresee the large number of children, and did not plan enough schools and kindergartens. The town is also currently suffering a housing shortage despite uncertainty about the future of the Chernobyl plant. If the plant were shut down, many of the people would stay to work on the decommissioning project. The town, however, is actively seeking new light industry.

At first only personnel at the Chernobyl plant and their families were authorized to live in Slavutich. However, the town also needs services, transport, small businesses, teachers, doctors, etc., and these have had to be recruited from other parts of the USSR. This has proved difficult because the town is rather isolated — 175 km from Kiev. Many families live in apartment buildings, which have all been designed to reflect the style of the Republic they represent, but a total of 20% of the families live in smaller houses.

In choosing where to build the settlement for Chernobyl plant personnel, many places were considered on the basis of convenience of settlement operations, existence of a railway or the possibility of constructing good quality roads. Studies were performed on the adjacent territories of the places considered in terms of effective dose equivalent commitment. The radiation protection requirements had to be fulfilled (0.5 rem (5 mSv) per year for the local population, including children). However, Slavutich was not on the list of places studied. The designers shifted the site by some 10–12 km east towards the railway station, and no radiation contamination study existed for this site, although the detailed measurements made between 1987 and 1989 showed that the radiation protection condition of 0.5 rem (5 mSv) per year was met. The work to build the town was begun in 1987. The first complete contamination map was published in 1989 and it showed that the town was partly contaminated in certain spots, as was the land in the surrounding forests.

Local foods are controlled. Inhabitants, especially children, undergo regular medical examinations. Clean food is brought in from outside the area. Town officials are seeking to obtain special rights for the inhabitants, and everyone has the right to decide whether or not to stay.

cars, jeeps and tanks are currently stored in the open air. Smaller equipment, parts of demolished houses, furniture and other household effects and soil are buried in thirty large, shallow trenches, each about the size of a football field and about 10 m deep. These trenches are layered with clay and sand. Some of the trenches are full and have been covered over with clay and soil, which has been planted with grass to prevent erosion. The site is adequately monitored for leakage.

A second site, located near the River Pripyat not far from the plant to the north, is for higher level wastes (up to 90 R/h (23.22 $mC \cdot kg^{-1} \cdot h^{-1}$)) which are stored in massive concrete containers with walls 1 m thick. This is mainly waste from Unit 4 and the site cleanup. Those in charge of decontamination and waste were not dealing with any higher level waste. There was no large metal waste compactor on the site, but one was being designed for use under Project Vektor. The 'final' stage of high level waste disposal is reportedly expected to be deep geological burial.

There were three phases to the cleanup. Phase 1 was designed to prevent further contamination from the destroyed reactor, and this phase ended with the completion of the sarcophagus. Phase 2 was intended to decontaminate the territory around the plant and bury the wastes in the 30 km zone; this phase was nearly complete, but the burial of the waste was continuing. Phase 3, which had only just begun, is considered to be long term. The year 1990 began with renewed scientific research, and this was strengthened with the signature in Vienna (at the General Conference session of the IAEA in September 1990) of an agreement with the IAEA on establishing an international scientific research centre at Chernobyl.

Part C

3. Effects of the Accident on the Population and the Environment

3.1. Evacuation of Pripyat

There is no indication that people living around the plant had received any prior information on the hazards of radiation, or had any idea of measures to be taken in the event of an emergency [7, 9]. Specific radiation related protective actions to be taken were not widely known. Likewise, emergency crews (doctors, firemen and police) seem to have had no specific knowledge of procedures or equipment to be used in a radiation environment. On 26 April 1986, no official information or instruction was given to the people of Pripyat. There were no publications to explain the consequences of radiation doses to the population or what to do in the event of increased levels of radioactivity [7]. Many people said that they knew that an evacuation plan existed, but no one was familiar with its content. The fact that people lived and worked in a 'nuclear village' was of little consequence, since the prevailing view was that an accident "couldn't happen here".

Early on Saturday 26 April 1986, the explosion and fire at the plant were reported to Civil Defence organizations in the UkrSSR and the BSSR and those of the districts of Kiev (in the UkrSSR) in which the plant is located and Gomel (in the BSSR) a few tens of kilometres to the north. Within hours a headquarters in the UkrSSR had been set up in Pripyat, the nearest boundary of which was 3 km west-northwest of the plant. Police set up road blocks to prevent all but emergency vehicles from entering or leaving the city [3, 8].

By noon, regular radiation measurements were being made by Civil Defence forces at fixed points around Pripyat [3, 8]. The highest readings were found just to the west of the plant, but the wind was light, so ground level atmospheric transport of released material was slowed. Material sent higher into the atmosphere by the fire drifted west and north. Although the highest recorded radiation levels were away from Pripyat, workers began to wash down the streets. The initial radiological measurements, however, forced Civil Defence officials, in accordance with emergency plans, to prepare for Pripyat's evacuation, even though, at that time, only All-Union officials had the authority to initiate it.

On the evening of Saturday 26 April, the radiological situation in Pripyat was considered by the Governmental Commission as not too alarming. Readings were between 1 mR/h (258 $\mu C \cdot kg^{-1} \cdot h^{-1}$) and about 10 mR/h (2.58 $mC \cdot kg^{-1} \cdot h^{-1}$). Yet the physicists on the Governmental Commission were recommending evacuation. Finally, the Head of the Governmental Commission decided at about 22:00 to evacuate the next day [7, 8]. V. Legasov notes in his memoirs [7] that he regretted that the information on evacuation was only orally transmitted on 27 April between 10:00 and 12:00 in the streets, while that morning children in the settlement had been playing outside.

The Governmental Commission contacted transport officials from as far away as Kiev and other localities. They arranged to send more than a thousand buses, which arrived throughout the night. Two special trains were also sent but were not used. To limit exposures, buses were stopped in the settlement of Chernobyl, although a few may have waited for a time in higher radiation areas near the plant before being sent back.

Officials in the Polesskoe and Ivankov regions of the Kiev district of the UkrSSR had to be alerted to prepare their citizens to receive evacuees. At Civil Defence headquarters, officials revised evacuation routes set by pre-established emergency plans according to the environmental radiation measurements received and formulated precise instructions for leaders, drivers, police, monitors and evacuees.

At 02:00 on Sunday 27 April, 24 hours after the first explosion, the Governmental Commission set in motion final preparations for the evacuation. At 07:00 the Head of the Governmental Commission confirmed the decision. He met with Pripyat officials at 10:00 and instructed them to prepare for evacuation at 14:00. The organizers of the evacuation in Pripyat had to calculate the number of buses and vehicles for cattle transport needed and how to supply food and medication to the evacuees.

Meanwhile, on the basis of obvious signs of the serious accident at the plant — the explosion had been heard; the fire was visible; Civil Defence forces were monitoring the city; plant workers had alerted their families and others; the injured were being received at the hospital — some individuals took actions on their own initiative. They warned other people to stay indoors or distributed available KI. Some teachers, recalling recent Civil Defence training, cancelled outdoor events on Saturday and kept students indoors. They also tried to keep contaminated outdoor air from entering the buildings. Other people decided to protect themselves by leaving by train or river boat before the service was cut off, or by car before road blocks were in place [3].

Officially, however, life in Pripyat was allowed to proceed more or less normally during the first day after the accident, and steps were taken to prevent panic [3, 4]. For example, not until after the evacuation did Civil Defence officials use face masks, because there were not enough to supply the children of Pripyat. An amusement park in Pripyat, which had been out of use for months, had been reopened a few days before the accident. On the Saturday of the accident, there were many people there. There had been no warnings or instructions to stay indoors and the park had not been closed. There was no systematic distribution of KI.

Evacuees from Pripyat

The problems faced by the evacuated residents of Pripyat are characteristic of those found by all evacuees. On Sunday morning, 27 April 1986, it was announced on local radio that the inhabitants of Pripyat should prepare for an evacuation, expected to last about three days, and should listen to the radio for more information. A second announcement at 12:00 said that the evacuation would commence at 14:00. Evacuees were taken to Polesskoe, where they arrived at 20:00 on Sunday evening. There were no immediate medical examinations, nor were the evacuees examined for contamination, and it was a few days before they could change out of their contaminated clothes. Evacuees said that on Sunday 27 April, most of the inhabitants of Pripyat were experiencing sore throats and diarrhoea. The evacuees had no prior knowledge of the dangers of radiation nor even of elementary protective measures.

In Polesskoe, evacuees stayed with families. Three days after their arrival, doctors came to do blood tests. On the basis of the results of these tests, some evacuees were sent to hospitals in Polesskoe, Ivankov and Kiev. Life with other families was not easy; there were too many people living in close quarters in small apartments. But most of the host families were helpful, even donating food and clothes.

The people from Pripyat received their first financial assistance in Polesskoe on the first day (15 roubles per person), and in June they received 200 roubles per person. In summer 1986, each head of family received 4000 roubles, the spouse 3000, and each other family member 1500 roubles. Most Pripyat families stayed in Polesskoe until August 1986 and were resettled in apartments in Kiev after that. Each family was authorized to return to Pripyat later that summer to retrieve items such as clothes stored in cupboards, books and crockery. They were not allowed to collect any clothes or belongings for their children. Each family was accompanied by a dosimetrist, who checked what they were taking. Another radiation control was made when they arrived back in Kiev.

In early 1987, doctors in Kiev asked evacuees to take their children to a special hospital for treating the effects of irradiation. This was their first medical examination for radiation effects. The hospital follows up these children regularly. The children from Pripyat go to two special schools in Kiev. They spend only five days in school instead of the normal six days, and milk is distributed in the primary grades. Since September 1990, they have also received special dietetic meals. Every month paediatricians come to the school to do medical analyses, and parents take their children for examinations in Kiev hospitals once a year. The children now lead a fairly normal life.

The adults do not feel integrated in Kiev, because their families are from the rural area around Pripyat. Many of them had helped to build the town of Pripyat. Their greatest worry is the health of their children.

Consequently, children and others were unnecessarily exposed.

Around noon on Sunday 27 April, when the evacuation order had been authorized and all preparations were complete, a short official announcement was broadcast to city residents to pack provisions for three days and to be ready to leave at 14:00. Finally, the nearly 1200 buses assembled near the settlement of Chernobyl (20 km southeast of Pripyat and 17 km southeast of the plant) set off in a line several kilometres long along the road that passed over the railway just west of Unit 4 [3, 4, 8].

Evacuation of Pripyat began at 14:00. Buses were provided directly at the entrance of each building. As soon as each bus was loaded in front of its assigned apartment building (Pripyat is a settlement of high rise blocks), it set off to join a police escorted line to the reception centres about 50 km away to the west-southwest in Polesskoe and to the south-southwest Ivankov region of the Kiev district. The number of people to be transported, which was to have been around 44 600, was in fact less, since some people had already left by car and many others were away for the weekend. Officials in the receiving settlements of Polesskoe and Ivankov arranged to meet the evacuees on their arrival at reception centres.

On the plant site, the plant superintendent assembled his personnel at 13:00. They did not know whether to stay or be evacuated. Some stayed at the plant, others left and joined their families for evacuation.

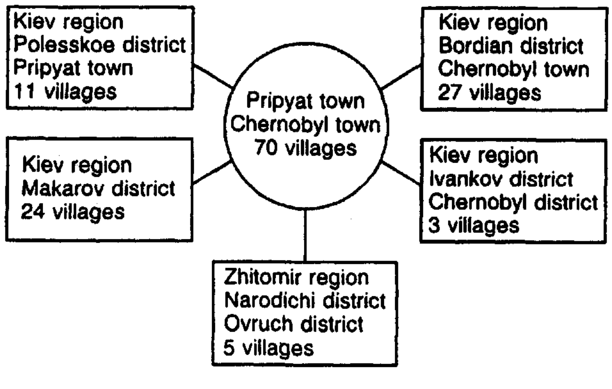


FIG. 7. Population evacuated from the 30 km prohibited zone.

There was adequate transport and the evacuation went smoothly. In less than three hours the city was emptied in orderly fashion of all but those with official duties. The over 44 000 evacuees were taken in by individual families who lived mostly in settlements in the surrounding regions [9] (Fig. 7).

3.2. Expanding the Evacuation Zone

On 28 April, the Civil Defence Chief of Staff of the USSR proposed the evacuation of the Chernobyl plant site and the establishment of a 10 km exclusion zone around the plant. The authorization was given. At a meeting of the Governmental Commission on 1 May, the Civil Defence commander asked for authorization to evacuate people and cattle from ten settlements in a zone of radius 10 km where there were relatively high levels of radiation [8].

On 2 May, six days after the accident, USSR Communist Party Central Committee members N. Ryzhkov and E. Ligachev arrived from Moscow [4, 7, 8]. They quickly appreciated the gravity of the situation, the severity of the accident and the long term engagement necessary. Finally, with their arrival, fundamental decisions could be taken to organize the work, estimate the costs and allocate the contributions to be expected from organizations and concerns over the USSR. The Politburo Central Committee created an operational group to direct the national effort. N. Ryzhkov was appointed head of this group. After this, the Governmental Commission became a part of the larger management effort [7, 8].

In the first stage after the accident, the main criterion used for decision making was the absorbed dose from all radiation sources. The evacuation decision was based on the 10 rem (100 mSv) dose for the first year following a nuclear accident, established by the Ministry of Health of the USSR. For the dose estimation, it was necessary to take into account the duration of the release from the destroyed reactor, the volume radioactive source (atmospheric contamination), the meteorological conditions, the radioactive isotope composition in the atmosphere and on the ground, and the abundance of the radionuclides most harmful from a health point of view.

The decision to evacuate the people from the 'geometric' 30 km zone (it was not a regular circle) was taken on 2 May at a Governmental Commission meeting. During the discussions on the evacuation issue, leading specialists insisted on the necessity of evacuation, especially because of the lack of predictions on the radioactive source behaviour under the prevailing meteorological conditions. On 10 May an absorbed dose rate map was drawn with isopleths: 20 mrad/h (0.2 mGy/h) formed the boundary of the prohibited zone (about 1100 km^2 in area), 5 mrad/h (0.05 mGy/h) the boundary of the evacuation zone (3000 km^2) and 3 mrad/h (0.03 mGy/h) the strict controlled zone (8000 km^2) from which children and pregnant women had to be temporarily evacuated. In addition to the geometric 30 km zone, evacuation was also needed from territories adjacent to the zone to the east and west where absorbed dose rate levels exceeded 5 mrad/h (0.05 mGy/h) on 10 May. The maps of contamination by long term isotopes prepared in June and July 1986 indicated that additional resettlement should be carried out: from 29 settlements in the BSSR and four in the RSFSR [3, 4, 8, 9].

The evacuation of the entire 30 km zone was completed by 6 May. It was a huge undertaking that required the transport of many tens of thousands of people from the UkrSSR and thousands of farm animals. The zone was fenced off and access has been controlled ever since. Transfer of radioactive materials from the zone was controlled at radiological checkpoints set up at zone exit points where vehicles were washed down or sent back for use within the zone. A substantial number of people refused to leave their homes; others who had left later returned surreptitiously. The zone remains evacuated, although some people have been allowed to go back to their homes in the less contaminated southern areas.

3.3. Assessing the Pathways of Exposure

Radiation monitoring was undertaken from 29 April 1986 by the USSR State Committee on Hydrometeorology and Environmental Monitoring, working with organizations from the Ministry of Health, the State Agroindustrial Committee, the Academy of Sciences, the Ministry of Defence and the State Committee on the Utilization of Atomic Energy, among others. Because of the scale of the accident, the amount of monitoring equipment available was increased and the personnel eventually numbered several thousand. For atmospheric monitoring, airborne units under the Ministry of Defence were brought in. Data were collected not only at permanent stations but also at observation posts, by expeditionary columns and mobile groups of workers, and with reconnaissance aircraft and helicopters. Data gathering included gamma and beta radiometry and spectrometry of contaminated areas, and analysis of air, water, soil and plant samples and radioactive fallout samples.

Following the emergency period, after the short term problems had been dealt with, the monitoring system that had been set up was converted into a continuously operating system in those areas affected. Different fallout structures, patterns and compositions over the fifteen days following the accident left different levels of contamination by radionuclides in the various areas around the zone and in the three Republics outside the zone that required continuous monitoring.

The first summary map of radioactive surface contamination by long lived radionuclides was prepared with the results of the series of measurements made in settlements and by air gamma-spectrometrical measurement of the corresponding areas and later with the results of surface measurements of agricultural and forest areas and aerial surveys. It should be noted that these activities involved different methods of obtaining the data (air gamma-spectrometrical surveys, massive soil sampling and sample analysis, etc.), thus allowing information for individual households in the settlements to be obtained. These activities were carried out first and in great detail for the most contaminated areas and adjoining districts.

A great deal of work on the detailed radioactive contamination (surface contamination by ^{137}Cs) up to surveys with scales of 1:10 000 was done by branches of the USSR Ministry of Geology with the help of the device 'Macfar'. For such measurements, 'matching' of the measurements to the area and the use of corresponding corrections for radionuclide penetration are very important for the objective interpretation of the data.

The detailed and corrected first maps were prepared stage by stage, with account taken of the fact that the majority of the population was covered by protective measures. Hence from 1986 to 1989, twice a year, specific maps were prepared. In 1986–1987 all activities centred on areas with a high density of contamination and were aimed at specifying isopleths with a density of ^{137}Cs contamination of 15–40 Ci/km^2 (555–1480 kBq/m^2); of ^{90}Sr of 3 Ci/km^2 (111 kBq/m^2); and of ^{239}Pu of 0.1 Ci/km^2 (3.7 kBq/m^2). Later, specific and detailed contamination surveys on less contaminated areas were carried out, especially in areas with a density of contamination of less than 15 Ci/km^2 (555 kBq/m^2). In 1988, areas with a contamination density of less than 5 Ci/km^2 (185 kBq/m^2) were identified and in many other places data were obtained on areas with even lower contamination levels. In 1989 areas with lower densities of contamination were surveyed and isopleths were plotted for 1 Ci/km^2 (37 kBq/m^2) of ^{137}Cs.

TABLE 4. Intervention Measures [9]

3 May 1986	Temporary permissible radioiodine contents for drinking water and a number of foodstuffs approved.
6 May 1986	Additional standards set for staple foodstuffs.
7 May 1986	To prevent excessive external and internal exposure of the public, the Ministry of Health approved temporary permissible levels of radioactive contamination for various surfaces (premises, transport and equipment), clothes, footwear, skin and means of personal protection.
30 May 1986	The Ministry of Health approved 'temporary permissible levels for the radionuclide content of foodstuffs, drinking water and medicinal herbs'.
2 June 1986	Revised permissible contamination levels based on latest dosimetric data set for ground surfaces, road surfaces and outer and inner construction surfaces following decontamination.
22 July 1986	'Temporary permissible levels for the radionuclide content of medical preparations' approved.
19 September 1986	'Temporary permissible levels for the radionuclide content of canned fruit and vegetables' approved.
19 September 1986	'Temporary permissible levels for the radionuclide content of endocrine and enzyme raw material' approved by the Ministry of Health and the State Agro-Industrial Committee.
	To improve control of manufactured produce, 28 standardization documents were adopted by the Ministry of Health and the State Agro-Industrial Committee for various livestock, poultry, fodder and fur products.
14 October 1986	Owing to changes in radionuclide composition and large scale decontamination operations, new 'temporary permissible contamination levels for the skin, underwear, clothes, transport, machinery and means of personal protection' were approved.
26 October 1986	'Temporary permissible contamination levels for roads, populated areas and outer and inner construction surfaces following decontamination' approved (with lower permissible exposure rates).
End of 1986	Ministry of Health set dose limits of 3 rem/a (30 mSv/a) for total (external and internal) exposure over the year 1987.
December 1987	The NCRP reviewed the temporary permissible level of 30 May 1986 and suggested a new temporary permissible level calculated for total radiocaesium activity with allowance for routine daily consumption of the principal foodstuffs (corresponding to an internal dose of no more than 0.8 rem/a (8 mSv/a)).

The results were compiled and mapped and, while the precision of the plots increased, the general pattern did not change significantly from that described as early as June 1986. (Official maps were not made publicly available, however, until March 1989.)

The distribution of caesium contamination was unpredictable and patchy owing both to the dynamics of the release and to the non-uniformity of the rainfall in areas over which the radioactive plume passed. In addition, analysis of meteorological data on wind direction gathered during the five days after the accident showed that the direction of movement of airborne particles in the air from the ground to an altitude of 1 km had reversed. After releases had been halted, changes in contamination patterns were the result of decay (primarily of iodine, which decays almost totally within a few weeks), wind, washout by rain, dispersion by flood waters after snow melts, and diffusion in the soil and in the food-chain [15, 16].

After the initial evacuations, the USSR National Committee on Radiological Protection (USSR NCRP) formulated a series of other intervention criteria for reducing exposure due to contaminated food and water. These are listed in Table 4 [9]. The main sources of exposure changed with time, as did the measures taken to control them. In the first few months, they were radioiodine in milk from cows that had grazed on contaminated pasture (intervention measures: administration of KI, substitution of clean milk) and radioiodine and other nuclides in fresh vegetables (intervention measures: administration of KI, washing, substitution). Over the long term, the principal sources of dose are gamma radiation from deposited materials, especially ^{134}Cs and ^{137}Cs (intervention measures: relocation, reducing time spent outdoors, avoiding more contaminated areas, decontamination) and internal exposure from radionuclides (especially ^{134}Cs and ^{137}Cs) in meat products and other foods (intervention measures: restrictions on food production and use, changes in agricultural management).

Other sources of exposure of potential significance included radiostrontium (^{90}Sr) in milk, plutonium particulates in the air and various nuclides in drinking water. When the levels of contamination in water from open wells in certain localities were found to exceed existing criteria, the wells were covered and a lip was built around them to exclude contaminated surface runoff.

3.4. Intervention Measures

After a radioactive release to the environment, the levels of activity and dose rates typically decrease, at first rapidly and later less rapidly. Levels can rise with seasonal and other effects (for example, the levels of radiocaesium in milk and beef normally fall in the winter when cattle are indoors and are fed stored feed, but rise again in the spring when the animals are put out to graze). Man is exposed to radiation in two ways: by external irradiation and internal irradiation. External irradiation derived from activity in the radioactive cloud as it passed over in the first few days and from radioactive fallout on the ground and other surfaces; this exposure to ^{137}Cs will endure for several decades. Internal irradiation derived from inhaling air contaminated either directly in the first few days after the accident or subsequently by materials resuspended from the ground, and from consuming contaminated food and drink. As noted, the levels of radioactivity decline with time and thus so do the radiation dose rates.

There is often considerable benefit to be gained by intervening to alter the mechanisms by which man is exposed to radiation and thus limiting the total radiation dose. These interventions can be of many types: sheltering or temporarily evacuating the population during the time of passage of the plume (reducing inhalation and direct exposure); issuing stable iodine tablets (reducing the thyroid doses due to inhalation or consumption of iodine contaminated food); relocation of the population and/or decontamination of the living environment (reducing exposure to deposited contamination); and food and agricultural countermeasures (reducing the intake of contaminated food).

After the major releases from the plant had subsided, it became clear that although dose rates would fall naturally with radioactive decay and normal weathering processes, there would be major benefits in attempting to reduce these dose rates further by decontamination of areas where levels were high and from which the population had not been evacuated. This could also reduce the hazard due to inhalation of radioactive dust that is resuspended from the ground and other surfaces back into the air by the wind or by vehicles in the area. The aims were to restore life as far as possible to normal. A broad range of decontamination work was done by a number of different techniques according to the extent of the contamination and the desired dose rate reductions.

Altogether more than 600 populated settlements were decontaminated over a total area of about 7000 km^2. About half these were treated more than once. Most attention was paid to municipal buildings such as schools, nurseries and hospitals and other social and industrial buildings. Buildings of lower value were demolished and the waste was buried. For more substantial buildings, up to three attempts were made to decontaminate them to preset levels. If this could not be achieved, these buildings were demolished.

The soil around many homes was removed to a depth of 10 to 15 cm, reducing dose rates by a factor of 3–4. Yards were paved over or covered with gravel, broken stones, sand or clean soil, which reduced gamma dose rates by a factor of about 10. In all, about 70 000 homes were decontaminated and about 200 000 m^3 of soil were removed for burial. More than 25 000 km of roads were also decontaminated. Roads were washed daily, which reduced gamma dose rates by half. Many were resurfaced with asphalt, concrete or stone, resulting in a threefold reduction in dose rate. At first it was anticipated that much of the area evacuated would be habitable after decontamination [9]. However, the efforts made eliminated only a small fraction of the deposited radionuclides and succeeded only in redistributing the rest. In many cases the surfaces quickly became recontaminated by radioactive materials migrating from trees in highly contaminated forests. It was reported that residents of only a handful of settlements were authorized to return to their homes in the BSSR.

Water that was used to decontaminate roads during the height of the decontamination effort was allowed to flow off into ditches. In the 30 km prohibited zone and surrounding areas to the south and north, signs were posted along the roads warning people that it is dangerous to walk along the side of the roads or in the forests. Contaminated water was collected only at decontamination control washing stations. A new sewerage system is being built in the vicinity of the plant. Decontamination work in general has been ineffectual, especially in the forests, and has been discontinued. The only places where decontamination had any success were at the plant and at some buildings in Chernobyl and Pripyat, and there decontamination continues.

In order to reduce the transport of radionuclides by wind, plastic sheeting was spread over the soil in some areas. Topsoil near the plant and from the switchyard behind the plant was removed and buried in the low level waste site. Experts have concluded that 'biological decontamination' is the best way to limit the distribution of radionuclides. Thus much of the area around the plant and in the prohibited zone has been allowed to become overgrown, which has had the beneficial result of virtually eliminating the sandstorms that were common in the area. It has increased the risk of fire, however. A number of houses have been torn down in the 30 km zone because they were fire hazards, generating additional waste material.

The fallout was inhomogeneous. This was mostly due to the uneven composition of the first deposits and partly to follow-up actions after the accident to reduce contamination. Streets, walkways, parks and school-yards were asphalted over or new soil was brought in (for example, in Bragin and Polesskoe), resulting in significantly lower external dose rates in these public places than in other areas nearby where there had been no special treatment. Dose rates in Daleta, a settlement with less primary contamination, on the other hand, showed a much more even distribution over the locality, a sign that no special decontamination measures had been taken in this region [20].

3.5. Agriculture and Food Supplies

3.5.1. Structure of Agriculture in the Region

To discuss the agricultural consequences of the Chernobyl accident [21], it is necessary to understand the setting of agriculture in the region. The climate is generally temperate and continental, with hot summers and relatively mild winters. Mean annual precipitation ranges from 500 to 650 mm. The terrain is in general flat with a maximum altitude of 200 m. Roughly half the land area has natural landscape (forests, marshlands and scrub) but the flat open areas of the region are almost entirely given over to agriculture, principally dairy farming and meat production (up to 60 cows per 100 hectares). Much of the remaining agricultural land is used for the production of potatoes (almost 8% of the remaining land), fodder crops (35–40%), cereals (almost 50%) and flax (up to 5%). The soils in general are of low productivity. Most soils are sandy to extremely sandy with areas of podzol, peat soils and marshlands, especially to the west of Chernobyl. These soils in general have a low natural fertility and are poor in mineral nutrients (in particular, poor in potassium, phosphorus and magnesium).

The system of agriculture is based on the collective farm (kolkhoz), which normally consists of a few thousand hectares of arable and often forest land. Farmers who work on the collective farms typically live together in the settlement, where they have a house and one-third to one-half of an acre of land to themselves to grow vegetables and fruit. Pigs and chickens are kept and, more so formerly, a cow for home milk production. The family cow is pastured on non-arable wasteland (natural pasture) and winter feed is harvested from similar areas. The collective farms in the region produce grain (winter wheat, winter rye, barley and oats), potatoes, beet (for cattle feed), beans and pasture hay and maize to support cattle production. Crop productivity is generally low owing to the poor soil, because fertilizer use has been limited and because herbicides and pesticides are apparently not in widespread use (judging by the heavy weed infestation and serious damage by insects to crops). Milk production per cow is well below typical yields in, say, western Europe. One farm visited reported 2000 L per cow per year as the average and another at Novozybkov reported 3000 L (a typical figure for milk production in western Europe is 4600 L per cow per year). Output of beef is also low. This low cattle productivity is due to a shortage of good quality feed. This condition is not a consequence of the Chernobyl accident. In fact, the feed quality has probably improved since the accident because of countermeasures that have emphasized the renovation of natural pastures and the use of chemical fertilizers. Some farms sell liquid milk which is processed for sale in cities; others produce their

TABLE 5. Comparison of Control Levels for Food and Drinking Water in Use after the Chernobyl Accident: Maximum Permissible Levels for Foodstuffs: Total ^{134}Cs + ^{137}Cs (Bq/kg)

Product	All-Union (6.10.1988) Temporary acceptable levels	BSSR (1990)	Gomel region (1988)
		Controlled levels	
Drinking water	19	19	19
Milk	370	185	185
Condensed milk	1 110	37	37
Dried milk	1 850	740	740
Buttermilk	370	370	185
Cheese	370	370	370
Butter	1 110	370	370
Cream	370	185	185
Vegetable oils	370	185	185
Pork	1 850	590	370
Beef	2 960	590	370
Poultry	1 850	590	370
Eggs	1 850	590	590
Fish	1 850	590	590
Vegetables	740	185	185
Greens	740	590	590
Potatoes	740	590	590
Fruits and berries	740	185	185
Grain	370	370	370
Bread	370	370	370
Sugar	370	370	370
Fresh mushrooms	1 850	370	370
Dried mushrooms	11 100	3700	3700

own butter and cheese. Beef is also sold. The farmers are self-sufficient in meat, milk and potatoes. They apparently do not process their grain but sell it on the market. Meat was so important to one settlement that the people would have to be relocated if it could not produce uncontaminated meat.

It was generally reported that farmers were leaving the collective farms. One collective farm in Novozybkov reported that a quarter of the workers had left the farm in recent years. The implied reason was fear of radiation, but it must be recognized that living conditions are relatively poor in many of these areas and that rural to urban migration accounts for some of the emigrants.

3.5.2. Monitoring and Control of Contamination

In the first two months or so following the accident, the main radionuclides contributing to internal radiation dose were the radioactive isotopes of iodine (primarily ^{131}I). These were ingested mainly in milk from dairy herds grazing in contaminated pastures. In order to limit the iodine intake of people living in the contaminated areas, temporary control levels were set for the radioactive iodine content of milk and dairy products. Stringent radiological monitoring of all dairy products was carried out. Similar measures were taken to limit the intake in food products containing ^{137}Cs, which remained the most important radionuclide for the dose resulting from internal radiation after the iodine radioisotopes had substantially decayed and ceased to be of significance.

TABLE 6. Levels of Radiological Monitoring of Food Products [20]

Level	Purpose	Staff and equipment
1. Expert monitoring by specialist organizations, e.g. research institutes, universities	To determine radionuclides present and their bioavailability; to establish control levels	Beta radiometry, gamma spectrometry, radiochemical analyses
2. Laboratory checks carried out by laboratories of medical/epidemiological institutes and by main branches of the food industry	To assist the various organizations in mass monitoring and to correct their results if necessary	Beta and gamma radiometry
3. Mass monitoring by various units of the national economy producing, processing, manufacturing, transporting and distributing food products (collective farms, firms, transport concerns, markets)	To increase the effectiveness of the primary control measures	Gamma radiometry

TABLE 7. Specific Activity of Natural K-40 in Various Agricultural Products [22]

Product	Specific activity of K-40 (Bq/kg)
Whole milk, kefir	44
Dried milk	300
Cheese	59
Beef, mutton, poultry	100
Sausage, cured meat	130
Eggs	44
Fish	90
Potatoes	170
Tomatoes	85
Fresh berries	110
Green vegetables	150
Wheat bread	56
Split peas	210
Rye flour	30
Oats	130
Soya	440
Tea	740

Levels of internal contamination were reduced by introducing restrictions on the consumption of contaminated food products. This was done by means of temporary regulations setting maximum permissible concentrations in food products of certain radionuclides liable to cause unacceptable doses if ingested. In addition, the BSSR, UkrSSR and the RSFSR have the authority to set their own levels. It is notable that in the BSSR the control levels for foodstuffs were reduced in 1989 and 1990 to those given in Table 5. Decisions on the following measures are taken on the basis of the radioactive contamination of food products:

(1) A complete ban on their consumption and use as fodder or in the food processing industry;
(2) Changes in methods of storage, preparation and use of foodstuffs;
(3) Authorization to consume products.

Systematic large scale monitoring was carried out of the levels of contamination of local food products in areas outside the 30 km prohibited zone. Three levels of monitoring are used in this control system, ranging from expert monitoring by specialist organizations, relatively few in number, to mass monitoring by many different units in the food and agriculture industry. Table 6 indicates the characteristics of these three levels of radiological monitoring. One of the problems in making such measurements at Levels 2 and 3, at which only beta and gamma radiometry are carried out, is that the naturally occurring radionuclide ^{40}K, which occurs in all agricultural products, may have a radioactivity higher than that of the radiocaesium. Table 7 presents typical values for the specific activity of ^{40}K in various foodstuffs. These figures can vary widely as a function of various influences. It is therefore very difficult to take account accurately of the presence of ^{40}K in samples by measuring beta activity alone. Sometimes ^{40}K is mistaken for radiocaesium and the produce is discarded even though it may contain virtually no radiocaesium. Gamma spectrometry offers the possibility of making more accurate determinations of radiocaesium concentrations in food products, but at present there are not enough such instruments for the number of measurements that have to be made, although the situation is improving.

3.5.3. Transfer of Activity Through the Agricultural Environment

The degree of contamination of agricultural products depends on many factors: the physicochemical characteristics of the radioactive materials contaminating the soil; the 'age' of the radioactive contamination; the agrochemical and physical characteristics of the soil; the plant species concerned; and meteorological and climatic conditions. One of the main objectives of research carried out by radioecologists in the USSR has been to determine the general characteristics of the contamination of agricultural crops and pasture, expressed in the form of a 'transfer coefficient' for the uptake of a given radionuclide from a specific soil type into the vegetation under given conditions.

The soil–plant transfer coefficient (transfer factor) is given by:

$$K_u = \frac{P}{U}$$

where P is the specific activity of the radionuclide in dry vegetable matter (expressed in Bq/kg) and U is the surface activity of the soil due to the radionuclide (in Bq/m^2).

These coefficients are then used to derive the radionuclide content in crops and pasture from the level of contamination of a particular site or area of arable land for similar conditions. The database on transfer coefficients that has been developed from measurements of crops and soil types is used in making decisions on countermeasures. These coefficients are tabulated in Ref. [21]. Further details on transfer coefficients are given in Part E, but some general comments can be made. The variations between transfer coefficients for different grain types are in general small, whilst those between coefficients for different soil types are large.

TABLE 8. Various Agricultural Countermeasures Taken after the Chernobyl Accident

Objectives	Methods	Treatment	Results
1. Decontamination			
(a) Soils	Removal of surface layer	Mechanical means	Effective but application restricted to highly contaminated zones. Problems with safe removal of waste.
(b) Vegetation	Cutting/felling	Mechanical means	Applied to about 400 ha of pine forest near the Chernobyl plant. Burying contaminated debris may cause long term problems.
(c) Livestock	Feeding with 'clean' fodder for 45-60 days before slaughtering		Effective against radiocaesium, whose biological half-life is relatively short.
(d) Dairy products	Production of by-products		Effective, although the use of some by-products, e.g. skimmed milk, can pose problems.
2. Changes in crop production	Changes in crop rotation	Production of plants for industrial use (fibres, etc.) or plants not directly consumed by human beings (seed potatoes, seeds)	Allows contaminated soils to be exploited but any use of by-products (e.g. sugar beet pulp) as animal feed must be monitored.
	Afforestation	Production of wood that will be cut in 30-40 years (≈40 000 ha)	Countermeasure planned for highly contaminated zones.
3. Reduction of radionuclide transfer from the soil to the crop or pasture	Removal of the contaminated layer from the root zone (0-25 cm)	Deep ploughing	Effective in the case of permanent grassland (transfer reduced by a factor of 8-10); however, ploughing must be restricted to podzol horizon so as not to affect fertility. Requires powerful mechanical equipment.
		Leaching by dilute chemical solutions (HCl, H_2SO_4, NH_4NO_3, etc.)	HCl and $FeCl_3$ are the most effective but large quantities are required (37 t/ha).
	Reduction in the biological availability of radionuclides	Application of fixing substances (zeolites, etc.) (UkrSSR: 25 000 t)	Effectiveness depends on type of soil: sometimes the reverse effect is observed. Several by-products of ore extraction may be suitable.
	Modification of the physicochemical characteristics	Liming (BSSR 214 500 ha, UkrSSR 51 000 ha)	Most effective in light, acid soils.
		Application of large quantities of fertilizer (especially those containing K, avoiding too much N) (BSSR 256 200 ha, UkrSSR 26 600 t)	Cs-137 uptake can be reduced by a factor of up to 3.5 depending on the biological characteristics of crop or pasture.
	Increasing leaching of radionuclides out of the root zone	Application of chelating solutions (amino-polycarbonic acid, etc.)	Promotes the shift of radionuclides towards the subsoil, whose drainage can be improved by deep ploughing (taking care not to contaminate groundwater).

Sandy soils, which predominate in the area, have a relatively high caesium transfer to plants; peat soils, which occur west of Chernobyl, have even higher transfer factors. The transfer factor for clay soils is generally less by about one order of magnitude. In general, the transfer factor for vegetables is lower than that for grain. By far the greatest transfer from the soil is that to forage from natural pastures. Indeed, the contamination of fodder from natural hay fields and pastures due to the uptake of caesium was about ten times higher than for fodder from regrassed land, and herein lies the major problem of contamination of the meat and milk of grazing animals.

The relation between ^{137}Cs activity on the land surface (in Bq/m^2) and consequent concentrations of ^{137}Cs in milk and meat (in Bq/kg) is very dependent on the soil–plant transfer coefficient for natural pastures, which, as mentioned above, varies significantly with soil type. For example, on collective farms in the Novozybkov area, despite relatively high fallout levels in the region of 1.5–3 MBq/m^2, the application of countermeasures provides for a high production of clean or useful products (butter, meat, feed, etc.). On the other hand, a farm manager on another farm with fallout levels of only about 0.6 MBq/m^2 reported that the accepted standards could not be met.

3.5.4. Countermeasures Affecting Food and Agriculture

A whole range of countermeasures have been developed and taken with the principal aim of permitting the production of food with activity concentrations below the maximum permissible levels; some of the measures have had the secondary effect of reducing the external dose from deposited contamination and/or the inhalation dose to agricultural workers from resuspended radioactive materials. Table 8 presents a summary of the various agricultural countermeasures taken after the accident, and some of these are discussed in more detail below.

Ploughing/Removal of Soil

Contaminated topsoil can be removed, but it is very difficult to remove topsoil from large tracts of land. However, deep ploughing shifts the surface layer of contaminated soil to the bottom of the furrow and significantly reduces radionuclide uptake by crops and pasture as well as external dose rates. The lower this contaminated layer is placed, the greater is the reduction in the soil–plant radionuclide transfer. This is because most of the root system of plants is in the topsoil. For example, it was reported that ploughing of natural pastures and subsequent regrassing can reduce the radiocaesium content of animal products by a factor of 2–5. However, the maximum depth at which the radioactive layer can be placed in turf podzol soils is limited by the podzol horizon. Ploughing too deep might lead to a transfer of the infertile layer towards the surface. Any working of the soil after the contaminated layer has been placed at the bottom has to be carefully done to prevent returning it towards the surface. It is recognized that shifting the radioactive layer to a greater depth is less effective in light, sandy soils. Indeed, for some soil types, deep ploughing can render the land useless.

Addition of Fertilizers and Chemicals to Contaminated Soils

A large number of research findings have shown that one of the most effective methods of reducing the migration of ^{137}Cs from the soil into the vegetation (for light, relatively infertile acid soils) is to apply mineral fertilizers (especially potassium based fertilizers) and lime. In addition, there is some evidence that the transfer of radionuclides into crops and pasture in light, grassy podzolic soils is inhibited when clay minerals of the zeolite type are added. On average, increasing the quantity of potassium based fertilizers used produces a reduction by a factor of about 3.5 in the transfer for both grain and other crops. However, it is also recognized that the use of nitrogen fertilizers can increase the uptake of caesium from soil into crops and pasture. It is therefore important that farmers take advice from agricultural specialists with regard to the correct mix of fertilizers for a given soil and crop type. To improve the radiological conditions, the following countermeasures have been taken: in the UkrSSR, chemical treatment, liming of 51 000 hectares, application of 26 600 t of phosphates and potassium fertilizers to the soil (it is also planned to apply 25 000 t of zeolites); in the BSSR, liming of 214 500 hectares, increased application of phosphate and potassium fertilizers to the soil (256 200 hectares); in the RSFSR, liming of over 65% of acid soils in the most contaminated region of Bryansk and manuring of 90% of ploughed land with organic fertilizers. The liming of the soil together with the application of zeolite and of phosphate, potassium and organic fertilizers carried out during the first year led to a reduction in the contamination of agricultural products by a factor of 1.3–3.

Production of Uncontaminated Milk and Meat

It has already been pointed out that forages were generally more contaminated with caesium than grain, especially natural grass areas. For the grazing of privately owned cattle, natural pastures are allotted where the grass contamination does not exceed 20 nCi/kg

(740 Bq/kg). If no such pastures are available, the animals are meant to be grazed on fields sown with annual grasses or winter crops and spring crops, which are less contaminated. It is recognized that the natural pastures have to be radically improved. The use of woodland pastures for dairy cattle is forbidden, nor may cattle graze on freshly mown hayfields. There is better access for cows from collective farms to the approved pastures and pastures improved after the accident than for cows from private farms. In addition, cows from collective farms are fed more concentrate low in caesium and in the winter more silage and beet in addition to hay. It was reported that clean feed had been imported from other areas. In contrast, cows from private farms have not had such ready access to hay from improved fields, concentrate, beet or silage. Where uncontaminated fodder is not available, there are two possible solutions: in some cases, the private farm cows have been added to the collective farm herd. In other cases the milk was collected from the private herds and converted to butter, which may safely be consumed, and owners were supplied with clean milk.

Beef production is from the same type of cows as those in the dairy herds, principally Friesian breeds. There are no separate beef cattle herds. Cattle fed some silage, beet, concentrates and hay from improved fields, which allows the production of acceptable milk, normally also produce beef that meets standards. Simple gamma detectors are used to assess the body caesium content of the animals before their slaughter is permitted. If any are found to have caesium concentrations above the limits, they may be sent to clean areas or be fed low activity fodder for a period of time before slaughter. The biological half-life of caesium in the bodies of the animals is about 35 days; thus two months of relatively 'clean' feeding can substantially reduce the body burden. (As mentioned earlier, the detectors used do not distinguish between the radioactivity measured due to ^{134}Cs and ^{137}Cs and that due to ^{40}K; although correction factors can be applied, the actual body contents of caesium are often overestimated.)

Livestock farming in the contaminated regions can simply be redirected away from milk production completely to meat production or else the milk may be used solely for butter production (see later). In this case, the raising and fattening of cattle, as well as of pigs and poultry, is then unrestricted; however, six to eight weeks before the expected date of slaughter, the animals must be confined and fed with uncontaminated fodder (which first has to be checked by a radiological laboratory). Because the types of feed used for pigs and poultry are normally low in caesium content, the production of pork and poultry meat does not pose problems. The down and feathers of the birds are washed in detergent solutions and their use is then also unrestricted. Hens are kept for egg production provided that they are confined to runs.

Food Processing Methods

The processing of many agricultural products leads to a reduction in the radionuclide concentration in the final food products. Strategies for food processing have been developed that redirect production towards those food products that have low final caesium contents. This has been a most effective approach for milk and dairy products, which are among the principal foods in which radionuclides are ingested. Cream and butter are depleted in caesium and strontium. Indeed, butter fat is free from these nuclides. Thus, when milk cannot be produced with activity below the maximum permissible levels, it is redirected towards butter production. There are other such examples in the food supply industry.

It was also reported that filters impregnated with Prussian Blue (a complexing agent that absorbs caesium by exchange of potassium ions) for reducing the caesium content of contaminated milk were under development.

Changes in Land Use

It was reported that some arable land had been converted to produce non-food and non-forage crops; for example, flax, potatoes for alcohol and oil seed crops. Afforestation is considered to be the best long term solution to the problems of the more contaminated areas. The greater part of the region is marginal farm land, and forest already covers a large part of the affected areas. In the Gomel area, for example, it was reported that some 2900 hectares of land with activity levels of more than 80 Ci/km^2 (3.0 MBq/m^2) had already been afforested since the accident.

3.5.5. Concluding Remarks

The problem of iodine contamination in foodstuffs lasted for a few months after the accident until radioactive decay made it insignificant. By the end of 1986, the exposure due to deposited radioactive caesium had become dominant. Not only was radiocaesium a source of external exposure directly from the surfaces on which it had been deposited, it also contributed an equal or even greater proportion of dose through food, including milk and meat. Because much of the basic diet in the region consists of locally produced milk, vegetables and meat, banning such local foods required that an adequate supply of clean food products be made available at a price people could afford.

It became evident early on that there were major problems in ensuring an adequate supply of dietary staples. People frequently had to eat banned products or go without. The picking of seasonal wild foods such as mushrooms and berries was also banned in many areas,

TABLE 9. Production on Farms in the Gomel District

Year	Total produce (t)	Product with level above maximum permissible level (t)	(%)
Milk			
1986[a]	450.1	299.3	66.5
1987	813.5	235.9	29.0
1988	860.5	146.3	17.0
1989	853.5	49.2	5.7
1990[b]	457.8	5.6	1.2
Beef			
1986[a]	341.0	64.8	19.0
1987	1842.0	71.0	3.8
1988	2055.0	24.0	1.2
1989	2244.0	10.0	0.5
1990[b]	385.6	0.7	0.2

[a] Fourth quarter.
[b] First six months.

Source: Information presented at the Agricultural Seminars, Gomel, 28–30 October 1990.

which not only restricted dietary options, but also curtailed a pursuit that is an important part of life in the region (see later). USSR officials believe that measures taken to control the consumption of foodstuffs made it possible to reduce substantially the internal radiation dose rate to the population and that in the absence of such controls internal dose rates could have been as much as ten times higher.

As has been described, major efforts were made to develop and apply agricultural techniques to reduce the passage of radionuclides through the human food-chain. These techniques substantially reduced the average levels of contamination in crops from 1986 to 1987, but the radionuclide content of pods remains variable from place to place. The assumption now seems to be that the activity levels in cereals and vegetables are relatively low, can be managed easily, and are not a source of concern. Questions arise about wild fruits, berries and mushrooms, for which only limited control can be applied, but the principal concern is with the levels in milk and meat, mostly beef. Table 9 shows the trend over the five years since the accident in the amount of milk and meat with contamination levels above the maximum permissible levels in the Gomel district.

In general, then, farms are able to meet the necessary standards for food products, although substantial numbers of cattle have to be sent to graze in 'clean' areas for a period before slaughter. This practice may have advantages in producing better quality meat and more meat per animal than under the old systems whereby the animals were 'managed' by private farmers. Indeed, the figures for milk and meat productivity for cows in the contaminated areas of the Gomel district bear this out (Table 10).

The effectiveness of countermeasures should be assessed not only in terms of their ability to reduce the intake of radionuclides, but also by the impact they have on the welfare of the people who depend on the collective farms for work and for their food, and on that of the private farmers, many of whom can no longer maintain themselves and their families by traditional farming methods. For these people, foodstuffs imported from 'clean' areas have been essential. The extent to which these foods are still used is not clear, but 'clean' milk continues to be provided to many families in lieu of milk from private farm cows. The social and psychological impact on these private farmers, whose cattle cannot yield clean milk or meat in situ by traditional methods and thus cannot support the family, should not be underestimated.

With regard to the control levels, until recently the acceptable level of contamination in milk for the whole area was 370 Bq/L and in beef 2960 Bq/kg. However, in 1990 a lower level for meat was proposed which was that perceived to be recommended by the European Economic Community (EEC), namely 600 Bq/kg. This EEC level was actually intended for controlling imports into the EEC countries after the Chernobyl accident. For a future accident, the EEC would apply levels of

TABLE 10. Milk and Meat Productivity of Cows in the Contaminated Areas of the Gomel District

Year	Annual milk yield per cow (L)	Daily average weight gain (g)
1983	2051	
1984	2281	
1985	2463	
1986	2708	419
1987	2929	433
1988	3056	465
1989	3053	482

Source: Information presented at the Agricultural Seminars, Gomel, 28–30 October 1990.

1000 Bq/L for milk and 1250 Bq/kg for other foods. The choice of the lower levels has created confusion in calculating the amount of produce that meets an acceptable standard for public consumption. Further confusion has been caused by the selection of 37 Bq/L by the milk processing plant in Gomel as the limit for milk products such as condensed milk. There was no basis or scientific justification for the selection of such a low level.

The difficulty of defining the problem after the Chernobyl accident and the efforts made by administrators, scientists and agricultural personnel in the USSR at all levels to contain the agricultural consequences and protect the public from both external and internal radiation should not be underestimated. The scale of the work was immense and credit must go to those who were operating under conditions of panic and with little analytical equipment. In view of the unprecedented scale of the agricultural problems, and the considerable time needed to collect the large volume of scientific data necessary, there does not appear to be any justification for suggestions that significant information has been concealed in relation to food and agriculture, at least at the technical level. However, there does in some cases seem to be a 'credibility gap' between many farmers and scientific and administrative personnel, which has undermined the well-being and confidence of the communities concerned. There remains some question to what extent the communities were given relevant and appropriate information concerning the countermeasures to be taken and whether the risks and control levels were put in perspective with other risks and/or with levels associated with foodstuffs elsewhere in Europe.

3.6. Ecological Effects

The so-called 'red forest' just to the north of the Chernobyl plant, which died from the effects of irradiation, was cut down and buried in place. Other forests in the vicinity of the plant and surrounding the 30 km prohibited zone continue to be a significant source of contamination for the biosphere, although wild animals are flourishing in the zone, largely because they are no longer being hunted. Since 1987, there has been evidence that the forests have stopped showing the effects of radiation exposure and contamination in terms of spontaneous mutations. Radioactive material has migrated to about 10 cm into the ground; however, the bark of trees continues to show contamination. The effects, if any, of uptake into the trees is not apparent. The research station in Pripyat is growing pine trees from seeds taken from the contaminated zone in 1986 and 1987, and comparing them with others being grown in contaminated soil from seeds from clean areas.

Experts studied the doses received by flora and fauna in the area as well as human doses. This information served as the basis for making decisions relating to the safety of the population, as well as to the conduct of commerce in contaminated areas. This information was supplemented by the results of scientific research on radioecology and the migration of radioactive substances in the environment, including migration via the food-chain. Uptake by plants depends essentially on soil type and the level of contamination. Areas low in caesium contamination can nevertheless have high uptake levels, for example, and vice versa.

Radioactive caesium in the soil is readily taken up by mushrooms. Whilst the uptake by mushrooms varies markedly depending on the species, on the radiocaesium level in the soil and on the nature of the soil itself, the levels of contamination in mushrooms are, in general, relatively high for a given soil contamination. This led to restrictions on the picking and consumption of mushrooms in many areas, particularly forest areas. Originally, distinctions were made between different species of mushroom, but later restrictions were placed on all types within designated areas. Controls on mushroom eating were and remain extensive; the areas concerned are larger than the areas in which agricultural countermeasures, for example, are taken. These restrictions, which might seem relatively minor, are highly significant in the affected areas. This is because mushrooms were freely available and supplemented the diet (indeed, mushrooms are considered a delicacy by many people); and secondly, mushroom picking was an important part of life. Each year newspapers carried reports on the biggest crops of mushrooms, families went on mushroom hunts, and there were even working holidays spent picking mushrooms. Thus the restrictions, whilst clearly not making life intolerable, have had a considerable social impact, as well as deeply affecting people's perception of the safety of the areas in which they live (although people in several areas were not aware that washing mushrooms in lightly salted water before cooking could reduce the radiocaesium levels by a factor of five).

The situation is similar (though less serious) with wild fruits, berries and game, all of which have elevated levels of radiocaesium in comparison with cultivated foodstuffs. Again, these wild foods supplement the diet and are a feature of the local cuisine. Restrictions on these foodstuffs, whilst not so widespread as for mushrooms, also shape people's perceptions of the safety of their living conditions. Indeed, there have even been calls for relocation of the entire population from some settlements where restrictions have been placed on mushroom picking in the surrounding forest.

There were animals, including cattle and horses, on an island 6 km from the Chernobyl plant that were not removed from the 30 km prohibited zone with other animals. Grazing animals have a high intake of fodder, and it was estimated that these animals received thyroid doses of 15 000–20 000 rem (150–200 Sv). In late 1990, there were still about 60 head of cattle from the herd at a research centre. All the horses died and the first cattle died after five months. Necropsy revealed the absence of any thyroid tissue. Surviving cattle were all hypothyroid and of stunted growth. The second cattle generation seems to be normal.

There were no clinical signs in cattle from outside the exclusion zone. A fact finding mission led by the Food and Agriculture Organization of the United Nations (FAO) investigated evidence for reports that had been widely published in newspapers around the world concerning birth abnormalities in domestic and wild animals in the affected areas. The team concluded that none of the abnormalities reported were other than could be seen anywhere else in the world. The question remained whether there was a significant excess of such effects in these areas. In this respect, a large scale survey found no effects that could be attributed to the accident.

3.7. Health Effects on the General Population

As a result of the whole range of social, medical, organizational and protective measures taken, stress and anxiety as well as mental disorders affected most of the concerned population of the three Republics (see Part F) [22].

The causes and conditions of formation of psychogenic disorders include: residence in the contaminated area; supply of inadequate information to the population about the radiation situation; losses of various kinds and change in life-style in the case of persons who participated in post-accident management.

Scientific institutions belonging to the Ministries of Health of the USSR, the BSSR and the UkrSSR and to the Academy of Medical Sciences of the USSR took part in providing psychiatric and psychotherapeutic assistance and later also in organizing new structures in the system of provision of psychiatric assistance.

A step-by-step study of the rate and prevalence of mental disorders resulting from the accident and of psychological consequences is a part of the long term All-Union and Republican programme. Improvement in the quality of life should balance psycho-emotional burdens. It is planned to restore confidence in official bodies and to implement medical rehabilitation measures for those in need.

In order to reduce the anxiety and stress in the population resulting from the difficulty in understanding the effects of radiation, the activities on imparting knowledge are focused mainly on clarifying and providing information on the actual radiation situation and possible radiological consequences.

Leading experts in radiation medicine and specialists of the USSR Ministry of Health have given lectures and presented reports and communications at the sessions of the Supreme, regional and local Soviets of Peoples' Deputies of the BSSR, the RSFSR and the UkrSSR, addressed Communist Party members and economic management groups, medical personnel and enterprises, appeared on television and held meetings with special interest groups and the population.

An information division has been set up under the All-Union Scientific Centre for Radiation Medicine. Its functions include co-ordination of information policy, collection, analysis, correlation and exchange of information and methodological support for information activities. Regular relations with the mass media have been established and maintained.

Regional public information groups on radiation safety problems have been set up under the Republic level epidemiological health stations. Their work includes participation in the study of public opinion and of the reactions by different population groups, imparting basic knowledge of radiation medicine to the population and the provision of regular objective information on the radiation situation.

Great attention is devoted to the problems of special training of medical personnel at the upper and middle levels for students of the public health and hygiene faculties of medical institutes and schools. In addition to holding classes for doctors, the lecturers and teachers meet every day with the public and with workers' bodies, deliver lectures, hold talks and give advice. In the BSSR, physicians of various specialities give talks on the radio every two weeks.

The All-Union and Republic governmental programme of urgent measures for mitigating the consequences of the Chernobyl accident calls for the establishment of a unified radioecological information system for the public based on the All-Union and regional radiological information centres. It is planned on a regular basis to issue information bulletins on the radiation situation, the state of health of the population, the quality of locally produced foodstuffs and other problems associated with mitigating the accident consequences, to publish the results of analysis of this information by special interest groups, specialists in various sectors of the economy and radiologists, and to circulate brochures, booklets, popular science books and cinematographic and video films on radiation safety problems and medical aspects of the consequences of the Chernobyl accident.

In accordance with a decision of the Ministry of Health of the USSR, a laboratory for the organization of publicity about radiation safety is being set up under the All-Union Scientific Centre for Preventive Medicine.

3.8. Medical Follow-up in Affected Areas

In addition to locally available medical facilities, there were up to 400 special brigades (doctors and health physicists) and about 15 000 medical workers, including

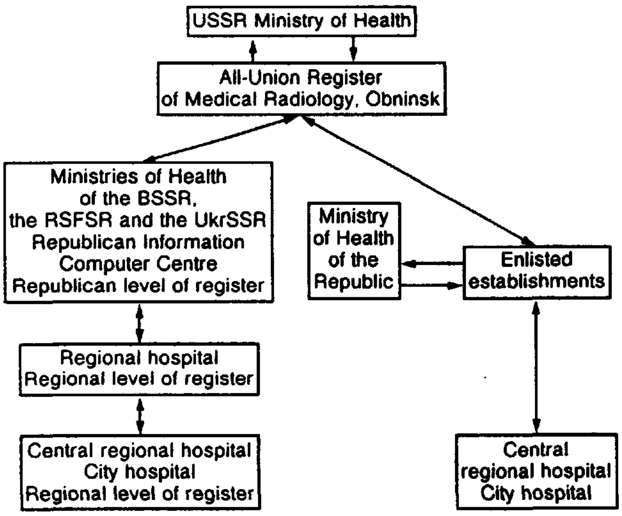


FIG. 8. Distribution register and organizations providing out-patient observations.

medical students, engaged in emergency examinations, treatment and follow-up measures [10]. About one million persons have been examined, of whom 700 000 underwent thorough dosimetric and clinical tests. A total of 32 000 people, one third of whom were children, were examined in clinics. Large amounts of KI were distributed to the affected areas. Supplies of KI ran out at an early stage, and more had to be found from outside the area. A summer health campaign for children and pregnant women was organized and officials set up a comprehensive system for monitoring radiation levels and the state of health of those working on decontamination.

In the weeks following the evacuations, medical teams were brought in to advise residents about personal decontamination and to survey the evacuated population for acute effects. No such effects were found. Thyroid uptake of radioiodine was also surveyed with simple field instruments and a registry of relevant data on evacuees was set up. In all, 6000 children evacuated from the 30 km prohibited zone received doses of over 200 rem (2 Sv) to the thyroid. There were 15 children conceived from men who had suffered ARS. The authorities in the USSR are still monitoring 600 000 people (including 90 000 children) who received radiation doses as a result of the accident, which is a vast undertaking [9].

The distributions of the thyroid doses analysed by the Ministry of Health of the USSR as a function of age showed two independent groups (statistical distributions), seemingly reflecting the fact that in each age group there were individuals who took preventive measures (such as taking iodine compounds, limiting outdoor excursions, not consuming milk, etc.) and other individuals who did not take such measures [13].

An All-Union State Registry (Fig. 8) was founded immediately after the accident and has data for 1986 to 1989 on persons irradiated as a result of the Chernobyl accident. It currently covers more than 500 000 individuals and is being added to daily. Three large high risk groups can be identified from the registry's database [13]:

- emergency accident workers (termed the 'liquidators');
- those who live in the contaminated areas and those who were evacuated from them;
- those people, including children and adolescents, who underwent thyroid irradiation.

Nearly half the emergency accident workers were exposed to external radiation and incurred doses ranging from 100 mGy to 250 mGy [23]. About 10% received doses exceeding 250 mGy. Those who lived in contaminated areas and those who were evacuated were exposed to continuous external and internal irradiation. Persons with absorbed doses to the thyroid of 2 Gy and above, and especially children and adolescents (see Fig. 9), have undergone extra clinical and dosimetric examinations since 1987. Although some functional disorders of the thyroid gland were detected in some persons in 1987, these seem to have been of a temporary nature. These persons will be subject to regular check-ups for any malfunctioning of their thyroid glands.

Thus, the Chernobyl accident resulted in 30 immediate fatalities (and one death due to a heart attack), 2 in the initial blast and 28 from ARS, there were 237 reported cases of ARS among survivors, and the long term health and environmental effects, especially for children, are considered to be significant. The disruption of behavioural and dietary patterns was followed by an increase in the frequency of medical complaints. These complaints, whether due to dietary deficiencies or to anxiety about the effects of radiation, or to radiation effects themselves, have generally been ascribed to the Chernobyl accident, both by much of the population and by local medical authorities.

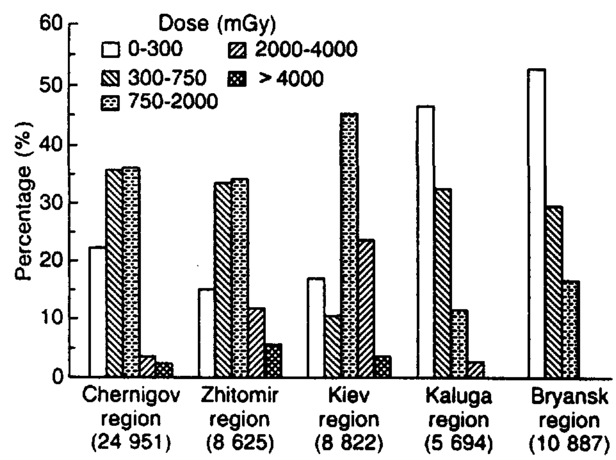


FIG. 9. Distribution of absorbed doses to the thyroid gland for children by geographical area.

4. Socioeconomic Effects

The Chernobyl accident has affected a much larger area than the 30 km prohibited zone. Hundreds of thousands of inhabitants of the BSSR, the UkrSSR and the RSFSR have had their lives disrupted by the accident (Fig. 10). Close to 115 000 people have been evacuated and there is the possibility that an additional 200 000 or more will be relocated in the future, depending on decisions to be taken on intervention criteria. Thirteen districts (Minsk, Brest, Rovno, Mogilev, Gomel, Zhimotir, Kiev, Cherkassy, Chernigov, Bryansk, Kaluga, Tula and Orel) have been affected by radioactive contamination, with total areas of 2000 km^2 in the RSFSR, 7000 km^2 in the BSSR and 1000 km^2 in the UkrSSR [16].

Some 650 000 persons were involved in the cleanup of the plant site and the 30 km zone. Over 275 000 persons are now living in 'strict control zones' (SCZs), areas where rigorous radiation surveys continue to be conducted. The 30 km prohibited zone around the plant is still in effect. Soviet health officials have proposed that a 35 rem (350 mSv) lifetime dose limit be applied for those people living in these SCZs (the 35 rem concept is discussed in detail in Part G of this report). Under this plan, people will remain in these controlled areas at present, but they will be strictly monitored and attempts will be made to reduce their lifetime doses. If this is not possible, 20 000 to 100 000 people would have to be relocated.

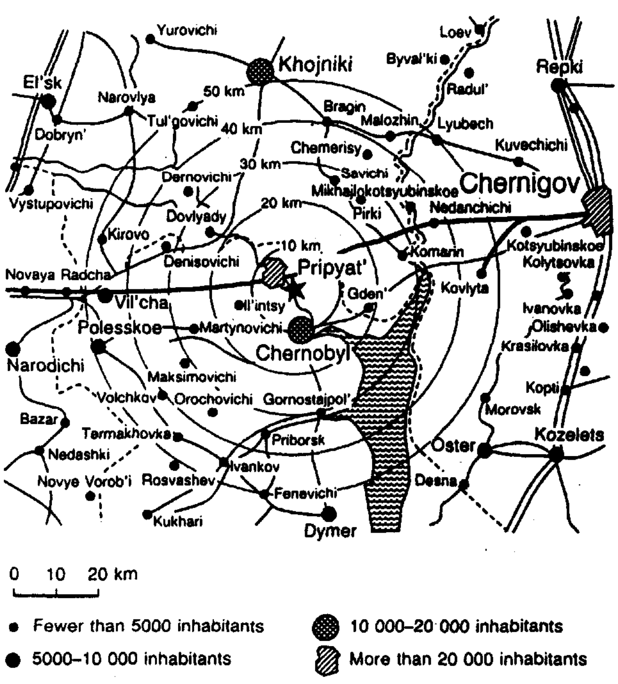


FIG.10. Population distribution within 50 km of the Chernobyl nuclear power plant. [Source: Ref. [18]]

4.1. The BSSR

Of all the territories in the European part of the USSR that were contaminated by radioactivity following the accident, 70% are in the BSSR (38 400 km^2 or 18% of the land area of the Republic). Twenty-seven towns and 2666 other settlements with a total population exceeding 2.1 million are located in areas where the level of contamination exceeds 1 Ci/km^2 (37 kBq/m^2). There are 14 towns and 1352 other settlements with a total population of 1 734 000 in areas where contamination levels are between 1 and 5 Ci/km^2 (37 and 185 kBq/m^2); eight towns and 919 other settlements with a total population of 267 000 in areas with contamination levels of between 5 and 15 Ci/km^2 (185 and 555 kBq/m^2); and five towns and 295 other settlements with a population of 105 000 in areas where contamination levels are 15 Ci/km^2 (555 kBq/m^2) or more. The latter areas include the zone where the level is above 40 Ci/km^2 (1480 kBq/m^2), in which there are 70 settlements and a population of 9400.

In the first stage after the accident, urgent measures were taken to protect the population by the evacuation of 107 settlements in the Bragin, Narovlyan and Khojnik regions of the Gomel province. A total of 24 700 people were evacuated, for whom 9770 apartments in farm type houses and other necessary buildings were promptly constructed.

Economic losses in the BSSR from 1986 to 1989 were calculated by the BSSR's Ministry of Finance to be 3.5 billion roubles. Agriculture suffered the greatest loss. Radioactive contamination affected more than 1.6 million hectares of agricultural land (more than 18% of the total), of which 106 000 hectares were excluded from production in the 12 months following the accident. Between 1986 and 1989, 257 000 hectares of farm land were taken out of agricultural use, including 79 000 hectares of arable land from which no uncontaminated produce could be obtained. About 1 million hectares (or 15%) of the forests were also contaminated to varying degrees.

Exclusion and evacuation zones were created in areas covering 194 000 hectares, and most of these were subsequently turned into State radioecological woodland preserves. In the evacuated areas, 20 collective and State farms working 90 800 hectares of agricultural land, including 36 100 hectares of arable land, were closed down. The radionuclide ^{90}Sr accounted for more than 0.3 Ci/km^2 (11.1 kBq/m^2) of the contamination of 77 000 hectares in the Mogilev district and of 396 000 hectares in the Gomel district.

The problems of farming in the contaminated area are growing, both on collective farms and on private holdings. The number of cattle is diminishing. The cattle stock in subsidiary farms dropped between 1987 and 1990 by 106 000 in the Gomel and Mogilev provinces alone. The corresponding figures for dairy cows and pigs are 77 000 and 41 000 respectively. The difficulties of supplying the population with food, especially meat and dairy products, are worsening. In the contaminated areas of the BSSR, social tension is mounting with these stresses.

Scientific studies and observations made between 1986 and 1989 show that the radiological situation in the BSSR will not change significantly in the next five to ten years. Experience from collective and State farms indicates that, despite the measures taken to improve agricultural land in accordance with the guidelines approved by the State Agriculture Committee for farming in contaminated areas, 25–50% or more of the fodder produced in areas where the levels of radioactivity are between 15 and 40 Ci/km^2 (555 and 1480 kBq/m^2) or higher have limited use owing to contamination. It is virtually impossible to produce uncontaminated milk in these areas.

The BSSR has adopted recommendations for farming in radioactively contaminated areas for 1990 and a schedule for further specialization of farms. These foresee the zoning of land in terms of ^{90}Sr contamination and a ban on the farming of land where levels of ^{137}Cs exceed 40 Ci/km^2 (1480 kBq/m^2). In addition, there is a ban on the production of milk in areas where caesium levels are over 15 Ci/km^2 (555 kBq/m^2), and arable and livestock farming methods have been identified that are intended to prevent the production of contaminated produce.

4.1.1. Gomel

Officials of the BSSR currently face a number of problems. First, the population of the region considers people from contaminated regions to be contaminated. This is a sociopsychological problem that only education can deal with. Second, the authorities must reach decisions on establishing priorities for providing relocated people with housing. These individuals displace those who have been waiting a long time for housing and this gives rise to antagonism. Third, the authorities may need to make allowance for elderly people who do not want to leave their home settlements. It is particularly difficult to resettle older people who have ancestors and relatives buried in the home settlements. The cemeteries are now closed and the people feel cut off from their roots. Finally, the BSSR does not have the economic capacity to provide housing for the new evacuees. Resources are needed from other areas.

Information about the accident was first received by Civil Defence officials of the BSSR in Gomel through All-Union military channels, whereupon it was passed to the State Ministry of Defence, the President of the BSSR and the Party Chairman. No decisions on evacuation or other protective measures were taken at the Republic level during the first days. The mayor of Gomel then personally decided to introduce radiation safety measures, which were announced over the radio. These consisted in recommending that people stay inside and avoid outdoor exposure. The same recommendations also applied to cattle. On 1 May a decision was taken to evacuate children and pregnant women from areas with high radiation levels in the 30 km zone. Twenty-five localities were affected by this decree. On 4 May, an additional 50 settlements were affected, and 11 035 people were moved during this phase.

Still in May, 28 more settlements were considered to have high enough levels to require evacuation, affecting an additional 6017 people who were then evacuated between 2 and 9 June. By the end of August, 7327 people in 29 settlements had been evacuated. Thus, a total of 24 700 people from 107 settlements were moved during the late spring and summer. The basis for these evacuations were radiation levels measured on 10 May. Then, in late 1986, 12 settlements were re-evacuated, affecting 1612 people. In 1987 an even greater number of people were re-evacuated from areas in the BSSR, and in 1988 there were still more re-evacuations from Bragin. Contamination was discovered in Minsk in 1987. Not until the end of 1989 was a complete picture of caesium, strontium and plutonium contamination in the entire BSSR available.

Potassium iodide was distributed to the entire population on 28–29 April. More KI was distributed regularly until 10 May, when iodine releases from the plant began to decrease. It is difficult to know how many of the population actually took the tablets. All countermeasures in the BSSR up to 27 August 1986 were taken at the Republic level. All-Union decisions were made only after August 1986. Evacuees reportedly received dosimetric checks of their thyroids in the places of evacuation in camps, schools and sanatoria where they were allowed to change their clothes. These people are currently included in a list of evacuees, data on whom are stored in Minsk, and the authorities are trying to reconstruct their doses.

These evacuations were made, and financial compensation was given, on the basis of maps that have been produced annually since the accident. In 1986, the first map showed only gamma radiation levels. Since then the maps have also shown caesium contamination.

Of the original 24 000 people evacuated, 1667 have decided to return to their homes. A decision was therefore made to decontaminate four settlements in the Bragin region, including kitchen gardens, public areas, production facilities, roads and running water. The authorities are relocating another 169 settlements — 10 000 families — from areas in the northern part of the BSSR contaminated to the extent that people could be expected to receive doses in excess of the 35 rem

(350 mSv) lifetime dose limit. These are families with small children or pregnant women, or families from areas where the contamination is greater than 40 Ci/km^2 (1480 kBq/m^2). The BSSR also recognizes voluntary relocation of people from areas of contamination of 15 to 40 Ci/km^2 (555 to 1480 kBq/m^2) as well as from areas where the food is not clean although the level of contamination is lower than 15 Ci/km^2 (555 kBq/m^2).

The total number of people potentially needing to be resettled, including those in more marginal areas, is about 40000 families, or somewhat over 100000 people. A total of 10 000 families (22 000 persons) are in areas of contamination levels above 40 Ci/km^2 (1480 kBq/m^2) or include pregnant women or young children. An additional 78 000 persons in 30 000 families are being allowed to resettle from areas with contamination levels of between 15 and 40 Ci/km^2 (555 to 1480 kBq/m^2) or where the food is not uncontaminated. However, of these families, 7000 have decided to stay.

Of the BSSR's milk products, 40% are exported all over the USSR. After the accident, the BSSR wanted its milk to be publicly accepted as clean, in order to continue this level of agricultural production. Inspections are made by 190 laboratories and 340 000 samples are taken per year. Random checks are also made at production factories. Levels of contamination on private farms are also checked.

Owing to surface contamination, limitations were placed on the distribution of vegetables, berries, fish and mushrooms in 1986, in addition to milk and meat. Problems remain on private farms, where people do not like to take the trouble to test their produce. The BSSR has therefore set up a series of testing stations where produce can be tested and, if acceptable, sent to production centres.

4.2. The RSFSR

In the Bryansk region, a 24 hour continuous monitoring was established on 29 April 1986, after the first registered increase in radiation background. From the maps of contamination, it was found that five districts west of the Bryansk region were contaminated, which represented 5500 km^2 with a population of 278 300 people: 216 settlements were located in regions where the ^{137}Cs contamination density was between 15 and 40 Ci/km^2 (555 to 1480 kBq/m^2); 15 settlements (representing 104 500 people) were located in areas where the contamination exceeded 40 Ci/km^2 (1480 kBq/m^2).

In chronological order, the following protective measures were adopted by the local authorities:

— 3–4 May 1986 — drinking of milk from the western districts prohibited;

Novozybkov

The people of Novozybkov learned about the accident and the levels of contamination around 3 May. On 4 May authorities instructed the kindergarten to wash the rooms with water, to keep children indoors and not to open windows. On 6 or 7 May, it was recommended that all babies not being breast fed be given food prepared from powdered milk to prevent 'contamination'. On 9 May, the authorities issued a notice telling the inhabitants that they were living in a contaminated zone and that they should: (1) stay indoors; (2) wash down the rooms; (3) wash themselves; and (4) keep their windows closed.

On 11 or 12 May, a kitchen which provided milk to babies under one year old when mothers' milk was not available to them was closed. The milk kitchen was reopened on 17 May with supplies of powdered milk. Measurements to determine contamination levels and exposures in Novozybkov began on 15 May. A mobile radiation laboratory from Leningrad was used. The base institution in Leningrad calculated the doses; details of these were not made available in Novozybkov.

Potassium iodide was to have been given to children on 17 May and to adults a week later but the plan was cancelled because it was not considered useful at such a late date. Mass measurements began at the end of May in the district around Novozybkov. A total of 17 000 inhabitants were counted, including 7000 children; 1000 children were found to have had significant doses, 200 of them of more than 75 rad (0.75 Gy) to the thyroid.

Food control was started quite early and was directed at milk and meat. The milk is now imported from a clean area 120 km to the northwest of Novozybkov. Controls on milk and meat are still in effect. Locally grown vegetables and fruit are checked for contamination. Recommendations are known to the population and those who want to measure the levels of contamination of their own produce may take it to a laboratory. In addition, wild game, fish, mushrooms and wild berries may be taken in for measurement. In general, the population follows instructions for the control of foodstuffs. These controls cover the supply of food to kindergartens, schools and hospitals. The limits for these institutions are lower by a factor of two than those for the general population.

— 3 May — special instructions given to the population living in the contaminated areas;
— 6–7 May — setting up of special dosimetry checks on milk production;
— 3–7 May — seven additional radioprotection laboratories began work;
— 9 May — radiological checks established on foodstuffs at market places;
— 12 May — issue of special recommendations to the population about wild berries, mushrooms and herbs;
— 19 May — preparation of recreation camps in clean areas (80% of children and 70% of pregnant women were sent to these camps for summer holidays);
— 7 August — local authorities issue a plan on decontamination measures: relocation of four more settlements, decontamination of houses or buildings in 126 settlements, drinking water source (well) improvement, anti-dust road work, decontamination of arable land and cattle breeding farms;
— 5 September — Bryansk Soviet of People's Deputies approves a common dosimetric control system: population in contaminated areas to be provided with clean milk and meat from other regions of the USSR
— Summer 1987 — all children sent on holidays in clean areas.

In 1987, a special dosimetric passport was established for each person living in areas where the contamination density exceeded 15 Ci/km^2 (555 kBq/m^2) of ^{137}Cs.

Up to December 1986, medical surveys were performed for radiation related diseases on 86 000 persons but no cases of such disease were found.

In the Bryansk region, new settlements are being constructed for the relocation of the population living in areas where the contamination exceeds 40 Ci/km^2 (1480 kBq/m^2). This population of about 7000 would be projected to receive a lifetime dose in excess of 35 rem (350 mSv). The population living in areas with contamination levels of between 15 and 40 Ci/km^2 (555 and 1480 kBq/m^2) is 112 000, or more than one-fifth of the 497 000 inhabitants of the Bryansk region. The 35 rem (350 mSv) lifetime dose will be exceeded only in seven settlements, the inhabitants of which may be relocated.

4.3. The UkrSSR

In the UkrSSR, over 93 000 people were evacuated to new residential areas. A total of 11 000 new homes, 27 new apartment blocks and more than 600 community buildings were constructed. A total length of 14 000 km of new roads has been built and old roads have been repaired. Gas has been supplied to 10 800 houses and more than 5000 apartments. Technical projects were undertaken, including the construction of 131 dams on the Pripyat and other tributaries of the River Dnepr that are intended to hold back the movement of contamination into the Kiev reservoir. In residential areas of the Kiev and Zhitomir districts, 570 artesian wells were drilled and 810 water mains and water supplies were constructed. Decontamination was carried out in 342 localities covering hundreds of square kilometres, and 460 000 hectares of agricultural land were reclaimed.

The cost of the accident to the UkrSSR has been estimated at 2.3 billion roubles from the State budget and 8 billion roubles in all. The work has gone a long way towards stabilizing the radiological situation and lowering exposure levels to the people. Nevertheless, the situation in contaminated zones remains difficult. UkrSSR officials wish to build over 2 million additional square metres of housing space, expected to cost more than 830 million roubles. They also seek regular monitoring of radiation exposure levels, stricter permissible radiation norms for locally produced food, radiation monitoring for all residential units and annual medical examinations for the entire population, as well as rigid controls over the water supply and sewage disposal systems.

In addition, a programme proposed by the Government of the UkrSSR, on the basis of advice from the Academy of Sciences of the UkrSSR and other Ukrainian and local scientific bodies, would include:

— development of models for the migration of radionuclides and forecasts of the ecological consequences of the accident;
— radiological monitoring in the zone affected by the accident and the establishment of safe conditions for the people who live in contaminated areas;
— study of the distribution of contamination and development of recommendations to ensure the safety of the people and the satisfaction of their nutritional needs in these areas;
— scientific justification for new methods to stop the spread of contamination, as well as decontamination efforts;
— study of the socioeconomic aspects of life and work in the affected areas.

These and a number of other measures will be the subject of continuing debate among UkrSSR and USSR authorities in coming years.

4.3.1. Kiev

In Kiev — the USSR's third largest city (with nearly 3 million inhabitants), the capital of the UkrSSR and the seat of the Kiev district — people quickly became aware of the accident at the Chernobyl plant 160 km to the north. Civil Defence officials were mobilized, the transport system was depleted to provide buses to transport evacuees, and radiation casualties were brought to hospitals in Kiev. The first public word to the local

Borodyanka: A Town Which Received Evacuees

The settlement of Borodyanka was a major resettlement area for evacuees from Pripyat and the 30 km prohibited zone. The population is 60 000. The most important task the town officials had was to receive and resettle the evacuees, who were accommodated in every local settlement. A total of 38 000 people, mostly from Chernobyl, had to be housed. The first of the evacuees arrived on 3 May and they continued coming until 6 May. The UkrSSR Ministry of Health sent about 30 teams of doctors to help look after the evacuees. It was summer, the weather was warm and people had enough clothes, so the sharing that was necessary was mainly of food, which was brought in from elsewhere, for example from Kiev. Cattle and sheep were also evacuated from the 30 km zone to the Borodyanka area. Nevertheless, the evacuation put a serious strain on the resources of the village.

As a result of the evacuation, in the Borodyanka region alone, 1300 new buildings were constructed for 4500 permanent evacuees. In all, 28 new shops were opened in the town and 900 new apartments were constructed in blocks. Five new schools were built, and the children of evacuees are mixed with local children. The town of Borodyanka received help from other Republics and from Kiev. The authorities were preparing a map of contamination in the region; 18 settlements had been checked thoroughly. There are areas with up to 5 Ci/km^2 (185 kBq/m^2) of contamination by ^{137}Cs. Radiation checks continue to be made on food. The main preoccupation of the evacuees has changed with time. They are now more interested in adapting to their new surroundings, although most would like to return to their homes in Chernobyl. Medical problems seem to be the main issue for the evacuated families, although they have received regular checkups since the evacuation. In September 1990, about 1000 children were checked with whole body counters and no incidence of abnormal radiation levels was detected.

A Collective Farm Displaced from Chernobyl to Near Borodyanka

One collective farm had its entire population evacuated from a town 10 km south of the Chernobyl plant and resettled near Borodyanka. The inhabitants had worked normally during the first days after the accident, at times also helping to fill bags with sand for dumping from helicopters and watching the smoke above the reactor to monitor the wind direction. The village was not evacuated until 4 May, along with other areas of the 30 km prohibited zone. During the period 29 April to 4 May, the workers were all outside planting potatoes.

The collective farm had been one of the most productive in the region before the accident. The new collective farm is engaged in the same kind of production as before. The evacuees were given 200 roubles per person on arrival near Borodyanka and the same amount again later, plus compensation for their abandoned land. The decision to recreate the collective farm was taken in September 1986 by the people themselves. This decision was made after they had worked on other farms during the first months after the evacuation.

The people evacuated would have preferred to return to Chernobyl but they accepted that this was impossible. Therefore, they chose to reconstruct the town as similarly as possible to the one they were forced to leave. The houses are arranged as in Chernobyl, so that people have the same neighbours as before. The streets have been named as before, and people have tried to reconstruct their lives as they were before the accident. Several women said that they deeply regretted leaving Chernobyl, 'our home and that of our ancestors', and would go back if they could.

Polesskoe: A Town with an Uncertain Future

Polesskoe, a town of 13 500 inhabitants, was the temporary resettlement home of a large number of evacuees. It is the centre of the Polesskoe district, which has altogether 36 000 inhabitants. The district is part agricultural (cattle, potatoes, collective farms) and part industrial (production of furniture and clothes). Ten per cent of the district is within the 30 km prohibited zone.

Though few evacuees remain in Polesskoe, the effects of the accident still preoccupy local officials. The region includes five villages within the prohibited zone that were evacuated, and five others with 'hot spots' of contamination. The town itself has a number of 'hot spots'; residents question their safety there and the possibility of evacuation confronts everyone.

Sixteen villages and towns in the region are uncertain about their future because the levels of contamination by ^{137}Cs are in excess of 15 Ci/km^2 (555 kBq/m^2). Maps of detailed measurements were first published in 1989 and are now routinely published in local newspapers. A decision of the UkrSSR Council of Ministers taken in 1989 gave families with children under the age of 17 the right to relocate with compensation. In the Polesskoe region, 2050 families would qualify. Of these, 750 families have stated that they do not wish to be evacuated. The remaining 1300 families are awaiting 'suitable' accommodation and the construction of 1000 apartments in the Kiev region to house them has been proposed by the UkrSSR authorities.

The maximum contamination observed in the region was 115 Ci/km^2 (4.255 MBq/m^2). Sites of such contamination levels have been decontaminated many times, but decontamination has proved to be difficult and readings remain high. People are still living in areas that are considered dangerous. Individual dosimeters were distributed but dose data have not been made public.

The region is well supplied with uncontaminated food. Flax and hops used for brewing beer are no longer harvested because they are contaminated. Potatoes, however, seem to be clean. Cattle that are raised in the region are taken to areas of clean pasture for several months before slaughtering. Forests have never been decontaminated. New forests have been planted on contaminated fields in order to preclude agricultural use.

When asked whether people wanted to be evacuated, officials said that it would be very difficult for them to break their ties to the past and to their home villages. Nevertheless, in a recent local poll, 96% of those answering said that they wished to move. This was despite the fact that compensation terms would be less generous than those for evacuees from Pripyat, for example.

population was a television announcement on the evening of Monday 28 April, nearly three days after the accident. As additional resources were deployed to deal with the accident (Kiev being a principal source of those resources, as well as a transit point for resources from elsewhere), rumours intensified about the possible worsening of the situation at the plant.

Although the wind initially blew contamination away from Kiev, it slowly changed direction, so that by 30 April it was blowing from the north and city Civil Defence monitors indicated that radiation levels were beginning to rise. Local officials issued guidance on how to limit exposures. Some residents took actions that went beyond the official guidance. Over a period of several weeks following the accident, many residents left the city or sent their children elsewhere. A crucial question in Kiev was whether to cancel May Day parades and other outdoor festivities on 4 May or on Victory Day (9 May). It was decided that the expected radiation levels would not justify cancelling such major events.

Later, officials and specialists published additional suggestions about actions that could lessen exposure (monitoring all milk after 4 May, checking and rinsing vegetables after 15 May, spending less time outdoors, refraining from sunbathing or swimming and keeping children out of sandboxes). Other municipal precautions included: setting up a circle of checkpoints on main roads into the city at which contamination was monitored and vehicles were washed; more frequent street washing; special handling of fallen leaves collected in 1986; and banning the open air sale of food. Official decisions confirmed the spontaneously adopted practice of sending children and pregnant women away on holidays.

The radiation situation in Kiev due to the releases of radioactive iodine in the accident was evaluated by the All-Union Scientific Centre for Radiation Medicine in Kiev. More than 1000 samples were taken from the atmosphere and various environmental media to measure iodine concentrations and individual measurements of radioiodine levels in the thyroid glands of over 3000 Kiev inhabitants were made in 1986 [24].

In May 1986, the milk consumed by the inhabitants of Kiev had a radioiodine concentration that averaged about 1100 Bq/L (taken over a period of 25 days). During this time a temporary national limit of 3700 Bq/L was introduced for iodine concentrations in milk. As a result of the various measures taken, there were virtually no instances of people in Kiev consuming milk with radioiodine concentrations greater than this national limit. Because of the fact that leafy vegetables had such heavy surface contamination, public media announcements warned the inhabitants of Kiev not to consume them.

Special precautions were taken with regard to the huge Kiev water reservoir. A temporary pipeline was laid to an alternative source of water east of Kiev and a pumping ship was brought to complete the link. In mid-1986, the reservoir was drained to let accumulated materials wash through. This, combined with the loss of the Chernobyl plant's power output, led to a serious electricity shortage that summer.

5. The Sociopolitical Setting

5.1. Establishing the Safe Living Concept

The current radiation protection situation in the USSR is complicated by the large areas contaminated and the huge control programme necessary for measuring environmental and food contamination. The situation is at a critical state also because the populations still living in contaminated areas and waiting for relocation are frightened and believe that the current living conditions are very dangerous. The criteria that form the basis for securing what in the USSR is termed 'safe living' in these areas are therefore very important.

The Supreme Soviet of the USSR has established a programme with financial compensation for a two-year period from 1990–1992 for various countermeasures, including different agricultural measures as well as relocation. Different relocation concepts have been proposed. These include *temporary dose limits* introduced during the first year, a *lifetime dose limit concept*, a *two tier lifetime dose limit concept*, a *dose rate concept* and a *surface contamination concept*.

5.1.1. Temporary Dose Limits

Following the accident, the Ministry of Health of the USSR, on the recommendation of its NCRP, introduced a previously prepared regulation (SP-AES-79) establishing a *maximum acceptable dose* of 10 rem (100 mSv) for accidental whole body irradiation of the population in the first year after the accident. The NCRP also recommended a set of additional so-called *temporary dose limits* for the years 1987–1989. These limits were approved by the Ministry of Health of the USSR and they are shown in Table 11.

5.1.2. Lifetime Dose Limit Concept

By early 1987, it became increasingly apparent that the food and behavioural restrictions were having a major impact on everyday life in the more affected areas of the BSSR, the RSFSR and the UkrSSR. USSR authorities recognized that the system of restrictions on farming in the predominantly rural, agricultural region near the Chernobyl plant was not going to be satisfactory for the long term. Accordingly, in late 1988 authorities completed a 'concept of safe living' study that would serve to define radiological conditions under which life

TABLE 11. Temporary Dose Limits for Relocation of the Population in the First Years after the Chernobyl Accident (for External Exposures as a Result of the Accident)

Year	Temporary dose limits (mSv)
First year to end 1986	100 (10 rem)
1987	30 (3 rem)
1988	25 (2.5 rem)
1989	25 (2.5 rem)
Total 26 April 1986 to 1 January 1990	180 (18 rem)

[a] The limits apply to the critical group, which is defined as children born in 1986, i.e. the limit for 1987 applies to a one year old child, the limit for 1988 to a two year old child, etc.

could proceed without continuing restriction on diet or behaviour, yet with adequate safety over the course of a lifetime. The so-called 'lifetime dose limit concept' defined a limit on the dose received over 70 years from the time of the accident.

The USSR NCRP recommended a projected lifetime dose limit of 35 rem (350 mSv) as the intervention level for relocation for the period starting on 1 January 1990. The lifetime dose commitment of 350 mSv was said to be based on three factors which included external and internal doses:

(1) Dose related dependence on radiobiology, allowing 5 mSv per year for 70 years, which is the average life expectancy in the USSR;
(2) The requirement that doses from the first year to the 70th should have no health consequences;
(3) The requirement that the dose to any individual shall not exceed 350 mSv over his or her lifetime.

All information on the causal relation between radiation doses and possible health effects were analysed. For all the populations analysed, there appeared to be no deterministic health effects at a whole body dose of 1 Sv incurred at high dose rates. At low dose rates, this minimum dose could be increased by a factor of 2-200. However, children are more sensitive to radiation with regard to possible effects later in life, by a factor of about 2, which reduced the minimum dose to 1 Sv. To account for inhomogeneous dose distributions, a reduction by a further factor of 3 was introduced, leading to the conservative value of 350 mSv.

On the recommendation of the NCRP the 350 mSv concept was approved by the Council of Ministers of the USSR in September 1988. Scientists from the BSSR, however, disagreed with the concept. Nevertheless, the value was also approved by the Governmental Commission set up to deal with the consequences of the accident at Chernobyl, and it was to have been introduced at the beginning of 1990. By the beginning of 1989, the lifetime dose limit of 350 mSv for people living in contaminated areas was being debated by politicians, public figures and others. The issue became very controversial and political. Partly as a result of the political controversy, the public became critical of this approach.

Among the consequences of the controversy has been greater uncertainty among the population and lowered credibility of the scientists.

In April 1989, the BSSR Academy of Sciences sent information to the BSSR Council of Ministers and the Central Committee of the Communist Party of the BSSR on the main results of the work connected with eliminating the consequences of the Chernobyl accident. In the letter they expressed their concerns on the difficulties in the application of the 350 mSv lifetime dose limit: up until now, a dose limit for continuous external and internal exposure in the population has never been implemented in the domain of low doses. In addition, it was thought that the concept should offer measures for preventing the possibility of exceeding the dose limit and a system for monitoring the dose received. It was also proposed that a contamination density of between 10–15 Ci/km^2 (370–555 kBq/m^2) of ^{137}Cs should be considered as a maximum level so that the 350 mSv dose limit would permit living without restriction. This resulted in propositions to relocate the population living in areas with density of contamination over 15 Ci/km^2 (555 kBq/m^2) of ^{137}Cs and to focus on improving conditions of living (agricultural, social organizations, etc.) in areas of density of contamination lower than 15 Ci/km^2 (555 kBq/m^2) of ^{137}Cs.

The USSR requested international assistance in setting criteria. Representatives of the International Commission on Radiological Protection (ICRP), the World Health Organization (WHO) and the League of Red Cross and Red Crescent Societies visited the region and commented that the lifetime dose limit was perhaps not an appropriate criterion, and that a 350 mSv limit was probably low by the standards of other countries (see Part A). In their judgement, therefore, the Government of the USSR, faced with a difficult decision, probably erred on the side of caution owing to the complicated political situation.

In response to the letter in April 1989, the BSSR Academy of Sciences was sent the report of 28 November from the USSR which had approved the 350 mSv concept. The BSSR Academy of Sciences said that it did not have a counterproposal since it did not have independent data and did not have access to the USSR data. But the position of the Academy of Sciences was that it disagreed with the 350 mSv concept.

In October 1989, the Supreme Soviet of the BSSR first adopted the State programme on the elimination in the BSSR of the consequences of the Chernobyl accident during 1990–1995. The programme includes the following:

(1) People in areas with contamination levels of above 40 Ci/km^2 (1480 kBq/m^2) would be resettled as well as families with children up to 14 years old and pregnant women living in land where the density of the contamination was between 15 and 40 Ci/km^2 (555 and 1480 kBq/m^2);
(2) People in areas with contamination levels of between 15 and 40 Ci/km^2 (555 and 1480 kBq/m^2) would be subject to voluntary resettlement;
(3) People in areas with contamination levels of between 5 and 15 Ci/km^2 (185 and 555 kBq/m^2) may be susceptible to high doses from other pathways such as the food-chain, depending on uptake values.

The Supreme Soviet of the BSSR then decided that all those in areas with contamination levels of above 15 Ci/km^2 (555 kBq/m^2) should be resettled if they wished. On 18 October 1989, the BSSR Academy of

Sciences made its own proposal for a safe living concept and sent it to the Ministry of Health of the USSR for comment. It states that:

(1) No level of dose can be considered absolutely safe;
(2) A correct assessment of expected risks requires carrying out a further investigation on effects of chronic low doses (from 0 to 1000 mSv over lifetime) on human and animal organisms;
(3) A 350 mSv lifetime dose is recommended as an absolute maximum never to be exceeded;
(4) For people living in contaminated areas but receiving less than 350 mSv, optimization needs to be carried out with cost-benefit analyses taking into consideration an increased standard of life and improved medical care; if life cannot be pursued in these areas without restrictions, the population would be resettled;
(5) Information on the consequences of living in contaminated areas and the measures planned must be made available to allow people to decide for themselves on their own future.

In late 1989, certain members of the BSSR Academy of Sciences proposed a lifetime limit of 70 mSv (based on a dose of 1 mSv per year for 70 years). They claimed that this would be more in line with ICRP and IAEA recommendations. The BSSR Academy itself did not give a value except to state that those living in areas with contamination levels exceeding 15 Ci/km^2 (555 kBq/m^2) should be resettled. They also preferred contamination levels to lifetime dose as a criterion for resettlement. In July 1990, the BSSR Supreme Soviet passed a resolution:

- The Republic is declared a zone of national ecological disaster;
- In 1991, it is necessary to finalize the resettlement of people living in areas contaminated above 15 Ci/km^2 (555 kBq/m^2) and more and to forbid industrial and housing constructions in these areas;
- It is necessary to stop the production of farm products with levels of contamination over the permissible values, irrespective of contamination density in agricultural land;
- A system of privileges and compensation must be established for the people living in areas contaminated over 1 Ci/km^2 (37 kBq/m^2).

USSR scientists do not agree, and claim that the BSSR has taken away the people's choices. This compulsory resettlement is to start in 1991, but may be reconsidered before then.

5.1.3. Two Tier Lifetime Dose Limit Concept

In April 1990, the USSR Supreme Soviet decided *not* to approve the 350 mSv limit of the USSR NCRP, but adopted a programme of emergency measures for 1990–1992 *independent* of the 350 mSv concept. The Ministry of Health of the USSR has not given up the 350 mSv concept, however. The 350 mSv lifetime dose concept was, in its original form, an action/non-action level, i.e. above this level action should be taken in the form of relocation and below this level no action need be taken. As a result of the criticism expressed, the concept was expanded and emerged as a two tier system. This modified version included a lower level of lifetime dose (70 mSv) below which no action should be taken. Between the lower and the upper levels (still 350 mSv), different measures would be introduced. And above the upper level, relocation remained compulsory.

5.1.4. Dose Rate Concept

Currently, a commission with some 60 members under the chairmanship of Academician S.T. Belayev has been established by the USSR Council of Ministers to review the existing criteria and to consider the development of a new approach and rationale instead of the NCRP lifetime dose concept. The commission is considering a dose rate criterion for the introduction of countermeasures which — as a concept — will only include future doses, and not doses from the past. The dose rate concept will also be a two tier system. The commission is also expected to elaborate on the concepts of risk and acceptable risk.

5.1.5. Surface Contamination Concept

In April 1990 the Supreme Soviet of the USSR introduced a surface contamination concept as a criterion for both relocation and payment of compensation. In this programme, relocation is compulsory for people living in areas with a surface contamination level of caesium above 40 Ci/km^2 (1480 kBq/m^2). People who live in areas with contamination levels in the range of 15–40 Ci/km^2 (555–1480 kBq/m^2) are paid a compensation rate of 30 roubles per month, and relocation is optional. Compensation of 15 roubles per month is paid to people living in areas with contamination levels in the range of 1 to 15 Ci/km^2 (37 to 555 kBq/m^2), but relocation is not an option. Similarly, strict control zones are defined as areas with a surface contamination level of ^{137}Cs above 15 Ci/km^2 (555 kBq/m^2) and controlled zones as areas with a surface contamination level of between 5 and 15 Ci/km^2 (185 and 555 kBq/m^2).

5.2. Political Controversy

The present controversy in the USSR about the consequences of the Chernobyl accident arose against the background of contemporary political developments, and it surely had a catalytic effect on these developments. Until mid-1985, when M. Gorbachev assumed the leadership of the USSR and the twin policies of glasnost (openness) and perestroika (restructuring) were introduced, authority was strongly centralized in Moscow and the dissemination of information was tightly controlled.

The magnitude of the accident and its consequences, not only in the USSR but also around the world, put the USSR in an unprecedented situation. In response to international enquiries, USSR authorities initially issued only terse, limited statements. They then invited IAEA representatives as witnesses. In August 1986, at an IAEA organized review meeting in Vienna, USSR representatives gave an exceptionally comprehensive report [1] on the causes and consequences of the accident. In September 1986, the IAEA's International Nuclear Safety Advisory Group (INSAG) issued a report that was as authoritative a summary of the accident as could then be presented [2]. At that time the official outlook was quite optimistic, taking the view that life could return to normal in the area.

In retrospect, however, it is apparent that the seeds of the current controversy were even then being sown. Since the decontamination of large areas had never before been undertaken, it became a learning process. Efforts to return evacuees to their homes were not as successful as had been expected. Moreover, more contaminated areas were identified, from which further evacuations and relocations became necessary. The disruption of people's lives was great and the stressful conditions were giving rise to an unhealthy living environment.

The first maps of various isotope contaminations were produced and were widely used by the authorities and organizations in charge of protective measures at the All-Union level and in the three Republics concerned as early as July 1986, but they were not made publicly available. In the following years, extensive surveys provided the basis for updating these maps under the USSR State Committee on Hydrometeorology. During the same period, some information was released to the public about the contamination resulting from the accident, but official maps showing the distribution and extent of the contamination were made publicly available only in March 1989.

This was linked to the lack of prior knowledge about radiation and its health effects on the part of the majority of the population. The evolution of policy on intervention levels could not be understood by the general public, and this helped to create distrust towards scientists and the decisions being taken at the All-Union level. The trend toward greater political independence of the USSR's Republics from the central government in Moscow helped to raise the Chernobyl accident to the status of a central symbol of the growing movement to promote political restructuring under perestroika. The USSR Government's handling of the Chernobyl accident was, for example, an important issue in the 1988 elections to the Congress of People's Deputies [25].

With greater liberalization, there was more freedom to speak out on issues, and Chernobyl was one. Articles and books about events at Chernobyl appeared with increasing frequency. Reports of widespread health effects had a particularly strong impact on the public, since public knowledge about nuclear energy and radiation effects was largely limited to Civil Defence measures in the event of nuclear war. When the new safe living concept was announced in early 1989, it immediately became the target of criticism in the BSSR, the RSFSR and the UkrSSR, and many, including scientists, disagreed with important elements of the concept. Such arguments have certainly maintained public uncertainty and generated stress.

The implications of the social disarray were staggering. The USSR's economy continued to deteriorate, and it is not expected to improve in the short term. Over a million people, including victims of the accident and those trying to aid them, have had their lives and livelihoods disrupted by the accident. As a result of this disruption, the USSR's social system, its political and legal institutions and its public health facilities have all been put under intense strain. This type of social infrastructural problem greatly complicates matters for government officials. Publicity and public concern seemed to peak on the occasion of the fourth anniversary of the Chernobyl accident, in April 1990. The availability of new facts and figures in the BSSR and the UkrSSR contributed to this. On 25 April 1990 there was a USSR Supreme Soviet press conference with a lengthy discussion on Chernobyl. The first Soviet 'telethon' (television marathon) was broadcast live from Moscow, with performances and interviews interspersed with films of rescue workers at Chernobyl and children from the contaminated zones.

The USSR press reported protests by residents of some of the most contaminated areas, demanding better medical treatment, protection from radiation and punishment for those implicated in the alleged cover-up of the consequences of the accident.

Most of the programme in the future will consist of medical assistance. The central government plans to build four million square metres of housing space, schools for 35 700 students, clinics to accommodate 7300 patients and hospital space totalling 2860 beds — all costing about 6.5 billion roubles. Public opinion in the USSR, encouraged by the success of the reform movements in eastern Europe, has become increasingly critical of the USSR's nuclear power programme. The Deputy Director of the I.V. Kurchatov Institute of Atomic Energy in Moscow has written:

> "Public opinion has become a new factor in this country, essentially affecting energy policy. An in-

centive to wide public opposition to nuclear power was, of course, the Chernobyl accident. However, special attention paid to ecological problems as a constituent of the democratization of Soviet society has led to the extension of public protest to a wide spectrum of energy facilities, such as nuclear power plants and nuclear fuel cycle enterprises, hydroelectric plants, gas production and coal mining complexes, plants for fossil fuel processing, etc. Nevertheless, the 'synergetic' effect of the Chernobyl accident and the general ecological problems of society have made nuclear power the most 'suffering' branch of the fuel energy complex. There is practically not a single new nuclear power plant site where the local population would not protest against construction. ..."

"Having no experience of the formation of an unbiased public opinion, the Soviet specialists, who are convinced of the lack of any alternatives to nuclear power and at the same time approve strict public control over potentially dangerous modern technologies, proved to be in a rather difficult situation." (See Ref. [25].)

5.3. USSR Request for Assistance from the IAEA

In this atmosphere, the Government of the USSR requested international assistance. It decided in 1989 to invite experts from other countries and international organizations to investigate the situation and to make recommendations. The WHO sent a team of officials in 1989, as did the International Red Cross in early 1990 (see Part A). At the end of 1989, the Government of the USSR requested the IAEA to co-ordinate the organization and implementation of a project to carry out an international assessment of "the concept which the USSR has evolved to enable the population to live safely in areas affected by radioactive contamination following the Chernobyl accident, and an evaluation of the effectiveness of the steps taken in these areas to safeguard the health of the population".

In response to a Soviet request, a planning meeting between officials of the USSR, the BSSR, the UkrSSR and the IAEA was held in Moscow from 7 to 9 February 1990 to outline a plan of action to carry out such an assessment. From 25–30 March 1990, an international preparatory team, composed of experts from Austria, Japan, the USA, the Commission of the European Communities (CEC), WHO, FAO and the IAEA, visited the affected areas and drafted a work plan for the project based upon the information collected.

The visit gave the IAEA led team an opportunity to observe the situation in the affected areas, to listen to the concerns of the population, and to begin to investigate the type and amount of data that have been collected over the last four years. It became apparent to the participants that a vast amount of information had been collected. However, it was not all in one place and it was contradictory and frequently ad hoc. Questions asked of the IAEA experts revealed the high levels of public anxiety about the health of children. People asked for the experts' views on the appropriateness of the 350 mSv lifetime dose limitation, about the independence of the assessment team and about the public availability of the results of the assessment. (See Annex II, Questions Put to Experts.)

One early result of the visits was that personal dosimeters were provided for several thousand citizens in seven settlements. In addition, portable whole body counters were used to carry out selected monitoring of intakes of ^{137}Cs to help determine actual levels of internal doses. Fixed air samplers were used to measure atmospheric concentrations of resuspended radioactive particles. Seminars were organized to provide opportunities for asking questions, and it is hoped that meetings with health professionals lead to improvements in local expertise in handling questions from patients. Information booklets on thyroid diseases were publicly distributed.

Part C

References

[1] USSR STATE COMMITTEE ON THE UTILIZATION OF ATOMIC ENERGY, The Accident at the Chernobyl Nuclear Power Plant and Its Consequences, Parts I and II (information compiled for the IAEA Experts Meeting, Vienna, 25-29 Aug. 1986) (1986).

[2] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident, Safety Series No. 75-INSAG-1, IAEA, Vienna (1986).

[3] MEDVEDEV, G., The Truth about Chernobyl, Basic Books, New York (1991).

[4] SHCHERBAK, I., Chernobyl: A Documentary Story, Macmillan, London and New York (1989).

[5] MEDVEDEV, Zh., The Legacy of Chernobyl, Norton, New York and London (1990).

[6] MEDVEDEV, Yu., "Power without responsibility" (interview with A. Kovalenko), Science and Technology, Arguments and Facts **4** (1990) 15-16.

[7] C'est mon devoir de raconter tout ce qui s'est passé, Legasov's memoirs, Pravda, No. 141 (25493) (May 20 1988) 3 (French translation).

[8] IVANOV, B., Chernobyl, Parts 1-4, Grazhdanskaya Oborona (Civil Defence), Moscow (1988) (in Russian).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Medical Aspects of the Chernobyl Accident, IAEA-TECDOC-516, Vienna (1989).

[10] UNITED NATIONS, Sources, Effects and Risks of Ionizing Radiation (Report to the General Assembly), Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), UN, New York (1988).

[11] MOULD, R., Chernobyl: The Real Story, Pergamon Press, Oxford and New York (1988).

[12] ASMOLOV, V.G., et al., "The accident at the Chernobyl nuclear power plant: one year after", Nuclear Power Performance and Safety (Proc. Conf. Vienna, 1987), Vol. 3, IAEA, Vienna (1988) 103.

[13] IL'IN, L.A., et al., "Health problems in the USSR following the Chernobyl accident: Need for international collaboration", paper presented at WHO Scientific Advisory Committee Meeting on the International Programme on the Health Effects of the Chernobyl Accident, Hiroshima, October 1990.

[14] MARPLES, D., RISOVANNY, Y., Revelations of a Chernobyl insider, Bull. At. Sci. **46** (1990) 10.

[15] IZRAEL, Yu.A., et al., Modelling of the Transport and Fallout of Radionuclides from the Accident at the Chernobyl Nuclear Power Plant, USSR State Committee on Hydrometeorology, Moscow (1989).

[16] IL'IN, L.A., et al., Radiocontamination patterns and possible health consequences of the accident at the Chernobyl nuclear power plant, Radiol. Prot. Bull. **10** (1990) 3-29.

[17] APSIMON, H., et al., Analysis of the dispersal and disposition of radionuclides from Chernobyl across Europe, Proc. R. Soc. London **425** 1869 (1989) 245-483.

[18] COMMISSARIAT A L'ENERGIE ATOMIQUE, L'Accident de Tchernobyl, Rep. IPSN 2/86 Rev. 3, CEA, Paris (1986).

[19] PERSSON, C., et al., The Chernobyl accident — A meteorological analysis of how radionuclides reached and were deposited in Sweden, Ambio **16** (1987) 1.

[20] KIRCHMANN, R., Agricultural Countermeasures Taken in the Chernobyl Region and Evaluation of the Results, International Union of Radioecologists (1990).

[21] STATE AGRO-INDUSTRIAL COMMITTEE OF THE USSR, Guides on Agricultural Works under Conditions of Radioactive Contamination of Part of the Territories of the Russian SFSR, the Ukrainian SSR and the Byelorussian SSR for the Period 1988 to 1990, Moscow (1990).

[22] IVANOV, S.I., Personal communication, 1991.

[23] DUSHUTIN, K.K., "The results of medical research in the 30 km zone of the Chernobyl nuclear power plant", paper presented at Luxembourg Conference, 1990.

[24] LIKHTAREV, I.A., et al., "Radioactive iodine concentrations in elements of the environment and evaluation of exposure doses to the thyroid among inhabitants of Kiev after the Chernobyl accident", Environmental Contamination Following a Major Nuclear Accident (Proc. Symp. Vienna, 1989), Vol. 2, IAEA, Vienna (1990) 351.

[25] PONOMAREV-STEPNOY, N.N., GAGARINSKII, A. Yu., "Nuclear power in the USSR: status, prospects, public opinion", paper presented at the 7th Pacific Basin Nuclear Conf., San Diego, March 1990.

Part D
Environmental Contamination

Contents

1. Introduction

The basis for the assessment of the dose to the population from a release of radioactivity to the environment, the estimation of the potential clinical health effects due to the dose received and, ultimately, the implementation of countermeasures to protect the population is the measurement of radioactive contamination in the environment after the release.

Since the occurrence of the accident at the Chernobyl nuclear power plant on 26 April 1986, several scientific institutions and regulatory agencies in the USSR have been engaged in detailed field assessments and ecological modelling of the different radiological components in the environment. This assessment concentrates on the corroboration of the measurements of the following major radionuclides present in the environment: ^{134}Cs, ^{137}Cs, ^{90}Sr and Pu, as well as 'hot' particles. Official Soviet information on the environmental contamination was requested during the international expert missions to the All-Union institutes responsible for the co-ordination of environmental data in the USSR. During visits to the major institutes that have participated in the large amount of work that was done in the BSSR, the RSFSR, the UkrSSR and the USSR, both official and unofficial data were requested.

In the USSR, the most common method of representing environmental contamination data was in the form of maps. Thus, an important aspect of this task was to corroborate the information shown on the contamination maps.

1.1. Objectives

The objective of this task is the corroboration of official and unofficial environmental contamination data for radionuclides in the soil, water and air in the regions of the BSSR, the RSFSR, the UkrSSR and the USSR that have been affected by the Chernobyl accident. In particular, the information presented on the contamination maps must be corroborated. The approach to accomplishing this task was agreed upon and outlined during the meetings of the International Advisory Committee (IAC) in Moscow, Kiev and Minsk in April 1990.

1.2. Methodology

In view of the large areas affected by the fallout, and the size of the population in those areas, it was decided that, within the constraints of time and the resources available, it would not be feasible to duplicate the detailed studies carried out by the Soviet authorities since 1986. Rather, a method was approved which is based on the hypothesis that, provided that essential environmental components of the official Soviet radiological assessment could be corroborated, it would be reasonable to extrapolate from the corroborated set of data to the overall environmental situation. This method consists of: (a) a review of the environmental data and the methods used for the assessment of environmental contamination in the USSR, and (b) the independent verification of Soviet environmental data and contamination maps by field measurements taken at selected sites.

International teams of experts visiting institutions and laboratories reviewed: (1) the sampling techniques used in the field and in the laboratory; (2) the instrumentation and analytical methods used to determine the radionuclide content in the samples; and (3) the quality assurance programmes applied by Soviet authorities in the laboratories carrying out the analysis. In addition, an intercomparison exercise was conducted by the Agency's Laboratories (RIAL) (specifically the Physics, Chemistry and Instrumentation (PCI) Laboratory) at Seibersdorf.

The independent verification of Soviet environmental data and contamination maps was conducted by international independent teams of experts surveying selected radiological and environmental components at specific sites in the BSSR, the RSFSR and the UkrSSR.

Official and unofficial data on the environmental contamination were requested for the following geographical areas: (1) the BSSR; (2) the northern part of the UkrSSR; and (3) the central economic region of the RSFSR. Although the existence of unofficial data was referred to by Soviet participants at several of the meetings in the initial phases, no such data were provided to the experts.

Teams of international experts were sent on missions to the BSSR, the RSFSR, the UkrSSR and the USSR to obtain environmental samples. The data from the analysis of these samples would be used in accomplishing the objective of corroboration. In some cases, it was not possible to collect information consistently at each location visited, while in other cases, the team members were able to collect more data than was needed to fulfil the objective of this task. The results of each mission were used to achieve the objective and will be presented in this report. The independently collected data that are not used directly in the corroboration of the Soviet data are also included in this section to provide additional information on the extent of environmental contamination in the USSR.

Part D

2. Review of the Soviet Data and Methods for the Assessment of Environmental Contamination

The official Soviet data were provided to the IAC by the USSR State Committee on Hydrometeorology (Goskomgidromet) in the form of: (a) contamination maps for ^{137}Cs, ^{90}Sr and Pu, and (b) listings of the mean contamination values by settlement for the BSSR, the RSFSR and the UkrSSR (Annex 1 to Part D). Table 1 presents a summary of the official data on surface activity for selected settlements.

The first steps towards corroborating the environmental data were: (1) to review the established system of databases; (2) assess the reliability of the data included in the databases by reviewing the sampling techniques, analytical procedures and instrumentation used; and (3) conduct an intercomparison exercise involving the laboratories providing the bulk of the environmental contamination data in the BSSR, the RSFSR, the UkrSSR and the USSR. To corroborate the contamination maps, it was essential to review the assumptions and procedures used to draw the maps from the contamination data. This work was carried out at the All-Union level at the Institute of Experimental Hydrometeorology, Obninsk, RSFSR.

2.1. Databases

In the areas most affected by the fallout, the USSR State Committee on Hydrometeorology, the Ministry of Defence of the USSR, the State Agroindustrial Complex (Agroprom) and the Ministry of Public Health of the USSR have collected a large amount of data. This information has been compiled in the archives of related institutes or stored in designated databases. Over the past few years, data have been partially published by some Soviet institutions in the form of scientific–technical reports and maps describing environmental contamination levels in the BSSR, the RSFSR and the UkrSSR [1–4].

In the USSR, the collection of radiological data for the monitoring of radionuclide levels in the environment and food related to the Chernobyl accident is organized at the All-Union, Republic and regional institute levels. For example, the Ministry of Public Health of the USSR, the USSR State Committee on Hydrometeorology, the State Committee for Standardization and the State Committee for the Peaceful Uses of Nuclear Energy have counterparts in the Republics. This is also the case for the All-Union Scientific Research Institute of Agricultural Radiology (Obninsk) and the Institute of Radiation Hygiene of the Academy of Medical Sciences of the USSR (Leningrad). At the regional level, the institutes involved are research, agricultural and veterinary laboratories and State Sanitation Supervision Epidemiology stations.

In theory, data flow from the regional institutes through the Republic institutes to the All-Union institutes. While in practice this does indeed occur in most cases, some institutes collect data that are not transferred. Consequently, some data were not used by the Soviet authorities in preparing the official contamination maps.

At the level of the Republics, these data are collected daily from various field laboratories, experimental farms and similar sources. This information is transmitted to the central database in Moscow and updated regularly by the USSR State Committee on Hydrometeorology. In addition, each Republic organizes its own database using information from various institutions.

There is a steady flow of information among the institutes and between the Republic databases. However, a limited exchange of databases takes place between the USSR State Committee on Hydrometeorology and the institutes in each Republic. This results in important data which are obtained at the All-Union level (for example, on biannual airborne radiometric measurements in the contaminated areas in each Republic) not necessarily being transmitted to databases at the Republic level.

The scheme of the database at the UkrSSR level, the Integral Radioecological Databank (IRDB) at the Glushkov Institute of Cybernetics, Kiev, is illustrated in Fig. 1 [5]. This is the central database for Chernobyl related data in the UkrSSR. The database 'administrator' is reserved for the list of users, codes and priorities. Database sources, classification and standards are designed for the users of the IRDB.

Information on doses and mapping of various physical and chemical data files of the geographical region of interest, together with meteorological, geochemical and geological data, can be stored and retrieved. At present, IRDB contains about 50 000 records. No information is available on error estimates associated with these data. It is unclear what quality assurance procedures are used (by the laboratories and the compilers of the database) in the inputting of data into the database. Limited information has been provided on past intercomparison exercises carried out in the USSR [6].

2.2. Sampling Techniques and Food Control Monitoring

Taking 'representative samples' of the soil, water, air vegetation and food is one of the key elements in a proper assessment of the environmental contamination

TABLE 1. Characteristic Statistical Parameters for Official Soviet Data on Surface Activity in Different Settlements [*Source: V. Borzilov*]

Location	No. of measurements	Mean	Median	Mode	Geometric mean	Variance	Standard deviation	Standard error	Min.	Max.
					(a) ^{137}Cs surface activity (Ci/km^2)[a]					
Malozhin	21	1.43	1.2	1.2	1.1	0.87	0.93	0.21	0.03	3.85
Gden	22	3.04	3	3	2.71	1.89	1.37	0.29	0.88	6
Bragin	51	21.81	11.9	11.9	12.57	399.20	19.97	2.79	0.13	67
Mikulichi	18	21.76	17.25	17	18.64	161.60	12.71	3.00	5	45
Dvor-Savichi	25	5.04	4.9	4.9	4.76	2.67	1.54	0.33	1.8	8.5
Komarin	101	4.21	3.2	2	3.24	17.49	4.18	0.42	0.14	37
Starye Bobovichi	34	29.67	25.15	25	27.91	117.43	10.82	1.82	11.9	56.2
Novye Bobovichi	79	28.27	26.70	25.8	27.07	59.10	7.69	0.86	3.64	56.84
Gatka	9	23.42	22.2	27.6	23.12	15.22	3.90	1.30	18.05	27.6
Svyatsk	25	39.15	38.1	16	32.25	424.35	20.60	4.12	6	71.1
Novozybkov	133	18.25	17.34	24	16.67	58.73	7.66	0.66	4.81	44.24
Daleta	3	2.33	2.2	2.2	2.32	0.10	0.32	0.18	2.1	2.7
Rakitnoe	9	5.17	4	3.6	4.87	4.00	2.00	0.67	3.5	3.5
Korchevka	7	2.47	2.5	2.5	2.25	0.99	0.99	0.38	0.87	3.8
Slovechno	3	1.13	1.3	1.3	0.79	0.74	0.86	0.50	0.2	1.9
Ovruch	103	3.2	2.6	1.8	2.4	6.2	2.5	0.2	0.2	15
Polesskoe	509	33.8	33	41	25.2	424.3	20.6	0.9	0.3	112.3
					(b) ^{90}Sr surface activity (Ci/km^2)[a]					
Novye Bobovichi	2	0.68							0.50	0.86
Novozybkov	13	0.32							0.10	0.65
Svyatsk	3	0.55							0.30	0.70
Starye Bobovichi	2	0.71							0.55	0.86
Gden	27	1.40							0.20	5.80
Malozhin	19	0.47							0.09	1.51
Mikulichi	7	1.03							0.56	2.21
Bragin	44	1.99							0.16	5.80
Komarin	29	1.00							0.10	2.04
Ovruch	3	0.78							0.12	1.92
Savichi	21	1.32							0.44	3.80
Ovruch	3	0.78							0.12	1.92
Polesskoe	51	1.41							0.09	4.40

[a] 1 Ci = 37 GBq.

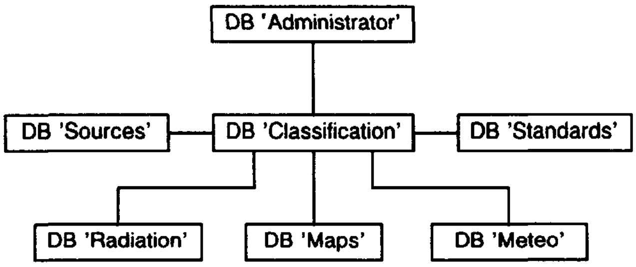


FIG. 1. Scheme of the integral radioecological databank (IRDB), Glushkov Institute of Cybernetics, Kiev, for data on the Chernobyl accident (DB: database).
[Source: N. Limic]

for a given area. Even the subsequent use of sophisticated analytical methods cannot compensate for inadequate sampling techniques. In the case of the fallout due to the Chernobyl accident, the environmental situation is complicated by the extremely heterogeneous nuclide deposition in the affected areas. Therefore, specific techniques were developed in the USSR [7, 8] for the sampling of:

- Soil in undisturbed areas (populated areas and the natural landscape), agricultural and non-arable areas;
- Vegetation, milk and meat;
- Surface water and groundwater;
- Air.

A brief description and review of each of the techniques used in the affected areas are presented in the following.

Sampling of Soil in Undisturbed Areas

- Multiple gamma dose rate measurements are used to screen for the occurrence of a 'hot spot' in the area to be sampled. If the results are positive, the area is considered as being unsuitable for sampling and a new area is chosen.
- If the results of these measurements are negative, multiple gamma dose rate measurements are taken in order to identify suitable soil sampling sites.
- When a suitable site is chosen, one to six soil samples are taken in the area of interest to obtain a representative sample of the area.

More details on the methods for sampling undisturbed areas are given in Annex 1.

Sampling of Agricultural Soils (Arable Areas)

- Mixed soil samples are taken during the sowing or planting season and prior to the harvesting of individual crops.
- Additional samples are taken at 'elementary plots' (undefined term), which are areas where only one kind of crop is grown.

Details are given in Annex 1.

Data obtained from the soil sampling programmes mentioned can be used to describe the occurrence of fallout deposition on a large scale, e.g. the official fallout maps (scale 1:500 000). Reported hot spot areas[1] are surveyed and the perimeters are marked. Recommendations for remedial action are also made to the local authorities. Provided that this procedure is followed in practice, these hot spot areas do not influence significantly the average exposure in the area under consideration. Therefore the method can also be considered to be suitable for a comprehensive description of the average exposure situation on a smaller scale, although the hot spot areas are excluded. Hot spot areas are neither listed in Soviet tables of deposition, nor are they considered in the calculation of averages of deposition.

Sampling of Vegetation

This is carried out jointly with soil sampling, using the envelope technique in order to obtain a mixed representative sample. The technique is adequate. Details are given in Annex 1.

Milk

Milk from the public sector is screened for caesium at dairies or collective farms prior to processing. For this purpose, a stick type sodium iodide detector, connected to a calibrated rate meter, is inserted into the tanks of milk delivery trucks. Subsequently, fresh milk samples are taken for spectrometric analysis in the laboratory. If the associated screening error is under 50%, as was reported to the experts (calibration data were not provided), this system of screening, combined with subsequent laboratory analysis of fresh samples, is able to provide a representative value of the contamination in milk in the tank.

This screening procedure is only adequate if the lower limit of detection of the detector ($\sim$37 Bq/L) is lower than the approved limit for the consumption of milk. This method is inadequate in the BSSR, where the detection limit is greater than the approved limit for consumption. Details are given in Annex 1.

[1] Defined as an area $\leq 30\ m^2$ with a gamma dose rate higher by a factor of 3 or more than the average given for this settlement in Ref. [6].

Meat

Meat is monitored at four locations between the farm and consumption by the population:

- In vivo measurements are taken at the State farms on animals selected for slaughter;
- Random samples of processed meat are taken at the meat processing plants;
- At the assembly line each piece of meat is monitored;
- Random samples are taken by the State Sanitation Supervision Epidemiology Station in the shops.

Further details are given in Annex 1. These multiple steps of screening, sampling and analysis represent a comprehensive system of radionuclide control in meat.

Surface and Ground Water Samples

These are collected, prepared and analysed for ^{90}Sr and ^{137}Cs according to the instructions updated by the USSR State Committe on Hydrometeorology in March 1989 [8]. The contamination of rivers and reservoirs is monitored regularly and comprehensively in the affected areas and along the course of the River Dnepr. For this purpose, a well equipped research ship is available with facilities for the sampling of water and sediments. In addition, groundwater sampling programmes are being initiated. However, procedural deficiencies were noted with regard to sample preparation and analysis, causing potential overestimation of the actual nuclide concentration in the dissolved phase.

Air Samples

Samples were reported to have been collected, prepared and analysed in accordance with recommendations made by the USSR State Committee on Hydrometeorology in March 1989 [8].

2.3. Equipment and Methods

Documented methods for the analysis of the radionuclides in the Chernobyl fallout recommended in the USSR were presented to the international experts [8–13]. The institutions, selected by the organizers in the USSR, were visited by the experts and are described in Annex 2. They range from small laboratories to research centres. Within the context of this Project, it is important to recognize the significance of the contribution of each of the following institutes to the official Soviet databases that were used to characterize the extent of the environmental contamination.

In this section, the analytical capabilities of the different radiological components at the major institutions visited are discussed. In accordance with standard scientific practice, the results of the visits are presented in coded form only.

2.3.1. Institute A, RSFSR

Significance: Approximately 50 000 samples by gamma spectrometry, 5000 samples for ^{90}Sr, and 500 samples for plutonium have been analysed since 1986.

2.3.1.1. Laboratory for Soil Analysis and Air Sampling

Geiger–Müller (GM) based dose rate meters are used for the mapping of radiation fields. Intercomparisons with NaI(Tl) (thallium doped) detector meters indicate a dose rate higher by a factor of 2 than in measurements made with GM meters. Gamma spectrometry and beta spectrometry are used for $^{137}Cs/^{134}Cs$ analysis and ^{90}Sr analysis.

All equipment is well maintained and the standards are suitable for the counting geometry. Calibration procedures are well documented. Sample identification is readily available and well organized.

2.3.1.2. Radiochemical Analysis Section and Counting Laboratory

The radiochemical separation procedures used for ^{90}Sr and Pu determinations are acceptable. However, the method of sample dissolution may be inadequate, since the acid leaching method applied does not ensure complete dissolution of refractory oxides (e.g. Pu, Zr, Nb and Th). This could result in undefined low recovery for Pu and Sr. However, the method was reportedly tested by the Soviet laboratories and recovery rates were found to be $\geq 90\%$.

Sample management and the control of contamination within the building and between laboratories are inadequate. Since sample management (handling, storage) is poor, intersample variability is significant and sample blanks are not used routinely, the potential for cross-contamination between samples is possible, but not quantifiable at present.

2.3.1.3. Water Laboratory

Collection and preparation of the samples, as well as analytical methods for determining the concentrations of the radionuclides ^{137}Cs and ^{90}Sr, are carried out according to official recommendations [8]. The laboratory is well equipped with alpha, beta and gamma spectrometers and liquid scintillation counters. Groundwater sampling methods and sample processing need to be reviewed in order to ensure that cross-contamination is avoided. Further details are given in Annex 3.

2.3.2. Institute B, RSFSR

Significance: Provision of radiation maps for individual State and collective farms and agricultural areas, radioecological studies and the development of recommendations for agriculture in contaminated areas.

2.3.2.1. Radiometry Laboratory

Caesium, Pu and ^{90}Sr are measured in agricultural products, samples of soil and plants with:

- Gamma spectrometry systems (NaI(Tl), high purity Ge (HPGe));
- Alpha/beta spectrometers.

Calibration and determination of the efficiency of the NaI(Tl) system are not optimal, since Cs standards with density 1 are used. No records on absorption correction are available.

With regard to the HPGe system, no correction for summing effects is carried out for the efficiency calibration with the ^{152}Eu standard used. Routine quality assurance data are not available. The alpha spectrometer is used predominantly for gross alpha counting of Pu samples owing to its poor resolution. Instruments are generally in working order, except for three gamma spectrometers in need of repair. Contamination control in the laboratory is lacking. Sample blanks are not run routinely. Owing to the use of the same procedures for sample dissolution and ^{90}Sr/Pu analysis as in Institute A, there is an unquantifiable degree of uncertainty associated with the Sr and Pu data. Further details are given in Annex 3.

2.3.3. Institute C, UkrSSR

Significance: Provision of data for a radiological map of the 30 km zone.

2.3.3.1. Radioelemental Analysis Laboratory

The research oriented laboratory carries out investigations on Cs, Pu and Sr levels in soil, hot particle distribution in the environment and radionuclide uptake by plants. The main methods used are alpha and gamma spectrometry, X ray fluorescence analysis (photon induced X ray emission) and alpha/beta counting with proportional counters.

The use of a shielded dose rate meter for the modified soil sampling method represents an improvement in that it is more representative of the actual activity distribution than results obtained on the basis of unshielded dose rate meter readings. The sample management for gamma spectrometric analysis is well organized and properly documented.

The radiochemical analysis cannot be evaluated satisfactorily owing to the restriction of information regarding sampling procedures and results of detailed analytical methods and the refusal to provide samples for intercomparison purposes at the time of review.

2.3.3.2. Ecological Laboratories

These laboratories emphasize research on ecology, radiobiology and agriculture.

The instrumentation used consists of gamma and alpha spectrometers. Externally supplied and self-made standards are used routinely for calibration. Radionuclide analysis is performed on soil, water, food products and plant samples. All samples are screened for the occurrence of hot particles and submitted for radiochemical analysis of ^{90}Sr and Pu, provided that this screening is negative. All equipment was found to be in good working order.

Contamination in the laboratory appears to be less of a problem than in facilities A and B owing to appropriate sample management. The quality of Sr and Pu data is uncertain owing to inadequate dissolution of sample material (for details, see Section 2.3.1). However, routine hot particle screening and checks for consistency between gamma spectrometric and radiochemical results provide a higher level of confidence in these data. Further details are given in Annex 3.

2.3.4. Institute D, UkrSSR

Significance: Approximately 600 000 samples have been analysed since 1986.

The major work carried out includes studies on:

- Physical and chemical properties of fallout in arable soils;
- Radionuclide behaviour in soil, vegetation and animals;
- Wind and water related transport phenomena of fallout;
- Mapping of hot particles and ^{90}Sr and Pu distributions.

For this purpose, alpha and gamma spectrometry is used.

The laboratories are well maintained and reflect an overall exceptionally high standard. Further details are given in Annex 3.

2.3.5. Institute E, BSSR

Significance: Gamma spectrometry for up to 18 000 soil samples per year; Pu analysis carried out for approximately 1500 samples since 1987.

2.3.5.1. *Laboratory of Radioecology*

Gamma spectrometry is used to analyse mainly soil samples for ^{137}Cs and ^{134}Cs. Lack of adequate calibration standards may result in inaccuracy in the determination of the true radionuclide content of the sample.

2.3.5.2. *Dosimetry and Radiometry Laboratory*

Plutonium and Sr separation and determination are performed with great skill on environmental samples using internationally accepted analytical methods. Lack of adequate modern equipment in sufficient quantities (for example, personal computers and gamma spectrometers) necessitates partially manual recording of spectra and frequent shipment of samples from other laboratories in Gomel, Brest and Mogilev to Minsk for analysis. Further details are given in Annex 3.

2.3.6. Institute F, UkrSSR

Significance: Assessment of the risk of groundwater resources to radioactive pollution.

2.3.6.1. *Isotope Laboratory*

Alpha, beta and gamma spectrometry are used to measure ^{137}Cs, ^{90}Sr and Pu isotopes. All equipment needs to be upgraded. Problems due to inadequate quality assurance programmes are evident. Further details are given in Annex 3.

2.3.7. Institute G, UkrSSR

Significance: Investigations on the geochemical behaviour of radionuclides in surface and groundwater.

Alpha and gamma spectrometers, as well as beta counters and liquid scintillation counters, are used — together with radiochemical methods — to measure Pu, Sr and gamma emitters. The institute is mainly research oriented. No information is available on quality assurance programmes. Further details are given in Annex 3.

2.3.8. Institute H, UkrSSR

Significance: Studies on the dynamics of radionuclide contamination of rivers and the Dnepr cascade of reservoirs since 1986.

A research vessel is available for water and sediment sampling. At present, water samples are analysed by the 'Typhoon' Scientific Production Association, Obninsk. Problems concerning potential cross-contamination of samples are apparent. Further details are given in Annex 3.

2.4. Soviet Methodology for Mapping Fields of Environmental Contamination

Technical publications describing the methodology used for the mapping of environmental radiation fields were not provided to the reviewers. Therefore the following section is based largely on personal communications during visits of the international experts to the All-Union Scientific Research Institute of Agricultural Radiology (Obninsk), Institute of Experimental Meteorology (Obninsk) and the Glushkov Institute of Cybernetics, Special Bureau of Mathematical Machines and Systems (Kiev).

In the post-accident phase, initial Soviet airborne radiometric surveys were reported to have been performed with aeroplanes carrying gamma spectrometers. The spatial resolution in this phase of the large scale survey of the potentially fallout affected areas ('global region') ranged from 5 to 10 km between survey transects. Information on the calibration procedures used is not available.

Subsequently, Soviet helicopters equipped with the same gamma spectrometers scanned special subregions of this global region from an altitude of 1–2 km. The criteria for selecting subregions were based largely on data on the radiation field derived in the initial survey. Because of the collimators used with the detectors, the data obtained in this kind of survey represent an averaged field with a radius ranging from 50 to 250 m. At present, aerial surveys are carried out biannually to update databases on the spatial variation of the radiation fields.

Airborne scanning is complemented by a biannual soil sampling programme. Samples are taken at about 500 settlements in the global region. The number of soil samples per settlement, as reported in the books published by the USSR State Committee on Hydrometeorology (Annex 1), is dependent on the number of inhabitants and the variability of the nuclide deposition pattern.

Data on the nuclide concentration in soil samples (representing point measurements), together with data on the radiation field from airborne measurement (representing averages), are combined to derive maps displaying the regional nuclide deposition by using scaling methods in order to match the two data sets.

The mapping of fields in the UkrSSR utilizes soil sample measurements that are interpolated across a regular grid for field values [12, 13]. Airborne measurements are not available for institutes at the Republic level. Extensive software is available in order to process the resulting radiological field data. No such information was made available to the international experts for the other Republics.

Information on the uncertainty associated with Soviet fallout maps is not available at this time, which affects the assessment of the accuracy of the official maps.

2.5. Intercomparison Exercise

In order to assess the reliability of results obtained by different Soviet institutions, it was agreed during IAC meetings that Soviet institutions engaged in sampling and laboratory analysis of environmental samples and foodstuffs would be invited to participate in an intercomparison exercise.

In this exercise, the participating laboratories would analyse a number of prepared samples and report their results and the associated uncertainties to the IAEA. Their results would be compared with the recommended values. This exercise provides an indication of the variability in accuracy of the results reported by many different institutions. In order to determine whether the Soviet materials were suitable for future intercomparisons and production of reference materials, a test for homogeneity of the sample material was included.

The intercomparison exercise was designed to include the participation of about 120 Soviet laboratories that had been involved in analysing for Cs, and between five and ten Soviet laboratories carrying out Sr and/or Pu analysis. It was further agreed that the results on the individual performance of each participant would be kept confidential and published in coded form only, in accordance with standard scientific practice.

2.5.1. Sample Preparation, Distribution and Response

In May 1990, the Agency's PCI Laboratory prepared a package of materials for all participating laboratories consisting of the following samples:

- Two bottles of milk powder (low and high activity);
- Simulated air filters;
- One bottle of vegetation (clover);
- One bottle of soil.

Two separate milk powder samples were prepared (low and high activity) in order to evaluate the measurement abilities at the different levels of contamination that might be found in milk samples. It could be that in an individual laboratory the accuracy of measurements at a higher nuclide concentration level is adequate but not at a lower one. This is particularly important in the case of meeting contamination limits for food consumption.

All materials (except vegetation) are used as reference materials within the IAEA's Analytical Quality Control Services; the vegetation material is being used currently (1991) in a worldwide IAEA intercomparison programme. This package was accompanied by detailed information sheets on its use and a standardized data reporting format. However, it is emphasized that the materials were submitted to the Soviet laboratories as blind samples.

In June 1990, 25 Soviet institutions nominated by the designated counterparts were each sent one of these packages (Annex 4). Upon the request of the Soviet authorities, an additional 38 institutions were supplied with these packages at the beginning of October 1990 (Annex 5). All participants were asked to send their results to RIAL not later than one month after receipt of the intercomparison exercise package.

To test the extent of homogenization of sample material as performed by the Soviet institutions, about 4600 kg of different materials (milk powder, grass, hay and soil) from the BSSR, the RSFSR and the UkrSSR were received by RIAL in two shipments from designated Soviet institutions (Annex 6). This material will also be used to produce reference material with RIAL standard procedures for an international intercomparison exercise.

By March 1991, results had been obtained by 24 laboratories. However, only the results obtained from 13 laboratories by January 1991 could be considered for this Report. The following comments concern the status as of January 1991. It was indicated that these laboratories represented major contributors to the overall assessment of the radioactive contamination in the environment [14]. Not all test samples were analysed for the presence of all nuclides by each of the participating laboratories.

2.5.2. Results of the Intercomparison Exercise and Homogeneity Test

2.5.2.1. Soil Samples

The participating laboratories submitted results for soil samples that had been analysed for ^{90}Sr, ^{239}Pu, ^{137}Cs and ^{226}Ra. Specific activity concentrations for nuclides ranged from 1.04 to 79.7 Bq/kg. The results obtained by the participants are compared with the recommended values and 95% confidence intervals in

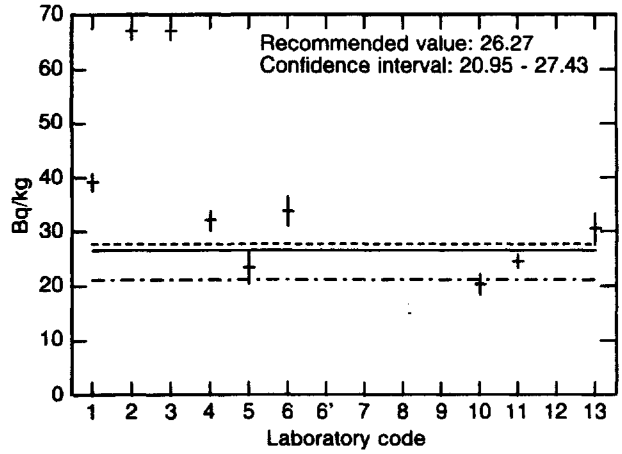


FIG. 2. Intercomparison results for soil samples (^{90}Sr).
[Source: V. Valkovic and team]

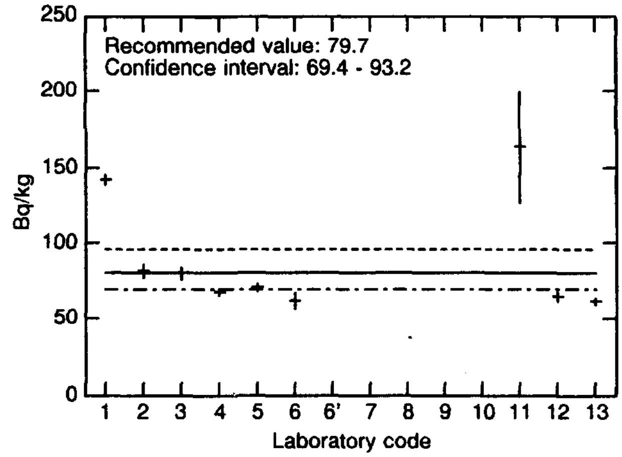


FIG. 5. Intercomparison results for soil samples (^{226}Ra).
[Source: V. Valkovic and team]

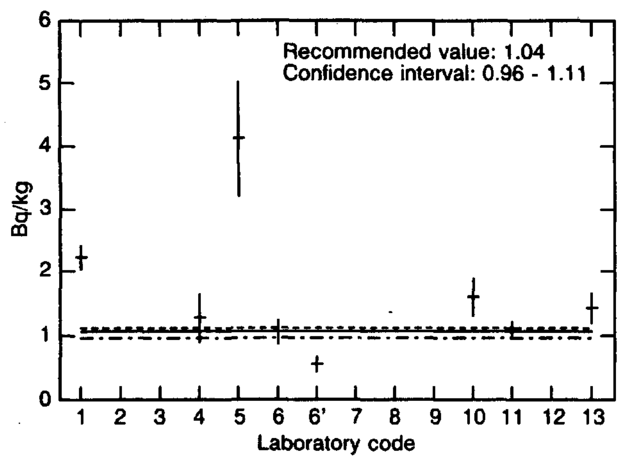


FIG. 3. Intercomparison results for soil samples (^{239}Pu).
[Source: V. Valkovic and team]

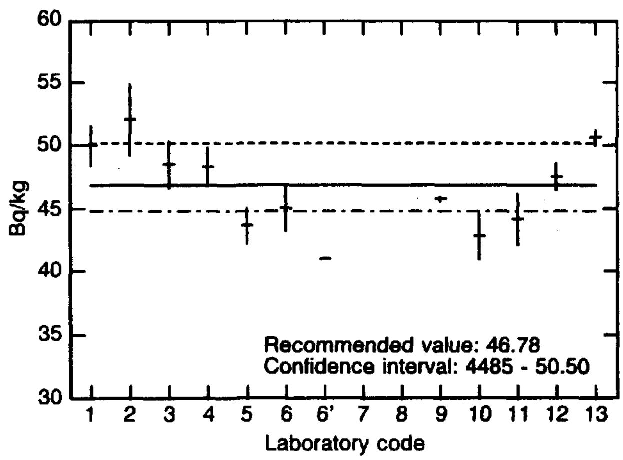


FIG. 4. Intercomparison results for soil samples (^{137}Cs).
[Source: V. Valkovic and team]

Figs 2–5. For ^{137}Cs and ^{226}Ra, radionuclide concentration values are mostly close to the confidence intervals (except for Laboratories 1 and 11), while for ^{90}Sr and ^{239}Pu there is a tendency for overestimation (up to a factor of 4 above the recommended values).

2.5.2.2. Milk Powder Samples — Lower Level

The milk powder samples were analysed for ^{90}Sr, ^{134}Cs, ^{137}Cs and ^{40}K. Specific activity concentrations for nuclides ranged from 3.3 to 552 Bq/kg. The results obtained by the participants are compared with the recommended values and 95% confidence intervals in Figs 6–9. At these lower nuclide concentration levels, many participants had problems with ^{90}Sr, generally overestimating the recommended values (by a factor of up to 8). While the ^{134}Cs results were mostly in reasonable agreement with the recommended values, some participants overestimated the recommended value for ^{137}Cs by a factor of 3. The ^{40}K results can be considered to be satisfactory (with the exception of Laboratory No. 8).

2.5.2.3. Milk Powder Samples — Higher Level

Milk powder samples were analysed for ^{90}Sr, ^{134}Cs, ^{137}Cs and ^{40}K. In order to investigate whether the general performance of the participants was influenced by the level of activity to be measured, samples with a nuclide specific activity concentration ranging from 7.45 to 2065 Bq/kg were included. The results obtained by the participants are compared with the recommended values and 95% confidence intervals in Figs 10–13. The number of participants with acceptable ^{90}Sr results

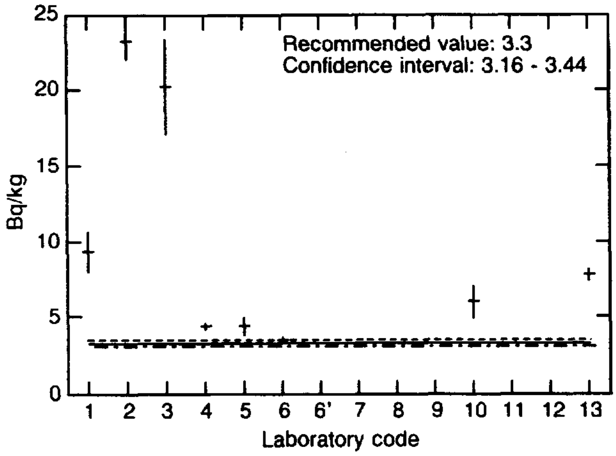


FIG. 6. Intercomparison results for lower level milk powder samples (^{90}Sr). [Source: V. Valkovic and team]

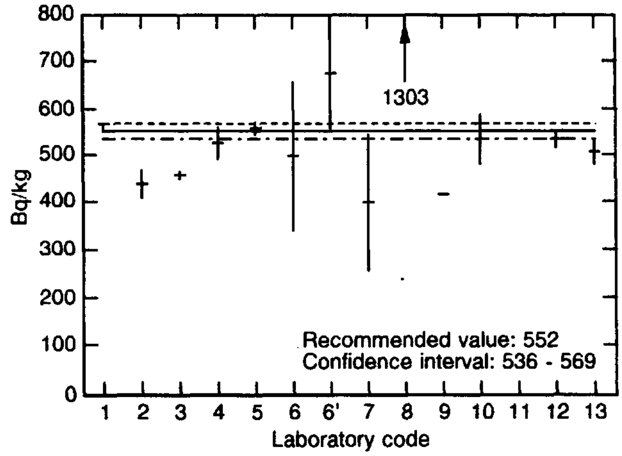


FIG. 9. Intercomparison results for lower level milk powder samples (^{40}K). [Source: V. Valkovic and team]

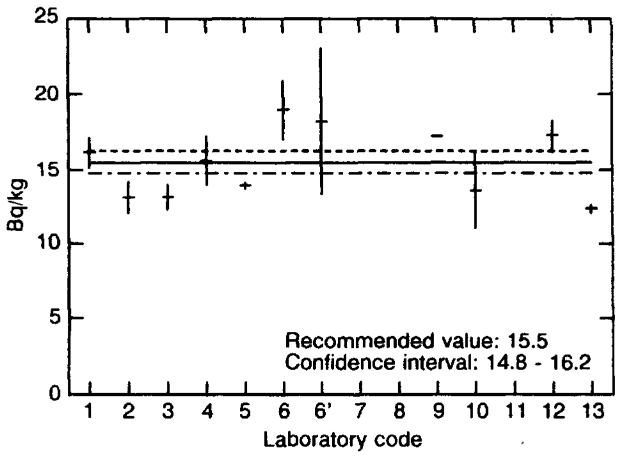


FIG. 7. Intercomparison results for lower level milk powder samples (^{134}Cs). [Source: V. Valkovic and team]

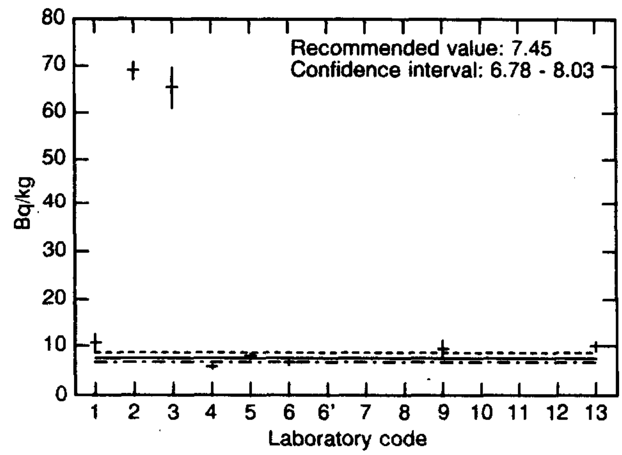


FIG. 10. Intercomparison results for higher level milk powder samples (^{90}Sr). [Source: V. Valkovic and team]

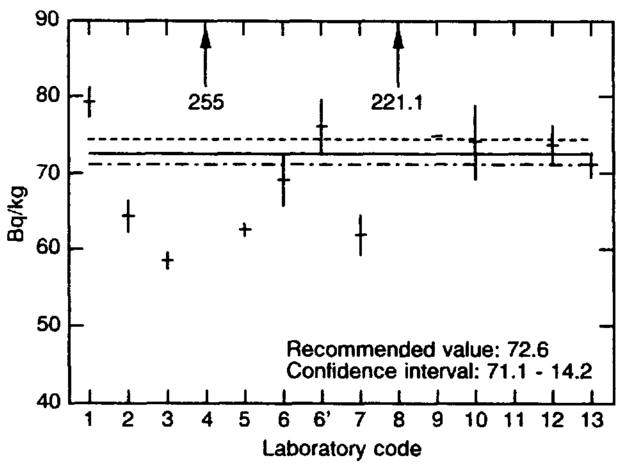


FIG. 8. Intercomparison results for lower level milk powder samples (^{137}Cs). [Source: V. Valkovic and team]

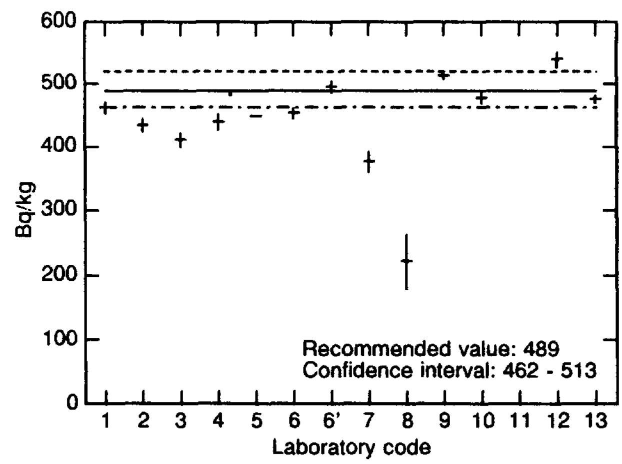


FIG. 11. Intercomparison results for higher level milk powder samples (^{134}Cs). [Source: V. Valkovic and team]

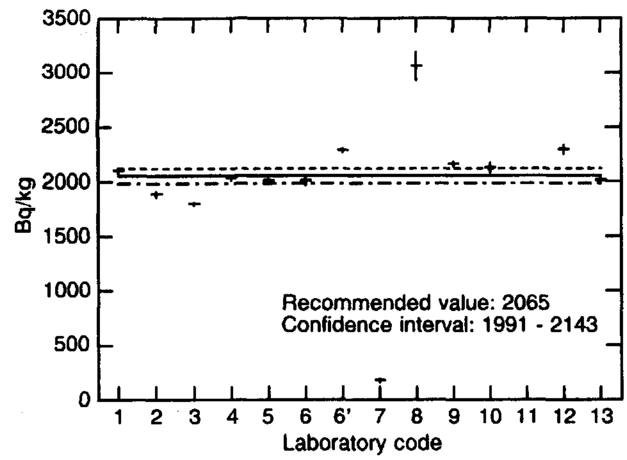


FIG. 12. **Intercomparison results for higher level milk powder samples (^{137}Cs).** [Source: V. Valkovic and team]

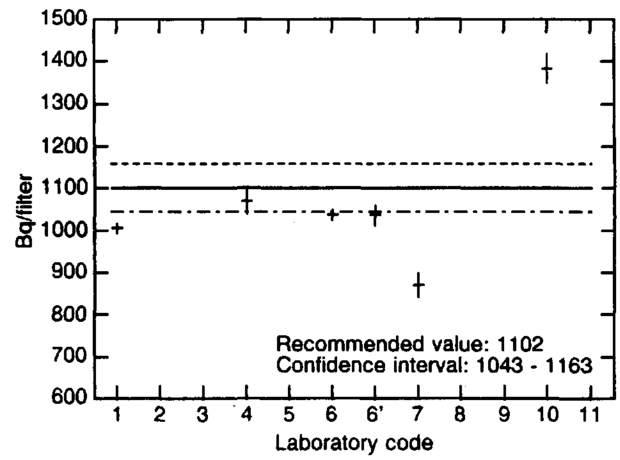


FIG. 15. **Intercomparison results for simulated air filter samples (^{137}Cs).** [Source: V. Valkovic and team]

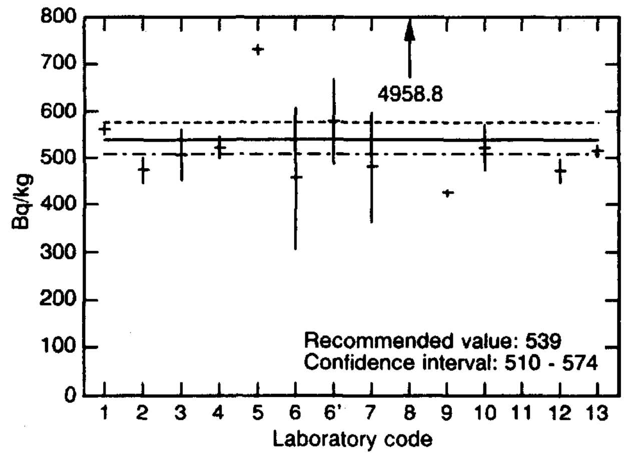


FIG. 13. **Intercomparison results for higher level milk powder samples (^{40}K).** [Source: V. Valkovic and team]

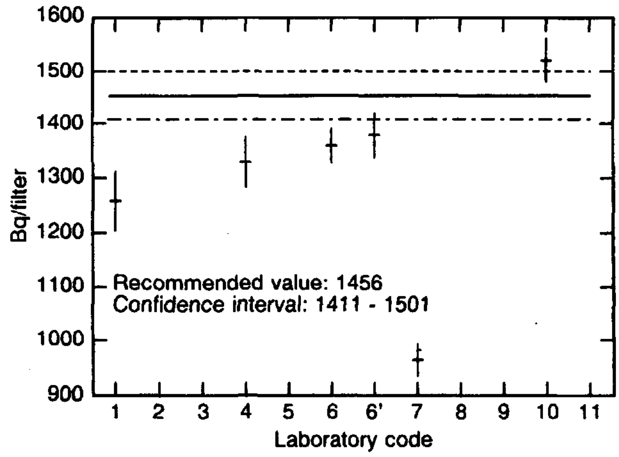


FIG. 16. **Intercomparison results for simulated air filter samples (^{60}Co).** [Source: V. Valkovic and team]

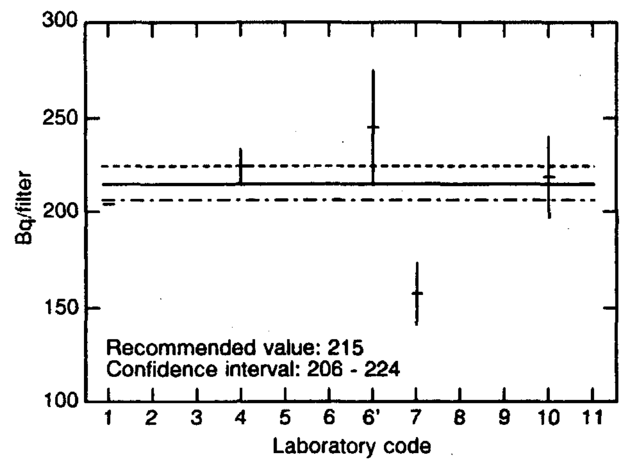


FIG. 14. **Intercomparison results for simulated air filter samples (^{90}Sr).** [Source: V. Valkovic and team]

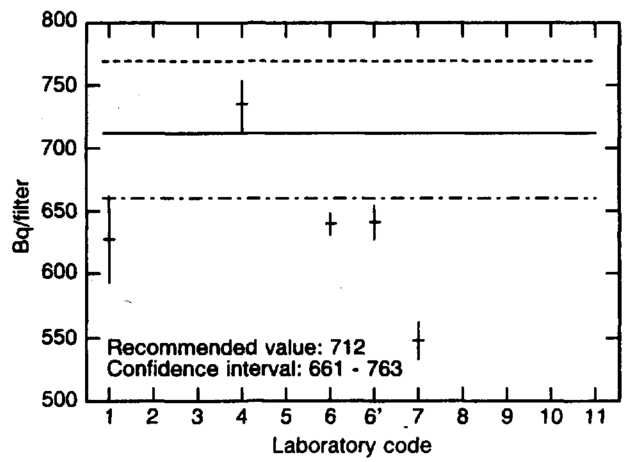


FIG. 17. **Intercomparison results for simulated air filter samples (^{133}Ba).** [Source: V. Valkovic and team]

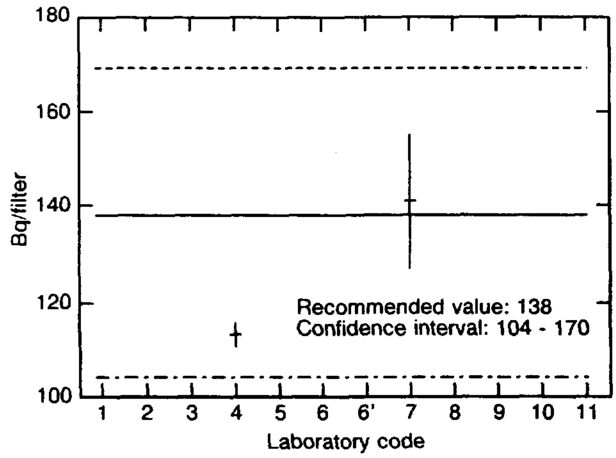


FIG. 18. **Intercomparison results for simulated air filter samples (^{210}Pb).** [Source: V. Valkovic and team]

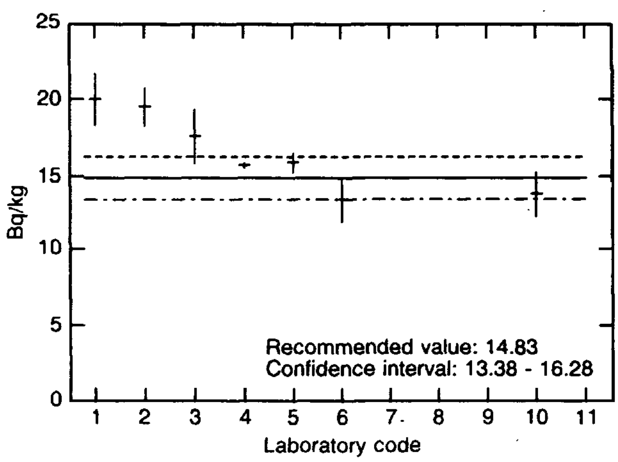


FIG. 19. **Intercomparison results for vegetation (clover) samples (^{90}Sr).** [Source: V. Valkovic and team]

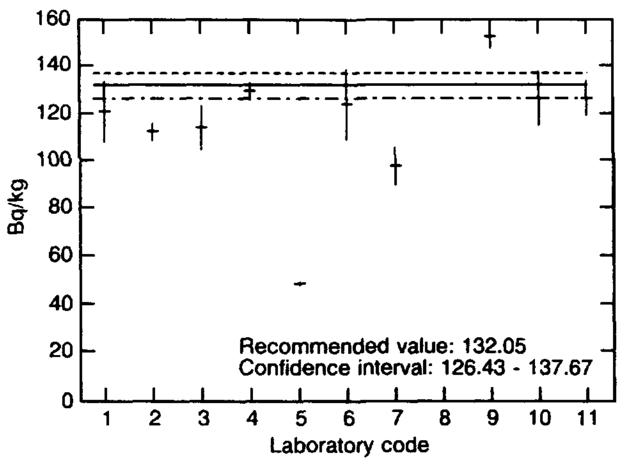


FIG. 20. **Intercomparison results for vegetation (clover) samples (^{134}Cs).** [Source: V. Valkovic and team]

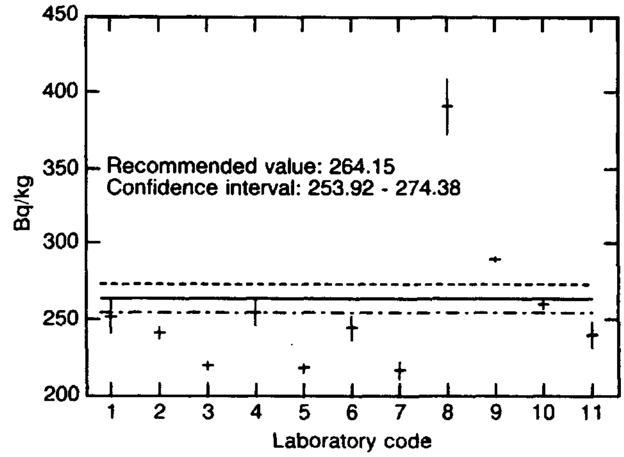


FIG. 21. **Intercomparison results for vegetation (clover) samples (^{137}Cs).** [Source: V. Valkovic and team]

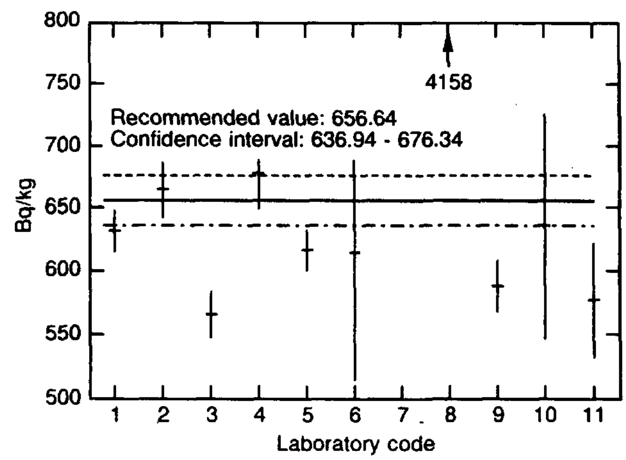


FIG. 22. **Intercomparison results for vegetation (clover) samples (^{40}K).** [Source: V. Valkovic and team]

increased at the elevated concentration levels, but some still overestimated the recommended values by a factor of up to 9. The ^{137}Cs results also improved significantly at higher levels and, like ^{134}Cs, can generally be considered to be satisfactory. This is also true for the ^{40}K results. However, Laboratories 7 and 8, respectively, underestimated and overestimated the recommended ^{137}Cs values significantly, indicating the need for a revision of their analytical methods. Both laboratories underestimated ^{134}Cs values, while Laboratory No. 8 grossly overestimated ^{40}K.

2.5.2.4. Simulated Air Filter Samples

Simulated air filter samples, prepared by depositing radioactive solutions onto air filter material, were

TABLE 2. Homogeneity Test of Different Types of Environmental Samples Provided by Soviet Institutions
[Source: V. Valkovic and team]

Material	Origin	Difference relative to average (%)	
		Mean (arbitrary units)	Standard deviation (%)
Soil	Kiev	1.170	1.4
Soil	Gomel	5.915	1.3
Soil	Novozybkov	7.467	1.4
Grass	Kiev	10.949	0.8
Grass	Gomel	3.216	1.7
Milk (dry)	Narodichi	3.029	1.8
Milk (dry	Novozybkov	4.332	1.3
Milk (dry)	Kalinkovichi factory	0.262	2.3
Hay	'Wave of Revolution' collective farm	5.709	6.4
As above (remixed)		13.567	5.5

analysed for ^{90}Sr, ^{137}Cs, ^{60}Co, ^{133}Ba and ^{210}Pb. Nuclide specific activity concentrations ranged from 138 to 1456 Bq per filter. The results obtained by the participants are compared with the recommended values and 95% confidence intervals in Figs 14–18. Values reported for ^{137}Cs and ^{210}Pb are in good agreement with the recommended values. Disagreement of the values obtained for ^{133}Ba, ^{60}Co and ^{90}Sr with the corresponding recommended value of the order of 30–50% cannot be considered to be acceptable.

2.5.2.5. Vegetation Samples

The vegetation (clover) samples were analysed for ^{90}Sr, ^{134}Cs, ^{137}Cs and ^{40}K. The specific activity concentrations for nuclides ranged from 14.83 to 656.64 Bq/kg. In Figs 19–22, the results obtained by the participants are compared with the recommended values and the 95% confidence interval. Data for ^{90}Sr are in good agreement for most participants; deviations from the recommended value indicate the potential for overestimation. The ^{134}Cs, ^{137}Cs and ^{40}K concentrations in vegetation samples were underestimated by most (up to a factor of about 3 for ^{134}Cs by Laboratory No. 5), except for Laboratory No. 8 (overestimation by a factor of up to 6).

2.5.2.6. Homogeneity Test

This was not a performance test of the Soviet laboratories, but a test of the determination of the suitability of materials sampled by Soviet scientists for producing reference materials.

The homogeneity of the samples taken by Soviet institutions in the USSR was tested by the Agency's PCI Laboratory for the following categories of material: soil, milk (dried), grass and hay.The results are summarized in Table 2. The standard deviation (SD) ranged mostly from 0.8% (grass) to 2.3% (dried milk); however, for 'hay' it reached 6.4%. This latter value was not significantly reduced after remixing (SD for remixed hay: 5.5%). Thus, these samples, with the exception of 'hay', can be considered to be sufficiently homogeneous and suitable for the production of reference materials.

Part D

3. Independent Verification of Environmental Contamination and Radiation Fallout Maps in Selected Settlements

As has been stated, the environmental data in the USSR are usually presented in the form of maps. Nuclide deposition on the ground (e.g. for Cs, Sr and Pu) is displayed either in colour coded form or as isopleths ranging from 1 to 40 Ci/km^2 (37 to 1480 kBq/m^2). Copies of these maps have been issued with the Overview to this Project. The mean concentration values, listed in tabular form, on ^{137}Cs and ^{90}Sr contamination by settlement are presented in Annex I.

As part of the verification procedure for the Soviet contamination maps, the underlying theoretical assumptions used for producing these maps, the experimental procedures and the resulting databases were reviewed in collaboration with the following Soviet institutions: Institute of Experimental Meteorology (Obninsk), All-Union Scientific Research Institute of Agricultural Radiology (Obninsk), Institute of Nuclear Research (Kiev), and the Glushkov Institute of Cybernetics (Kiev).

The other equally important task in the verification procedure was to conduct detailed independent assessments for selected radiological components in the settlements of Novozybkov (RSFSR), Bragin (BSSR), Polesskoe and Daleta (UkrSSR). The average surface activity values reported by the Institute of Hydrometeorology (HYDROMET) (Annex I) for these towns are shown in Table 1. The results of the independent surveys are presented in Sections 3.1, 3.2 and 3.4.

In missions to these settlements and other locations, the teams carried out additional surveys to further improve the assessment of the environmental contamination data. These include dose rate profiles taken along the sides of roads by a hot spot van, soil-grass-milk ecosystem studies and biomonitor assays, as well as soil, water, air and food sampling programmes (these will be presented in Sections 3.5 to 3.10.

In addition, environmental surveys were carried out in the settlements that were chosen by the medical investigators (see Part F) to represent areas with insignificant fallout contamination (control settlements). These results are presented in Section 3.3. All surveys were performed by teams of international experts using IAEA approved methods.

3.1. Survey of Novozybkov (RSFSR)

The population of the settlement of Novozybkov is about 45 000, resident in an area of about 3.5 km × 3.5 km. The community is mainly urban, with small one storey houses and a few new apartment blocks on the outskirts. The rural community of Novoe Mesto, located 9 km west of Novozybkov, is the major agricultural production area for the town. The official contamination maps place Novozybkov in the 15–40 Ci/km^2 (555–1480 kBq/m^2) zone and the mean value for the ^{137}Cs surface activity is 18 Ci/km^2 (666 kBq/m^2) (Table 1).

Surveys of external gamma dose rate measurements, soil sampling, aerosol sampling and field gamma spectrometry were conducted from 21 July to 8 August 1990.

3.1.1. Dose Rate Measurements

Most measurements of the dose rate in air in Novozybkov were made with calibrated pressurized ionization chambers. Additional measurements were carried out with an intercalibrated dual zinc sulphide coated plastic scintillation survey meter. Measurements were conducted approximately 1 m above ground with a total systematic error of less than 5%. Exposure rate readings in μR/h were converted to the dose rate in air in μSv/h.[2] A detailed description of the methods used can be found in Ref. [15].

Continuous recording of the hourly average exposure rates showed that the town did not receive any new source of radioactive deposition owing to a major resuspension event by wind or fallout from another source over the period of observation. Measurements were carried out in the following locations (Fig. 23):

(a) *Outdoors:* undisturbed grassy or wooded areas, gardens, bare soil areas, asphalt streets and concrete pavements.
(b) *Indoors:* wooden houses, brick or block houses, apartment buildings and public buildings.

Between two and five measurements were made at each location and the results were averaged. Figures 24–30 show the frequency distributions for undisturbed areas, gardens and disturbed areas, outdoors over urban surfaces and indoors in different types of dwellings.

The mean, standard deviation, median, maximum and minimum values are presented for the indoor and outdoor dose rate measurements in Table 3. The results can be summarized as follows:

---

[2] A factor of 8.7 was used to convert μR/h to nGy/h and a factor of 0.7 was then used to convert nGy/h to μSv/h.

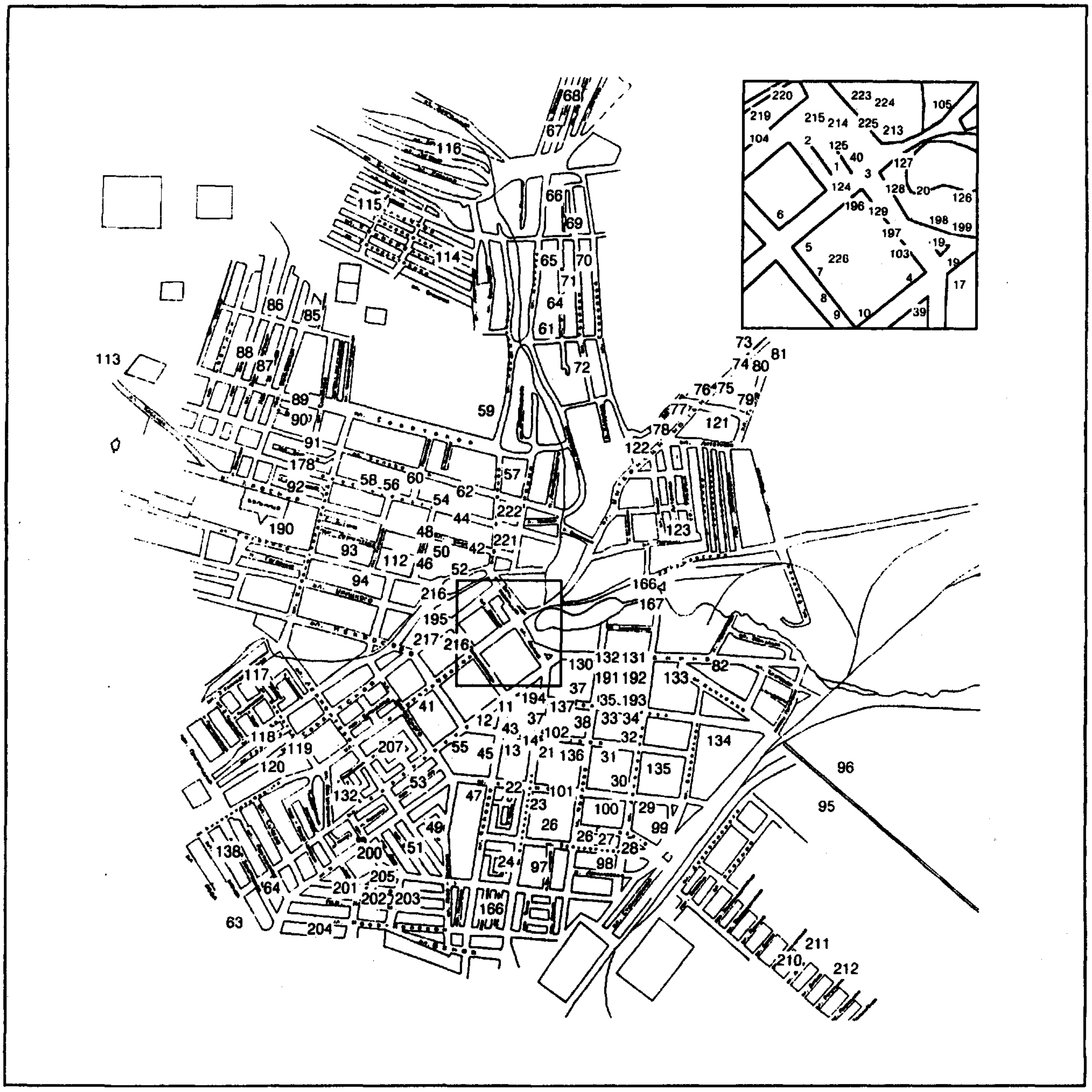


FIG. 23. Dose rate measurement sites in Novozybkov indicated by location number. [Source: K. Miller and team]

(1) The highest dose rates are measured in the category 'undisturbed areas' owing to the fallout residing relatively close to the soil surface.
(2) Lower dose rates are found in 'gardens, bare soil and disturbed areas' or 'hard surfaces', such as concrete, asphalt or pavements, owing to cultivation or runoff.
(3) Buildings can provide substantial shielding, depending on the building material, e.g. for masonry houses (mean: 0.085 μSv/h) shielding is more effective than for wooden houses (mean: 0.111 μSv/h).
(4) Apartment buildings have the lowest values (mean: 0.058 μSv/h), except for buildings that were under construction at the time of the accident.

No Soviet environmental data on a scale larger than that of the official contamination maps (i.e. in greater detail) were presented to the team in Novozybkov. In order to fulfil the objective of corroboration of the Soviet data, the international team and a technical team of local scientists under the direction of a representative from the 'Typhoon' Institute of Experimental Meteoro-

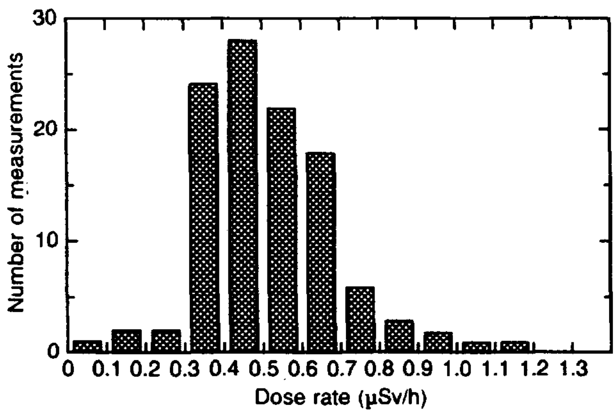


FIG. 24. Histogram of dose rate measurements in undisturbed areas in Novozybkov. [Source: K. Miller and team]

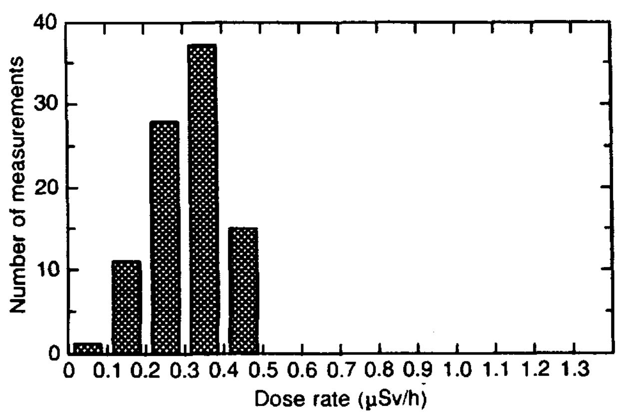


FIG. 25. Histogram of dose rate measurements in gardens and above soil and disturbed areas in Novozybkov. [Source: K. Miller and team]

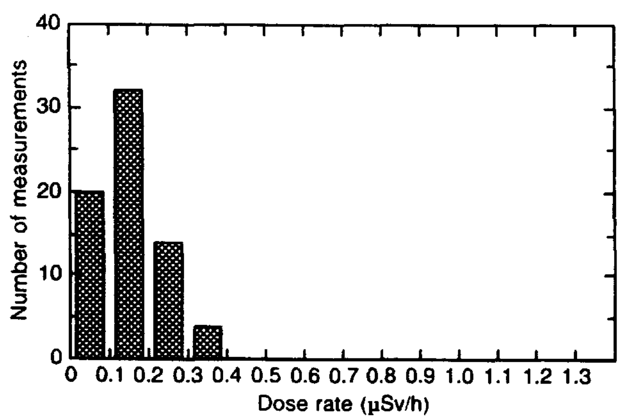


FIG. 26. Histogram of dose rate measurements over hard surfaces (concrete, asphalt and pavement) in Novozybkov. [Source: K. Miller and team]

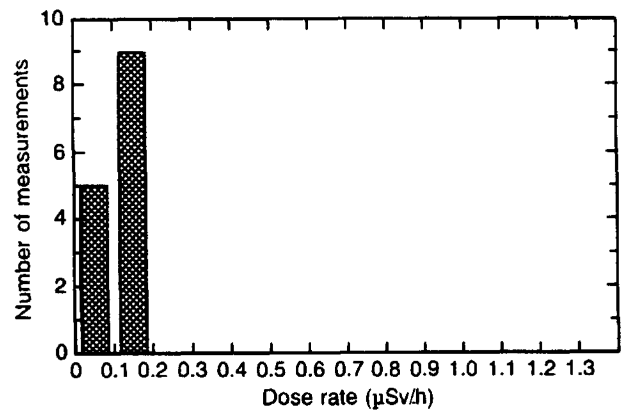


FIG. 27. Histogram of dose rate measurements in detached wooden homes in Novozybkov. [Source: K. Miller and team]

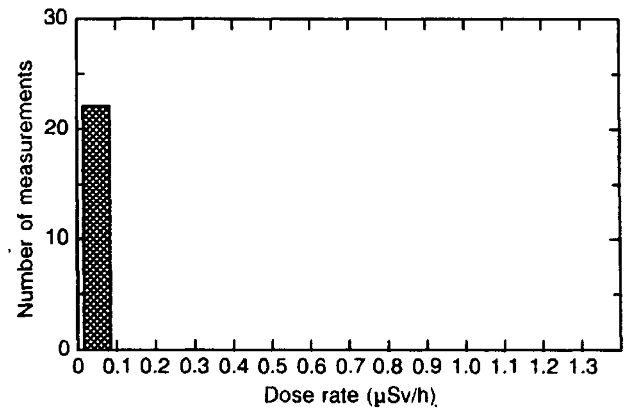


FIG. 28. Histogram of dose rate measurements in detached homes (mortar, brick or concrete) in Novozybkov. [Source: K. Miller and team]

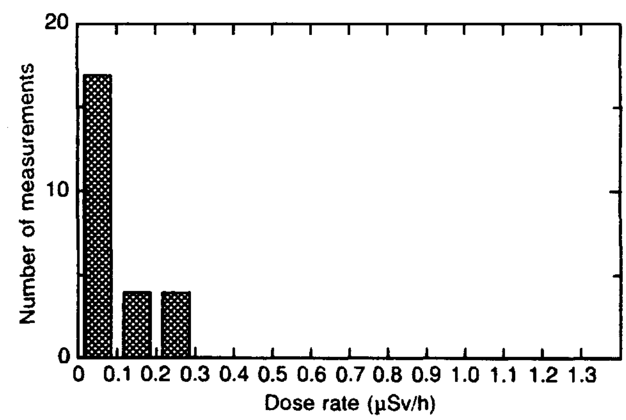


FIG. 29. Histogram of dose rate measurements in apartment buildings in Novozybkov. [Source: K. Miller and team]

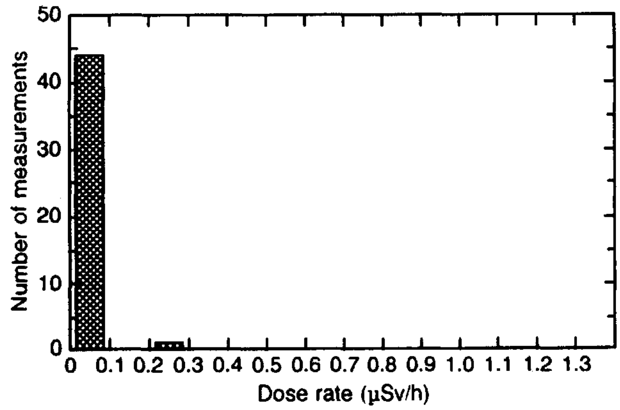


FIG. 30. Histogram of dose rate measurements in public buildings and work places in Novozybkov. [Source: K. Miller and team]

logy (Obninsk) conducted intercomparisons at several sites. Table 4 presents data on the dose rate measurements made outdoors during this intercomparison. On average, the data differed by only 6%.

In Table 5, the intercomparison for indoor measurements shows almost complete agreement.

3.1.2. Soil Sampling

Soil sampling was conducted in order to be able to estimate the nuclide inventory in the town of Novozybkov and to determine the depth distribution of ^{137}Cs in the soil profile. Soil samples were taken according to the procedure described in Ref. [15]. Sampling sites were in the town area and in Novo Mesto. The concentrations of ^{137}Cs and ^{134}Cs are shown in Table 6. The moisture content of the soil samples from fields and gardens ranged from 10 to 29%; the corresponding range for forest soil samples was 5 to 12%.

The results indicate that the ^{137}Cs:^{134}Cs ratio is rather constant, irrespective of the sampling site, and ranges from 6.4 to 6.8. The ^{137}Cs inventory estimates derived from the soil samples range from 470 to 1114 kBq/m^2 (approximately 13 to 30 Ci/km^2; see Fig. 31). According to the official Soviet contamination map, the ^{137}Cs deposition in Novozybkov is in the range of 15–40 Ci/km^2 (555–1480 kBq/m^2), with an average value of 18 Ci/km^2 (666 kBq/m^2) (Table 1), i.e. the data from the independent survey are in reasonable agreement with the official Soviet environmental contamination maps and data.

The depth profile data indicate that peak concentrations of Cs in soils are near the surface, but in some

TABLE 3. Characteristic Statistical Parameters for the Indoor and Outdoor Dose Equivalent Rate in Novozybkov [*Source: K. Miller and team*]

Measurement site	Dose rate (µSv/h)					
	No. of measurements	Mean	Standard deviation	Median	Min.	Max.
Undisturbed areas	110	0.57	0.18	0.55	0.17	1.30
Gardens, soil and disturbed areas	92	0.31	0.09	0.32	0.11	0.50
Hard surfaces (concrete, asphalt, pavement)	70	0.16	0.08	0.14	0.07	0.39
Detached wooden houses (indoors)	50	0.11	0.03	0.11	0.06	0.18
Detached mortar, brick or concrete houses	22	0.08	0.02	0.08	0.06	0.13
Apartment buildings	25	0.11	0.07	0.08	0.04	0.29
Apartment buildings excluding locations 191 and 192 (indoors)	13	0.06	0.01	0.06	0.04	0.08
Public buildings and work places (indoors)	45	0.07	0.04	0.06	0.04	0.28

TABLE 4. Outdoor Dose Rate Measurements: Intercomparison of the International Team (IT) with the Soviet Team (UT) [*Source: K. Miller and team*]

Location No.	Dose rate, IT (μSv/h)	Dose rate, UT (μSv/h)	Ratio UT/IT	Description of location
39a	0.52	0.51	0.98	Near yellow church
39b	0.52	0.46	0.89	Near yellow church
39c	0.45	0.40	0.89	Near yellow church
39d	0.47	0.44	0.95	Near yellow church
39e	0.49	0.49	1.01	Near yellow church
39f	0.37	0.41	1.13	Near yellow church
39g	0.47	0.39	0.83	Near yellow church
63a	0.94	0.90	0.95	High field in SW Novozybkov
63b	0.91	0.75	0.83	High field in SW Novozybkov
63c	1.10	0.95	0.86	High field in SW Novozybkov
63d	0.93	0.87	0.94	High field in SW Novozybkov
63e	0.90	0.86	0.97	High field in SW Novozybkov
63f	0.94	0.88	0.94	High field in SW Novozybkov
63g	0.96	0.83	0.86	High field in SW Novozybkov
63h	0.97	0.86	0.88	High field in SW Novozybkov
63i	0.94	0.83	0.89	High field in SW Novozybkov
63j	0.93	0.89	0.96	High field in SW Novozybkov
64a	0.45	0.43	0.95	Garden
64b	0.29	0.32	1.08	Strawberry patch
169a	1.13	1.14	1.01	NW transect
169b	0.89	0.84	0.94	NW transect
170	0.62	0.58	0.94	NW transect
171	0.50	0.52	1.04	NW transect
172	0.47	0.44	0.95	NW transect
173	0.55	0.54	0.98	N transect
174	0.74	0.71	0.95	N transect
175	0.56	0.55	0.98	N transect
176	0.51	0.41	0.80	N transect
177	0.49	0.49	1.00	N transect
179	0.89	0.80	0.89	N transect
180	0.72	0.71	0.98	S transect
181	0.60	0.49	0.82	S transect
182	1.05	0.99	0.95	S transect
183	0.88	0.90	1.02	S transect
184	0.55	0.54	0.97	SE transect
185	0.57	0.57	1.00	SE transect
186	0.51	0.49	0.96	SE transect
187	0.63	0.56	0.90	SE transect

Note: n = 41; mean outdoor ratio = 0.94; standard deviation = 0.07; median = 0.95; minimum = 0.80; maximum = 1.13.

TABLE 5. Indoor Dose Rate Measurements: Intercomparison of the International Team (IT) with the Soviet Team (UT) [*Source: K. Miller and team*]

Location No.	Dose rate, IT (μSv/h)	Dose rate, UT (μSv/h)	Ratio UT/IT	Description of location
64c	0.25	0.24	0.97	House in high radiation field
64d	0.25	0.24	0.97	House in high radiation field
64e	0.19	0.20	1.08	House in high radiation field
64f	0.17	0.16	0.95	House in high radiation field
64g	0.14	0.13	0.96	House in high radiation field
64h	0.12	0.12	0.98	House in high radiation field
190	0.05	0.06	1.10	Hospital

Note: n = 7; mean indoor ratio = 1.00; standard deviation = 0.06; median = 0.97; minimum = 0.95; maximum = 1.10.

cases there is a significant downward migration (Table 6). In private gardens, 90–95% of the inventory was contained in the top 15 cm; in agricultural areas, significant amounts of Cs were present at 30 cm.

3.1.3. Aerosol Sampling

Aerosol sampling was carried out to determine the atmospheric content of particulates and the radionuclide concentration indoors and outdoors. The particle size distribution was also measured.

Aerosol samples were collected by using low volume personal samplers (8 hours at 1.5 L/min), high volume samplers outdoors and indoors (up to 3 hours at under 0.4 m^3/min) and a cascade impactor (0.85 m^3/min). The six stages of the cascade impactor retained particles with aerodynamic diameters ranging from over 8.3 μm (stage 1) to below 0.58 μm (stage 6). All samples were analysed by gamma spectrometry. Detailed information on sampling sites and conditions is provided in Tables 7–9 and Fig. 32. The results are shown in Tables 10–12. No equivalent sets of Soviet data were provided to the international team.

The only radionuclide detected in the aerosol samples was ^{137}Cs. No measurable activity could be found on the personal aerosol samples, except for sample P-9. This filter was collected from a person who was gardening. It was more noticeably darkened by the material deposited on it than any other filter. The ^{137}Cs concentration in the samples collected by the high volume samplers was generally low and ranged between 0.38 and 2.3 mBq/m^3 indoors and from under 0.33 to 3.2 mBq/m^3 outdoors.

Samples taken at different heights (Nos O-13 and O-14) indicate the potential occurrence of localized resuspension phenomena, since the ^{137}Cs concentration in the immediate area around the sampler was higher at the lower sampling height.

The results from the cascade impactor measurements demonstrate that ^{137}Cs is associated with particles with an aerodynamic diameter greater than 3.45 μm, since no activity was found beyond the second stage (3.45–8.3 μm) for any of the collections (Table 12).

3.1.4. Field Gamma Spectrometry

Field gamma spectrometry was performed to quantify the radiation flux levels indoors and outdoors. These measurements were taken with a Ge detector (45% efficiency) at 1 m above the ground. The energy region examined was 50–4000 keV (collection time under 10 min). For the conversion of full absorption peak count rate to dose rate in air or activity per unit area on the ground, soil samples were collected from different depths and analysed by laboratory based gamma spectrometry [15]. For indoor measurements, a uniform depth profile was assumed. Although there is a higher ratio of scattered flux to primary flux than for outdoors, a relative measure of the contribution from the fallout and natural gamma emitters can be estimated by this method.

The results for in situ spectra outdoors and indoors are summarized in Tables 13 and 14. The locations listed in these tables correspond to the numbers in Fig. 23. The dose rate, as determined by the Ge detector, is in good agreement with the values derived from the pressurized ionization chambers.

The principal gamma emitters detected outdoors are ^{137}Cs and ^{134}Cs and, at significantly lower levels, ^{125}Sb and ^{106}Ru. All other peaks in the spectra are due to

TABLE 6. Soil Sampling Sites and Results for Novozybkov
(Sampling conducted by the international team) [Source: K. Miller and team]

Site No.	Depth (cm)	Area (cm^2)	Dry weight (kg)	Dry density (g/cm^3)	^{137}Cs (kBq/kg)	^{137}Cs (kBq/m^2)	Percentage of total	^{134}Cs (kBq/kg)	^{134}Cs (kBq/m^2)	Percentage of total	Ratio $^{137}Cs/^{134}Cs$
					A. Undisturbed areas						
					(a) Fields						
39	0–5	620	3.756	1.21	7.08	428.8	65	1.11	67.2	66	
	5–10	620	5.048	1.01	2.32	189.3	29	0.36	29.3	29	
	10–15	620	4.505	1.45	0.54	39.4	6	0.08	5.7	6	
	Σ 0–15		13.309	1.43		657.5			102.3		6.4
39	0–2.5	620	1.474	0.95	8.27	196.6		1.21	28.8		
	2.5–5	620	2.049	1.32	6.68	220.8		1.05	34.6		
	Σ 0–5		3.523	1.14		417.5			63.5		6.6
63	0–2.5	186	0.415	0.89	30.14	725.8 ± 75.5	82	4.75	106.1 ± 11.3	82	
	2.5–5	186	0.712	1.53	1.96	75.2	8	0.28	10.9	8	
	5–10	186	1.799	1.92	0.64	62.3	7	0.10	9.5	7	
	10–15	186	1.614	1.73	0.25	22.0	2	0.04	3.4	3	
	Σ 0–15		4.540	1.63		885.4			130.0		6.8
73	0–2.5	186	0.430	0.92	9.31	215.8 ± 0.7	39	1.44	33.2 ± 1.0	39	
	2.5–5	186	0.620	1.33	6.39	213.1	38	1.00	33.5	40	
	5–10	186	1.632	1.75	1.34	117.7	21	0.19	16.8	20	
	10–15	186	1.555	1.67	0.08	6.8	1	0.01	1.0	1	
	15–20	186	1.433	1.54	0.02	1.7	<1	0.002	0.2	<1	
	20–30	186	2.960	1.59	0.01	1.1	<1	0.001	0.1	<1	
	Σ 0–30		8.630	1.55		556.2			84.7		6.6
95	0–2.5	620	1.208	0.78	16.80	327.3	70	2.47	48.2	69	
	2.5–5	620	1.915	1.23	3.07	94.8	20	0.48	14.9	21	
	5–10	620	5.273	1.70	0.43	36.3	8	0.06	5.2	7	
	10–15	620	5.270	1.70	0.14	11.7	2	0.02	1.8	2	
	Σ 0–15		13.67	1.47		470.1			70.0		6.7

TABLE 6. (cont.)

Site No.	Depth (cm)	Area (cm^2)	Dry weight (kg)	Dry density (g/cm^3)	^{137}Cs (kBq/kg)	^{137}Cs (kBq/m^2)	Percentage of total	^{134}Cs (kBq/kg)	^{134}Cs (kBq/m^2)	Percentage of total	Ratio $^{137}Cs/^{134}Cs$
113	Grass	929	0.055	0.06	16.60	9.80	—	2.66	1.6	—	
113	0–2.5	186	0.429	0.92	14.8	359.8 ± 27.2	68	2.37	54.7 ± 6.2	68	
	2.5–5	186	0.745	1.60	3.08	123.5	23	0.47	18.9	24	
	5–10	186	1.596	1.72	0.36	31.3	6	0.06	4.8	6	
	10–15	186	1.825	1.96	0.12	12.1	2	0.02	1.8	2	
	Σ 0–15		4.595	1.65		526.7				80.2	6.6
166	0–2.5	186	0.329	0.71	16.72	293.4 ± 3.4	44	2.5	44.3 ± 1.9	45	
	2.5–5	186	0.695	1.50	6.30	235.4	35	0.91	34.0	35	
	5–10	186	1.495	1.61	1.40	112.3	17	0.20	16.2	16	
	10–15	186	1.546	1.66	0.32	26.6	4	0.04	3.7	4	
	Σ 0–15		4.065	1.46		667.7			98.1		6.8
						(b) Unploughed agricultural areas					
109	Grass	645	0.034	0.05	0.85	0.45	—	0.12	0.06	—	—
109	0–2.5	620	1.281	0.83	22.76	530.8 ± 85.5	58	3.88	80.1 ± 9.5	58	
	2.5–5	620	2.510	1.62	5.20	210.7	23	0.80	32.4	23	
	5–10	620	5.650	1.82	1.02	93.4	10	0.15	13.5	10	
	10–15	620	5.274	1.70	0.83	70.3	8	0.12	10.6	8	
	15–20	620	4.336	1.40	0.15	10.5	1	0.02	1.6	1	
	20–30	620	9.057	1.46	0.03	5.0	<1	0.005	0.7	<1	
	Σ 0–30		28.108	1.51		920.7			139.0		6.6

TABLE 6. (cont.)

Site No.	Depth (cm)	Area (cm^2)	Dry weight (kg)	Dry density (g/cm^3)	^{137}Cs (kBq/kg)	^{137}Cs (kBq/m^2)	Percentage of total	^{134}Cs (kBq/kg)	^{134}Cs (kBq/m^2)	Percentage of total	Ratio $^{137}Cs/^{134}Cs$
					B. Disturbed areas						
					(a) Private gardens						
81	0–5	186	1.149	1.23	3.03	187.0	33	0.47	29.2	33	
	5–10	186	1.444	1.55	2.76	214.3	38	0.43	33.4	38	
	10–15	186	1.328	1.43	1.93	137.7	24	0.28	20.3	23	
	15–20	186	1.226	1.32	0.40	26.4	5	0.06	3.9	4	
	20–30	186	2.285	1.23	0.02	2.4	<1	0.004	0.5	1	
	Σ 0–30		7.432	1.33		567.7			87.9		6.4
167	0–5	186	0.986	1.06	3.63	192.8	28	0.54	28.7	28	
	5–10	186	1.219	1.31	3.95	259.2	37	0.57	37.6	36	
	10–15	186	1.101	1.18	3.19	189.0	27	0.50	29.4	28	
	15–20	186	1.135	1.22	0.91	55.8	8	0.01	8.2	8	
	Σ 0–20		4.441	1.19		696.7			103.9		6.7
					(b) Ploughed agricultural areas						
96	0–2.5	186	0.639	1.37	1.83	62.9	11	0.27	9.2	11	
	2.5–5	186	0.682	1.47	1.85	67.7	12	0.29	10.5	12	
	5–10	186	1.511	1.62	1.78	144.2	26	0.26	21.0	25	
	10–15	186	1.477	1.59	1.97	156.4	28	0.29	22.8	27	
	15–20	186	1.249	1.34	1.94	130.2	23	0.30	20.2	24	
	Σ 0–20		5.558	1.49		561.6			83.7		6.7
111	0–5	620	4.694	1.51	2.79	211.3	32	0.41	31.2	31	
	5–10	620	5.884	1.90	1.13	106.9	16	0.16	15.7	16	
	10–15	620	5.724	1.85	1.24	114.8	17	0.18	17.0	17	
	15–20	620	5.100	1.64	1.03	84.8	13	0.16	13.2	13	
	20–30	620	8.441	1.36	1.72	140.4	21	0.27	22.7	23	
	Σ 0–30		29.861	1.60		658.2			99.8		6.6

TABLE 6. (cont.)

Site No.	Depth (cm)	Area (cm^2)	Dry weight (kg)	Dry density (g/cm^3)	^{137}Cs (kBq/kg)	^{137}Cs (kBq/m^2)	Percentage of total	^{134}Cs (kBq/kg)	^{134}Cs (kBq/m^2)	Percentage of total	Ratio $^{137}Cs/^{134}Cs$
					(c) Forest						
110	0–2.5	186	0.152	0.33	60.1	490.4	50	9.32	76.2	51	
	2.5–5	186	0.569	1.22	11.06	338.3	35	1.73	52.9	35	
	5–10	186	1.532	1.65	1.75	144.2	15	0.26	21.0	14	
	Σ 0–10		2.253	1.21	972.9				150.1		6.5
153	0–2.5	186	0.331	0.7	57.42	1021.9	92	8.94	159.2	92	
	2.5–5	186	0.781	1.68	1.28	53.7	5	0.18	7.8	5	
	5–10	186	1.237	1.33	0.37	24.3	2	0.05	3.5	2	
	10–15	186	1.816	1.95	0.15	14.5	1	0.02	2.1	1	
	Σ 0–15		4.165	1.49	1114.4				172.6		6.4

natural radionuclides. Of the dose rate from the fallout, 70% is due to ^{137}Cs and 30% to ^{134}Cs.

Inside brick houses the dose rate was lower on average than inside wooden houses as a consequence of their higher shielding factor. Only in the case of masonry buildings under construction around the time of the accident (e.g. locations 200 and 205) were higher dose rates from fallout evident.

3.2. Survey of Bragin (BSSR), Polesskoe and Daleta (UkrSSR)

From 22 July to 5 August 1990, a team of experts surveyed the settlements of Bragin, Polesskoe and Daleta.

Bragin has 5888 inhabitants living in an urban area of about 4 km × 4 km. The town consists of an older part, with predominantly one storey wooden buildings, and a new section with multistorey apartment buildings. It falls within the 1–40 Ci/km^2 (37–1480 kBq/m^2) category on the Soviet contamination map (Fig. 35) and is listed as having a mean value of 22 Ci/km^2 (814 kBq/m^2) (Table 1).

Approximately 11 800 people live in the urban settlement of Polesskoe in an area of about 4 km × 4 km. The town comprises mainly small one storey houses with adjacent gardens where vegetables are grown. However, there are a number of four and five storey apartment buildings in the town and there is a small commercial area. This town experienced extremely variable fallout deposition. This can be seen on the Soviet contamination maps, where the town falls into the contamination category of 15–40 Ci/km^2 (555–1480 kBq/m^2). The official average contamination value is 34 Ci/km^2 (1258 kBq/m^2) (Table 1).

The settlement of Daleta in the UkrSSR is in the northwest corner of Ovruch district, near the border with the BSSR. There are approximately 240 inhabitants in this rural settlement of one storey houses lining dirt roads. Residents grow their own vegetables in their gardens. Many residents own cows for milk production. This settlement falls within the contamination category of 1–5 Ci/km^2 (37–185 kBq/m^2), with a mean value of 2 Ci/km^2 (74 kBq/m^2) (Table 1).

External gamma dose rate measurements were made indoors and outdoors in all three settlements. Field gamma spectrometry was performed outdoors to quantify the ^{137}Cs and ^{134}Cs deposition in Bragin and Polesskoe. The radionuclide concentration and the depth profile in soil were also measured in Bragin and Polesskoe. Indoor radon measurements were made in Daleta and Bragin to determine the contribution from the major component of the natural radiation environment. In addition, the analysis of a hot particle found in Polesskoe is discussed.

3.2.1. Dose Rate Measurements

As a result of the multinational composition of the team of experts, several different instruments were used

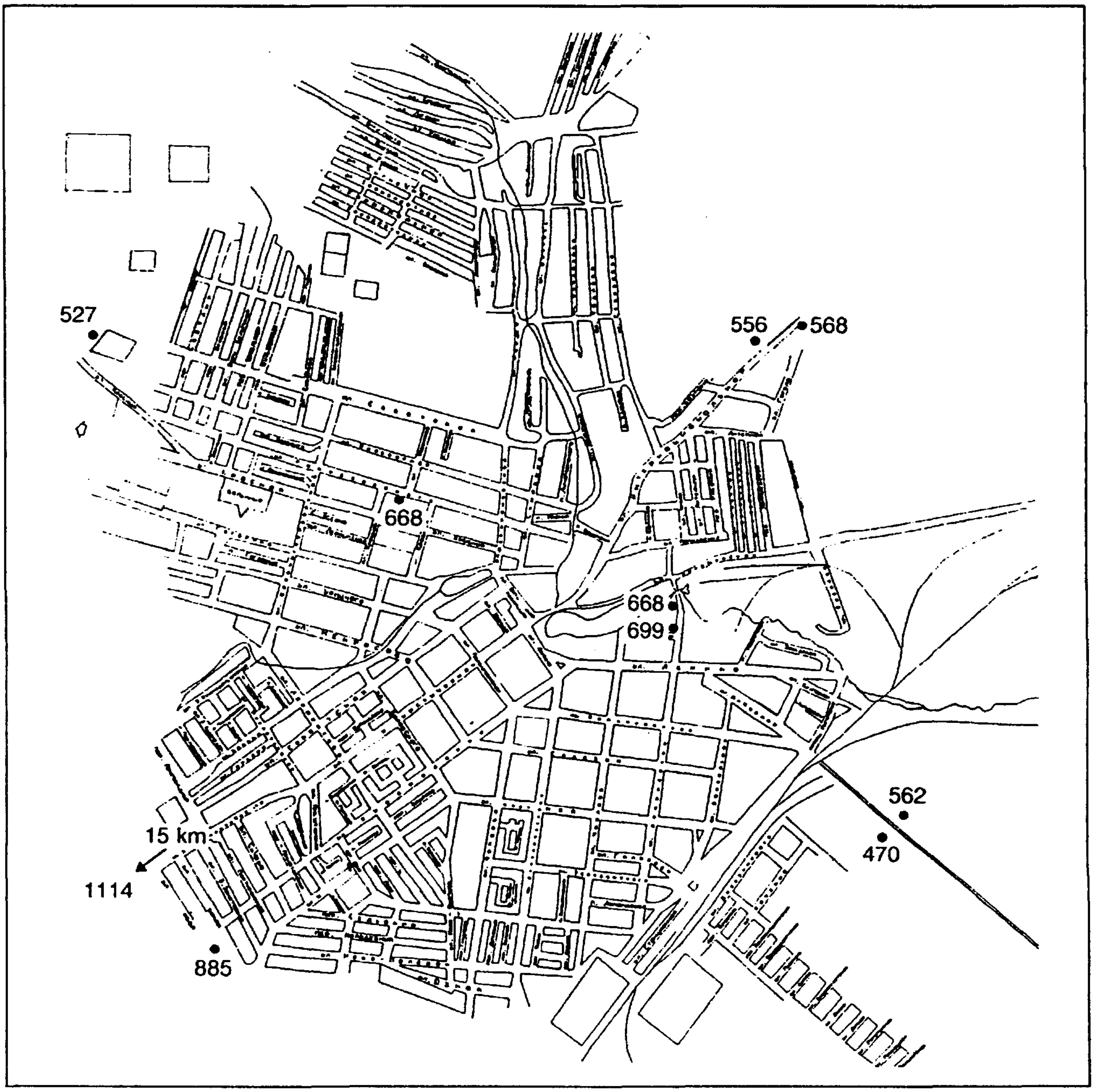


FIG. 31. ^{137}Cs Deposition on the ground (kBq/m^2) in Novozybkov, based on data from the Project team. [Source: K. Miller and team]

to measure the dose rate. One dose rate meter used a ZnS coated plastic detector; all other detectors were GM counting tubes. In order to ensure comparability of results, three intercomparison exercises were carried out indoors and outdoors. On the basis of these results, all instruments were considered as being interchangeable during these surveys.

The following categories of sites were investigated:

— *Outdoors:* grass covered, cultivated, undisturbed and asphalt covered areas, and others (e.g. roofs).

— *Indoors:* wooden and masonry buildings, dwellings whose occupants were participating in the IAEA personal dosimeter programme and which were selected preferentially.

At a given site, usually either multiple readings were taken with the same instrument (typical measurement time: 30–60 s) and the average was recorded, or the results of measurements with more than one instrument were averaged.

TABLE 7. Personal Aerosol Sampling Conditions in Novozybkov
(Sampling conducted by the international team) [*Source: K. Miller and team*]

Sample	Date	Time of day	General location and activities of participant
P-1	90-7-26	07:40 to 18:00	Out in the streets, fields and laboratory performing research
P-2	90-7-27	09:55 to 18:30	Out in the streets, fields, houses and laboratory performing research
P-3	90-7-27	10:00 to 18:30	Out in the streets, fields, houses and laboratory performing research
P-4	90-7-27	15:25 to 23:05	In clothing factory operating sewing machinery
P-5	90-7-27	15:25 to 23:05	In clothing factory operating sewing machinery
P-6	90-7-27	15:25 to 23:05	In clothing factory operating sewing machinery
P-7	90-7-28	10:15 to 18:05	At private residence performing daily duties around home
P-8	90-7-28	11:10 to 18:50	At laboratory working and private residence doing chores
P-9	90-7-28	12:05 to 18:35	Outside private residence performing daily chores and gardening
P-10	90-7-28	12:05	At private residence performing daily duties around home
P-11	90-7-30	11:00 to 18:00	At private residence performing daily duties around home
P-12	90-7-30	11:15 to 16:40	Outside apartment building sanding surface of building
P-13	90-7-30	11:25 to 16:35	On side of busy street performing road construction
P-14	90-7-31	07:35 to 16:00	All around town working, travel in car and duties at private home
P-15	90-7-31	09:20 to 17:15	At private residence working with machines and in garden
P-16	90-8-1	09:40 to 17:55	All around town working as a driver
P-17	90-8-1	10:25 to 17:25	At farm in Novomesto performing farming duties
P-18	90-8-1	10:30 to 17:20	At farm in Novomesto performing farming duties
P-19	90-8-1	10:40 to 17:25	At farm in Novomesto operating tractor
P-20	90-8-1	10:45 to 17:20	At farm in Novomesto performing farming duties
P-21	90-8-2	09:30 to 16:50	Out in the streets, fields and laboratory performing research
P-22	90-8-2	11:00 to 16:30	At food warehouse operating fork lift vehicle
P-23	90-8-2	11:05 to 16:30	At food warehouse working on loading dock
P-24	90-8-2	11:15 to 16:35	At food warehouse performing office duties
P-25	90-8-3	09:20 to 18:20	Out in the streets, fields and laboratory performing research
P-26	90-8-3	11:30 to 17:20	At hospital performing technician's duties
P-27	90-8-3	11:35 to 17:25	At hospital performing technician's duties
P-28	90-8-3	11:50 to 17:35	At hospital performing technician's duties

The detailed results of the individual dose rate measurements (in μSv/h) are given in Tables 15–21 for Bragin, Tables 22–24 for Polesskoe and Table 25 for Daleta. A summary of the mean, standard deviation, median, minimum and maximum values is shown in Table 26, categorized by the type of measurement site.

The results for the three settlements can be summarized as follows:

(1) *Bragin:* Outdoor dose rate values in the town covered a wide range, from normal natural background levels (0.1 μSv/h) to 3 μSv/h. The lowest values were found over paved surfaces (i.e. those resurfaced after the accident). The highest values were measured in private gardens and over undisturbed areas.

Indoor dose rates ranged from 0.1 to 0.3 μSv/h, with a slightly lower mean for masonry buildings (0.14 μSv/h) compared with wooden buildings (0.17 μSv/h) owing to the stronger shielding effect of the higher density masonry (Figs 33 and 34).

Figure 35 presents the official Soviet map for total caesium deposition in the Bragin area. Figures 36 and 37

TABLE 8. High Volume Aerosol Sampling Conditions in Novozybkov
(Sampling conducted by the international team) [*Source: K. Miller and team*]

Sample	Site No.	Date	Time of day	Location	Sampling height (m)	Description of site	Weather conditions
O-1	A-10	90-7-26	10:30 to 12:45	Outdoor	0.8	On pavement behind building	Partly cloudy and dry
O-2	A-10	90-7-26	12:45 to 14:45	Outdoor	0.8	On pavement behind building	Cloudy with some rain
O-3	A-7	90-7-26	15:15 to 16:45	Outdoor	1.0	In open grass field 150 m from paved road	Partly cloudy and dry
O-4	A-8	90-7-26	15:50 to 17:55	Outdoor	0.4	On benches around sports stadium	Breezy with threat of thunderstorm
O-5	A-15	90-7-27	10:25 to 13:50	Indoor	1.0	In large third floor room of clothing factory	
O-6	A-15	90-7-27	10:35 to 13:40	Outdoor	1.0	Behind clothing factory near entrance road	Partly cloudy and dry
O-7	A-22	90-7-27	16:45 to 18:05	Outdoor	1.0	In grass field with some small trees	Cloudy with some rain
O-8	A-23	90-7-27	17:20 to 18:05	Outdoor	4.0	On roof of garage near lightly travelled dirt road	Cloudy with some rain
O-9	A-17	90-7-28	10:30 to 12:45	Outdoor	1.8	On wood pile in private yard	Partly cloudy and dry
O-10	A-2	90-7-28	11:25 to 13:55	Indoor	0.5	Inside kitchen of residence	
O-11	A-3	90-7-28	15:50 to 17:20	Outdoor	0.3	5 m from moderately travelled dirt road	Breezy and threat of rain
O-12	A-4	90-7-28	16:20 to 17:55	Outdoor	0.3	In garden of private yard	
O-13	A-9	90-7-29	10:30 to 12:30	Outdoor	2.0	Outside building 5 m from paved road	Partly cloudy, dry and breezy
O-14	A-9	90-7-29	10:30 to 12:30	Outdoor	9.0	Outside second floor window of building	Partly cloudy, dry and breezy
O-15	A-25	90-7-30	12:30 to 16:00	Outdoor	0.3	Inside fenced private yard	Partly cloudy and dry with some breeze
O-16	A-25	90-7-30	12:35 to 16:05	Indoor	1.0	Inside small room of private residence	
O-17	A-20	90-7-30	16:20 to 17:30	Outdoor	0.2	6 m from heavily travelled paved road	Partly cloudy, dry and breezy
O-18	A-11	90-7-31	10:40 to 12:35	Outdoor	0.8	In play area of school yard	Partly cloudy, dry and breezy
O-19	A-11	90-7-31	10:50 to 12:30	Indoor	0.8	In corridor of school building	
O-20	A-26	90-7-31	14:50 to 16:20	Outdoor	0.3	In large grass field	Partly cloudy, dry and breezy
O-21	A-5	90-7-31	16:00 to 17:30	Indoor	0.8	Inside cattle barn	
O-22	A-1	90-8-1	12:15 to 14:50	Indoor	0.8	Inside kitchen of private residence	
O-23	A-21	90-8-1	15:50 to 18:00	Indoor	0.8	Inside living room of private residence	
O-24	A-21	90-8-1	16:10 to 17:55	Outdoor	0.5	In garden of private yard	Partly cloudy, dry and breezy
O-25	A-29	90-8-2	10:55 to 12:30	Indoor	1.4	Inside food warehouse near fork lift traffic	
O-26	A-28	90-8-2	11:10 to 12:35	Indoor	1.0	In second floor conference room of office complex	
O-27	A-13	90-8-2	14:30 to 16:15	Outdoor	1.0	In open grass field	Partly cloudy and dry with some breeze
O-28	A-14	90-8-2	14:45 to 16:20	Outdoor	0.5	5 m from heavily travelled dirt road	Partly cloudy, dry and breezy
O-29	A-6	90-8-3	11:15 to 12:55	Indoor	2.0	In small ground floor room of hospital	
O-30	A-16	90-8-3	14:50 to 16:55	Indoor	0.8	In fifth floor living room of apartment complex	
O-31	A-19	90-8-3	15:10 to 16:45	Outdoor	0.5	Inside fenced yard by roadside entrance	Partly cloudy and dry
O-32	A-12	90-8-3	15:20 to 16:40	Outdoor	1.0	On store front steps 10 m from dirt road	Partly cloudy and dry
O-33	A-24	90-8-4	11:00 to 12:20	Indoor	1.5	Inside bedroom of private residence	
O-34	A-24	90-8-4	11:05 to 12.25	Outdoor	0.5	In small fenced private yard	Hazy with occasional breeze
O-35	A-18	90-8-4	15:00 to 17:00	Outdoor	1.2	In fenced private yard	Hazy with occasional breeze

TABLE 9. Impactor Aerosol Sampling Conditions in Novozybkov
(Sampling conducted by the international team) [*Source: K. Miller and team*]

Sample	Site No.	Date	Time of day	Description of site	Weather conditions
I-1	A-10	90-7-31	9:15 to 18:00	On pavement behind building	Overcast with slight breeze
I-2	A-5	90-8-1	10:15 to 17:30	Near cattle barns and lightly travelled dirt roads	Partly cloudy with slight breeze
I-3	A-29	90-8-2	10:50 to 16:30	On loading docks of food warehouse	Overcast with some rain
I-4	A-6	90-8-3	11:00 to 17:05	Near lightly travelled road behind hospital	Overcast and breezy
I-5	A-27	90-8-4	10:10 to 16:50	Over pavement in front of agricultural school	Hazy and breezy

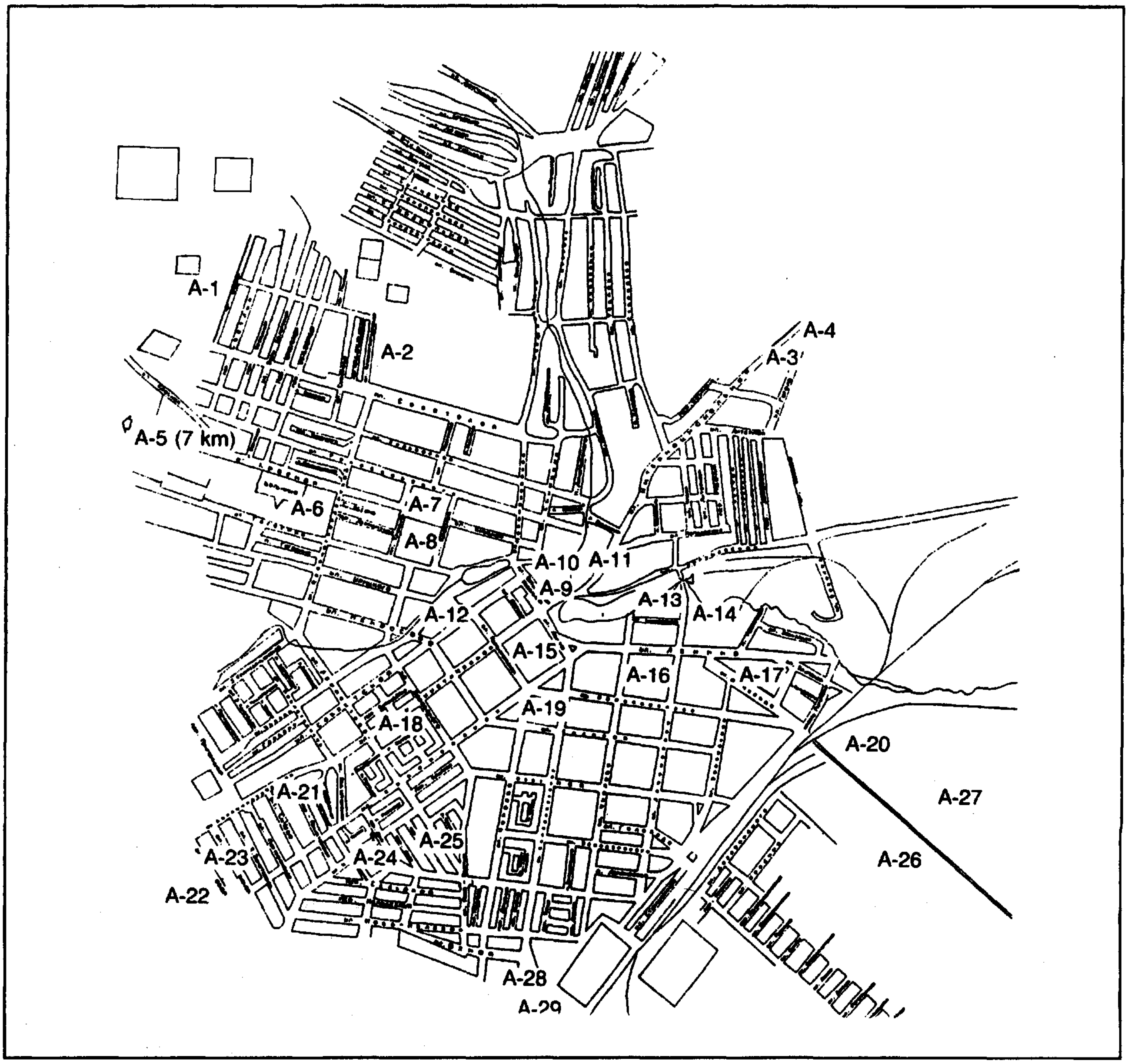


FIG. 32. Aerosol sampling locations in Novozybkov. [Source: K. Miller and team]

TABLE 10. Activity of ^{137}Cs in Personal Aerosol Samples in Novozybkov
(Sampling conducted by the international team) [*Source: K. Miller and team*]

Sample	Date	Time (min)	Volume (m^3)	Activity[a] (mBq)	Error (±SD)[b]	Conc. (mBq/m^3)
P-1	90-7-26	505	0.73	*		<25
P-2	90-7-27	515	0.95	*		<19
P-3	90-7-27	510	0.92	*		<20
P-4	90-7-27	460	0.61	*		<30
P-5	90-7-27	460	0.65	*		<28
P-6	90-7-27	460	0.67	*		<27
P-7	90-7-28	470	0.85	*		<21
P-8	90-7-28	400	0.74	*		<24
P-9	90-7-28	390	0.45	7.5	0.8	17
P-10	90-7-28	Bad sample				
P-11	90-7-30	420	0.78	*		<23
P-12	90-7-30	325	0.46	0	7	<15
P-13	90-7-30	310	0.45	*		<40
P-14	90-7-31	505	0.91	0	7	<7.7
P-15	90-7-31	475	0.57	0	3	<5.3
P-16	90-8-1	495	0.90	*		<20
P-17	90-8-1	420	0.61	*		<30
P-18	90-8-1	410	0.58	*		<31
P-19	90-8-1	405	0.54	0	18	<33
P-20	90-8-1	375	0.45	*		<40
P-21	90-8-2	440	0.81	0	3	<3.7
P-22	90-8-2	330	0.47	*		<38
P-23	90-8-2	325	0.47	*		<38
P-24	90-8-2	320	0.43	*		<42
P-25	90-8-3	540	1			<18
P-26	90-8-3	350	0.47	*		<38
P-27	90-8-3	350	0.49	*		<37
P-28	90-8-3	345	0.49	*		<37

[a] An asterisk denotes that these samples were only screened for radioactivity.
[b] SD: standard deviation.

show the outdoor dose rate maps produced by the international team. There is satisfactory agreement between these maps, i.e. the part of town with the highest caesium deposition values coincides with the area with the highest external dose rate.

(2) *Polesskoe:* Outdoors in the urban area, dose rate values range from 0.3 to 2.3 μSv/h. The maximum value, 12 μSv/h, was found in the outskirts of the town, reflecting the inhomogeneity of the fallout deposition. Dose rates are generally low over paved surfaces and elevated over undisturbed areas. Hot spot areas, some with officially marked occurrence of hot particles, were detected and corroborated by the international team (see, for example, Table 22, Site 7g: dose rate exceeding 100 μSv/h).

Text cont. on p. 146

TABLE 11. ^{137}Cs Activity of High Volume Aerosol Samples in Novozybkov
(Sampling conducted by the international team) [*Source: K. Miller and team*]

Sample	Date	Time (min)	Volume (m^3)	Activity (mBq)[a]	Error (±SD)[b]	Concn (mBq/m^3)
O-1	90-7-26	135	63.5	0	20	<0.63
O-2	90-7-26	120	56.4	0	18	<0.64
O-3	90-7-26	90	9.3	0	6	<1.3
O-4	90-7-26	125	56.3	13	1	0.46
O-5	90-7-27	205	92.3	22	4	0.48
O-6	90-7-27	185	83.3	110	11	2.6
O-7	90-7-27	80	8.7	0	10	<2.3
O-8	90-7-27	45	20.7	0	17	<1.6
O-9	90-7-28	135	60.8	0	10	<0.33
O-10	90-7-28	150	69	13	2	0.38
O-11	90-7-28	90	9.5	9	1	1.9
O-12	90-7-28	95	42.8	0	29	<1.4
O-13	90-7-29	120	55.2	43	6	1.6
O-14	90-7-29	120	54	25	4	0.93
O-15	90-7-30	210	96.6	110	11	2.3
O-16	90-7-30	210	94.5	110	11	2.3
O-17	90-7-30	70	7.7	0	17	<4.4
O-18	90-7-31	115	50.6	0	20	<0.79
O-19	90-7-31	100	46	12	2	0.52
O-20	90-7-31	90	9.5	0	7	<1.5
O-21	90-7-31	90	42.3	28	3	1.3
O-22	90-8-1	155	72.9	0	17	<0.47
O-23	90-8-1	130	59.8	0	15	<0.50
O-24	90-8-1	105	10.3	0	12	<2.3
O-25	90-8-2	95	41.8	14	2	0.67
O-26	90-8-2	85	40	0	17	<0.85
O-27	90-8-2	105	10.3	9	2	1.7
O-28	90-8-2	95	42.8	69	6	3.2
O-29	90-8-3	100	40	0	21	<1.1
O-30	90-8-3	125	56.3	27	4	0.96
O-31	90-8-3	95	44.7	54	5	2.4
O-32	90-8-3	80	8.7	11	2	2.5
O-33	90-8-4	80	36.8	0	24	<1.3
O-34	90-8-4	80	34.4	0	24	<1.4
O-35	90-8-4	120	50.4	43	8	1.7

[a] Activity is reported for only one half of each filter.
[b] SD: standard deviation.

TABLE 12. ^{137}Cs Activity of Impactor Aerosol Samples in Novozybkov
(Sampling conducted by the international team) [*Source: K. Miller and team*]

Sample	Date	Time (min)	Volume (m^3)	Activity (mBq)[a]	Error (±SD)[b]	Concn (mBq/m^3)
I-1/1	90-7-31	525	441	33	5	0.15
I-1/2	90-7-31	525	441	0	15	<0.068
I-1/3	90-7-31	525	441	0	6	<0.027
I-1/4	90-7-31	525	441	0	16	<0.073
I-1/5	90-7-31	525	441	0	15	<0.068
I-1/6	90-7-31	525	441	0	16	<0.13
I-1 total	90-7-31	525	441	33		≥0.15
I-2/1	90-8-1	435	365	92	6	0.5
I-2/2	90-8-1	435	365	39	4	0.21
I-2/3	90-8-1	435	365	0	6	<0.033
I-2/4	90-8-1	435	365	0	6	<0.033
I-2/5	90-8-1	435	365	0	14	<0.077
I-2/6	90-8-1	435	365	0	16	<0.16
I-2 total	90-8-1	435	365	130		≥0.71
I-3/1	90-8-2	340	286	140	6	0.97
I-3/2	90-8-2	340	286	52	5	0.36
I-3/3	90-8-2	340	286	0	14	<0.098
I-3/4	90-8-2	340	286	0	16	<0.11
I-3/5	90-8-2	340	286	0	14	<0.98
I-3/6	90-8-2	340	286	0	16	<0.20
I-3 total	90-8-2	340	286	190		≥1.3
I-4/1	90-8-3	365	307	140	4	0.93
I-4/2	90-8-3	365	307	49	6	0.32
I-4/3	90-8-3	365	307	0	20	<0.13
I-4/4	90-8-3	365	307	0	6	<0.039
I-4/5	90-8-3	365	307	0	11	<0.072
I-4/6	90-8-3	365	307	0	16	<0.18
I-4 total	90-8-3	365	307	190		≥1.3
I-5/1	90-8-4	400	336	27	3	0.16
I-5/2	90-8-4	400	336	0	19	<0.11
I-5/3	90-8-4	400	336	0	18	<0.11
I-5/4	90-8-4	400	336	0	16	<0.095
I-5/5	90-8-4	400	336	0	5	<0.030
I-5/6	90-8-4	400	336	0	18	<0.19
I-5 total	90-8-4	400	336	27		≥0.16

[a] Activity is reported for only one half of each filter from stage one through stage five and about 28% of each filter from stage six.
[b] SD: standard deviation.

TABLE 13. In Situ Gamma Spectral Measurements Outdoors in Novozybkov
(Sampling conducted by the international team) [*Source: K. Miller and team*]

		Dose rate in air (nGy/h)						
Site	Description	Cs-137	Cs-134	Sb-125	Ru-106	Background[a]	Total	PIC[b]
20	Field	263	109	3	3	48	426	461
39	Field	416	173	5	6	60	660	671
63	Field	937	399	12	12	44	1404	1560
73	Field	432	174	3	5	61	675	701
95	Field	646	260	7	4	57	974	995
109	Field	1220	539	11	11	47	1848	1763
113	Field	539	219	7	4	48	817	844
166	Field	623	254	7	5	58	947	958
110	Forest	1187	471	14	9	44	1725	1717
153	Forest	1290	519	15	7	42	1873	1991
76	Garden	266	106	4	3	62	441	439
167	Garden	447	181	5	4	56	693	613
200	Garden	378	159	5	6	53	601	629
96	Ploughed	218	92	3	3	65	381	385
111	Ploughed	325	131	5	3	49	513	499
40	Asphalt	15	NM[c]	NM[c]	NM[c]	NM[c]	NM[c]	117

[a] Includes ^{238}U series, ^{232}Th series, ^{40}K and cosmic ray equivalent.
[b] PIC: pressurized ionization chamber.
[c] No measurement.

TABLE 14. In Situ Gamma Spectral Measurements (Dose Rate Approximations) Indoors in Novozybkov
(Sampling conducted by the international team) [*Source: K. Miller and team*]

		Dose rate in air (nGy/h)[a]				
Site	Description	Cs-137	Cs-134	Background[b]	Total	PIC[c]
81	Wood house	29	14	76	119	125
167	Wood house	16	5	70	91	115
—	Brick house	14	6	49	69	87
200	Brick house[d]	54	23	61	138	154
204	Brick house[d]	79	34	70	183	197

[a] Except for PIC measurements, values are approximate and should be used on a relative and not an absolute basis.
[b] Includes ^{238}U series, ^{232}Th series, ^{40}K and cosmic ray equivalent.
[c] PIC: pressurized ionization chamber.
[d] Built about the time of the accident or afterwards.

TABLE 15. Bragin: Outdoor Dose Rate Measurements, Mainly Grass Covered Sites
(Sampling conducted by the international team) [*Source: H. Lettner and team*]

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2
11	Restaurant, Bragin, front garden	Grass covered	0.45	
31	Sovetskaya, bank building	Grass covered	0.50	
51	Sovetskaya, 100 m N of bank	Grass covered, partly asphalted	0.80	
61	Sovetskaya, 150 m N of bank	Grass covered, partly asphalted	0.60	
91	Sovetskaya	Grass covered, partly asphalted	0.30	
181	Mampkina 40, sidewalk		0.45	
191	Mampkina 30	Grass covered	0.40	
201	Mampkina 13	Grass covered	0.50	
251	Skorokhoda 17	Grass covered	0.40	
301	Partizanskaya 11	Grass covered	0.35	
321	Partizanskaya 19	Grass covered	0.36	
341	Partizanskaya 37	Grass covered	0.34	
371	Partizanskaya crossing, near pond	Grass covered	0.20	
381	Partizanskaya crossing, street corner	Grass covered	0.22	
391	Partizanskaya crossing	Grass covered	0.34	
401	Partizanskaya NW crossing	Grass covered	0.42	
421	Zelenaya 7	Grass covered	0.38	
461	Collective farm, machinery park	Grass covered	0.41	
491	Zelenaya/Kalininaya crossing	Grass covered	0.23	
511	Kalininaya 8	Grass covered	0.32	
551	Pionerskaya, opposite No. 35	Grass covered	0.27	
571	Pionerskaya, meadow	Grass covered	0.51	
591	Pionerskaya 24	Grass covered	0.38	
601	Pionerskaya 14	Grass covered	0.37	
651	Pionerskaya main street, near store	Grass covered	0.23	
671	Meadow W of main street	Grass covered	0.42	
681	50 m SW of meadow W of main street	Grass covered	0.51	
691	150 m SW of meadow W of main street	Grass covered	0.68	
701	300 m SW of meadow W of main street	Grass covered	0.72	
731	Manzhosa 18	Grass covered	0.57	
741	Manzhosa 26	Grass covered	0.21	
751	Gagarina 31	Grass covered	0.42	
761	Gagarina	Grass covered	0.29	

TABLE 15. (cont.)

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2
83l	Pervomajskaya 35	Grass covered	0.36	
84l	Komsomol'skaya 15	Grass covered	0.20	
88l	Komsomol'skaya, opposite No. 44	Grass covered	0.37	
90l	Komsomol'skaya 45, edge of street	Grass covered	0.22	
1z	Sports ground		0.68	
2z	Gidromet station		1.32	
3z	Gidromet, back yard	Grass covered	1.92	
4z	Car training yard	Sandy, grass covered	0.51	
5z	Memorial park	Sandy, grass covered	0.90	
6z	In front of restaurant, Bragin	Grassy sidewalk	0.45	
7z	Beside restaurant, Bragin	Grass covered	1.32	
8z	Post Office, Sovetskaya 15	Grass covered	0.61	
9z	Sovetskaya 21	Grass covered	0.63	
10z	Sovetskaya 29	Grass covered	0.67	
11z	Sovetskaya 37	Grass covered	0.73	
12z	Sovetskaya 45	Grass covered	0.65	
13z	Sovetskaya 45, garden	Grass covered	1.42	
14z	Sovetskaya 49	Grass covered	0.70	
15z	Sovetskaya 69	Grass covered	0.37	
16z	Sovetskaya 79	Grass covered	0.25	
17z	Partizanskaya 2	Grass covered	0.34	
18z	Mampkina 54	Grass covered	0.29	
20z	Mampkina 56	Grass covered	0.36	
21z	Mampkina 42	Grass covered	0.49	
22z	Mampkina 36	Grass covered	0.83	
23z	Mampkina 28	Grass covered	0.85	
24z	Mampkina 3	Grass covered	0.81	
25z	Mampkina 4	Grass covered	0.83	
29z	Lawn by storehouse, Mampkina	Grass covered	0.80	
30z	Park by storehouse, Mampkina	Sandy and grass covered	0.72	
31z	Same, further south, Mampkina	Sandy and grass covered	1.05	
32z	Skorokhoda 6		1.12	
33z	Skorokhoda 8	Grass covered	1.20	
35z	Skorokhoda 6	Grass covered	0.86	
37z	Kooperativnaya 10	Grass covered	0.70	
40z	Partizanskaya 22	Grass covered	0.60	

TABLE 15. (cont.)

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2
41z	Partizanskaya 34	Grass covered	0.69	
42z	Partizanskaya 36	Grass covered	0.33	
43z	Partizanskaya, main road crossing	Grass covered	0.51	
44z	Partizanskaya, same as 43, by the road	Grass covered	0.17	
45z	In front of TV tower	Grass covered	0.72	
47z	Entrance to TV tower	Grass covered	0.31	
48z	Zelenaya/Berezka crossing	Grass covered	0.56	
49z	Farm machinery station	Grass covered	0.45	
50z	Zelenaya 43	Grass covered	0.35	
51z	Kalininaya 19	Grass covered	0.33	
55z	Pionerskaya 25	Grass covered	0.35	
56z	Pionerskaya 21, garden	Grassy	0.60	
57z	Pionerskaya 3	Grass covered	0.32	
58z	Pionerskaya, main road crossing	Grass covered	0.42	
59z	Lugovaya 2	Grass covered	0.55	
60z	Lugovaya 16	Grass covered	0.62	
61z	Main road 1/2, TV and fire station	Grass covered	0.70	
62z	Manzhosa 18	Grass covered	0.43	
63z	Manzhosa/Gagarina crossing	Grass covered	0.35	
64z	Gagarina 40	Grass covered	1.12	
65z	Gagarina, new blocks	Grass covered	0.69	
66z	Pervomajskaya 10	Grass covered	0.28	
67z	Pervomajskaya 22	Grass covered	0.55	
68z	Komsomol'skaya 8	Grass covered	0.55	
69z	Komsomol'skaya 22	Grass covered	0.30	
70z	Komsomol'skaya 46	Grass covered	0.30	
1s	Sovetskaya		0.28	0.28
2s	Sovetskaya 96	Grass covered	0.22	0.30
3s	Sovetskaya 100/103	Grass covered	0.22	0.19
4/as	Sovetskaya 104		0.19	0.19
5s	Sovetskaya 116/94	Grass covered	0.20	0.20
6s	Sovetskaya 118	Grass covered	0.22	0.15
7s	Sovetskaya 118, next to the house	Grass covered	0.28	0.28
8s	Sovetskaya 132/111	Grass covered	0.22	0.27
9s	Sovetskaya 117/142	Grass covered	0.20	0.28
11s	Sovetskaya/Avaresar, end of road	Grass covered	0.14	0.14

TABLE 15. (cont.)

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2
13/a	Sovetskaya 148/119	Grass covered	0.40	0.49
14s	Sovetskaya 127/154	Grass covered	0.28	0.22
15s	Sovetskaya 135/162	Grass covered	0.30	0.21
20s	Sovetskaya 182/155	Grass covered	0.22	0.20
21s	Sovetskaya	Grass covered	0.30	0.30
22s	Sovetskaya 192	Grass covered	0.24	0.15
23s	Road crossing	Grass covered	0.20	0.15
24/as	Same place, Sovetskaya 194	Grass covered	0.40	
26s	Last house in the street	Grass covered	0.14	
27s	Sovetskaya, main road crossing	Grassy	0.32	0.34
28s	First side road in Sovetskaya: No. 1	Grass covered	0.28	0.29
29s	No. 3	Grassy	0.34	0.36
31s	Extension	Grass covered	0.32	0.32
32s	No. 27	Grass covered	0.30	0.35
33s	House at curve	Grass covered	0.20	0.22
33/as	Vostonyar, garden in street	Grassy	0.36	0.38
34s	Vostonyar, open field	Grassy	0.25	
35s	Vostonyar 36	Grass covered	0.18	0.22
36s	Vostonyar 28	Grass covered	0.16	0.17
38s	Vostonyar, meadow	Grassy	0.44	0.23
38/as	Vostonyar, meadow	Grassy	0.36	0.31
39s	Side road from Sovetskaya	Grass covered	0.34	0.35
40s	First parallel to Sovetskaya, crossing	Grass covered	0.40	0.24
41s	Same as 40, next crossing	Grass covered	0.24	0.28
42s	Same as 41, next crossing	Grass covered	0.24	0.26
43s	Street between Sovetskaya 42 and 44	Grass covered	0.24	
44s	Same as 42, next crossing	Grass covered	0.40	0.26
45s	Same street, No. 103/72	Grass covered	0.20	0.23
47s	Same street, No. 115	Grass covered	0.32	0.34
48s	Same street, No. 119	Grass covered	0.24	0.25
49s	Meadow beside No. 48	Grassy	0.38	
50s	Same street, No. 125	Grass covered	0.25	0.34
51s	Same street, No. 129 crossing	Grass covered	0.26	0.28
52s	Same street, No. 182, meadow	Grassy	0.40	
53s	Same street, sports ground	Grassy	0.20	
53/as	Same as 53, right side	Grassy		0.50

TABLE 15. (cont.)

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2
54s	Next crossing	Grass covered	0.32	0.30
55s	Same street, No. 47/56	Grass covered	0.27	0.35
56s	Last crossing, Sovetskaya	Grass covered	0.56	0.24
1g	Football stadium	Under trees (in situ)	0.70	0.75
2g	Same as 1, 100 m NE	Under trees	0.75	0.75
3g	Kirova 100 m from main square	Sidewalk, grass covered	0.50	0.40
4g	Kirova road 200 m from main square	Sidewalk, grass covered	0.35	0.35
6g	Kirova road crossing 50 m from 5	Grass covered	0.40	0.40
7g	Kirova/Pushkina crossing	Grass covered	0.40	0.40
8g	Kirova/Krasnoarmejskaya crossing	Grass covered	0.35	0.45
9g	Krasnoarmejskaya, public water supply	Grass covered	0.30	0.30
10g	Krasnoarmejskaya, 100 m NW of 9	Grass covered	0.40	0.40
11g	Football stadium, centre	Lawn	0.40	0.40
12g	Krasnoarmejskaya/side street crossing	Grass covered	0.45	0.35
13g	Side street 110 m SE of 12	Grass covered	0.30	0.50
14g	Side street 200 m SE of 12	Grass covered	0.40	0.45
15g	Side street 300 m SE of 12	Grass covered	0.45	0.40
16g	Side street 400 m SE of 12	Grass covered	0.60	0.50
18g	Side street bend 50 m NE of 16	Grass covered	0.35	0.40
19g	Side street dead end 50 m NW of 18	Grass covered	0.55	0.50
20g	Kirova road, SW park corner	Grass covered	0.40	0.35
21g	Dead end street 100 m SE of 20	Grass covered	0.40	0.30
22g	Street 150 m S of 20	Grass covered	0.55	0.65
23g	Street 250 m S of 20	Grass covered	0.50	0.35
24g	Across Zinovicha from 23	Grass covered		0.55
25g	Zinovicha, 100 m W of 23/24	Grass covered	0.30	0.40
26g	Zinovicha, 200 m W of 23/24	Grass covered	0.50	0.45
27g	Zinovicha, 300 m W of 23/24	Grass covered	0.60	0.65
29g	Zinovicha, 150 m from 27		0.50	0.65
30g	Side street to Kirova 20	Grass covered	0.70	0.65
31g	Kriav, SW park end 100 m from 20	Grass covered	0.60	0.70
32g	Same as 31, 200 m from 20	Grass covered	0.60	1.05
33g	Kriav/Oktyabr'skaya crossing	Grass covered	0.70	0.70
35g	Oktyabr'skaya 9, 100 m from 33	Grass covered	0.60	0.80
36g	Oktyabr'skaya 23/Chaliaze crossing	Grass covered	0.60	0.45
37g	Oktyabr'skaya, end paved road 200 m from 36	Grass covered	1.20	1.20

TABLE 15. (cont.)

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2
38g	Pesochnaya, side street of Oktyabr'skaya	Grass covered	0.80	1.05
39g	Pesochnaya, 100 m from 38	Grass covered	0.80	0.90
40g	Pesochnaya, 200 m from 38	Grass covered	0.50	0.85
41g	Kirova, SE end of Lenin Square	Grass covered	0.60	0.65
42g	Kirova, 100 m SE of 41	Grass covered	—	0.45
44g	Kirova 11, 100 m SE of 41	Grass covered	—	0.50
46g	Kirova 19, opposite 5	Grass covered	0.40	0.40
47g	Kirova 100 m SE of 46	Grass covered	0.40	0.40
49g	Kirova 37/Krasnoarmejskaya crossing	Grass covered	0.45	0.35
50g	Kirova 53, 100 m from 49	Grass covered	0.40	0.45
52g	Kirova 59	Grass covered	0.35	0.25
55g	Kirova, end of village	Grass covered	0.35	0.35
58g	Krasnoarmejskaya, 100 m SW of 49	Grass covered	0.35	0.45
61g	Krasnoarmejskaya, 100 m E of 60	Grass covered	0.25	0.35
62g	Krasnoarmejskaya, 200 m E of 60	Grass covered	0.40	0.40
63g	Krasnoarmejskaya, 300 m E of 60, dead end street	Grass covered	0.35	0.45
64g	Krasnoarmejskaya, 100 m NW of 60	Grass covered	0.50	0.55
65g	Krasnoarmejskaya, 100 m NW of 60	Grass covered	0.35	0.35
66g	Kirova/Pushkina (repetition of 8)	Grass covered	0.35	0.45
67g	Pushkina, 100 m SE of 66	Grass covered	0.40	0.40
69g	Pushkina 9 (repetition of 59)	Grass covered	0.40	0.40
71g	Lenin Square/park corner	Grass covered	0.80	0.60
72g	Oktyabr'skaya 6	Grass covered	0.70	0.55
73g	Oktyabr'skaya 12	Grass covered	0.70	0.55
74g	Oktyabr'skaya 16/18	Grass covered	0.40	0.60
75g	Kriav/Oktyabr'skaya	Grass covered	0.40	0.40
76g	Kriav 100 m NW of 75	Grass covered	0.40	0.55
81g	Same as 80, opposite side	Grass covered	—	0.55
84g	Chaliaze 19, 300 m NW of 80	Grass covered	0.90	0.70
85g	Chaliaze 25, 400 m NW of 80	Grass covered	0.90	1.20
93g	Traffic circle 50 m from 92	Grass covered	0.35	0.30
97g	Aerodromnaya, 100 m NE of 84	Grass covered	1.10	0.70
99g	Aerodromnaya 9, 100 m N of 97	Grass covered	1.20	1.20
100g	Aerodromnaya 20, 200 m N of 97	Grass covered	0.70	0.90
104g	Sovetskaya 147/149	Grass covered	0.35	0.50
105	Komsomol'skaya, 100 m W of 104	Grass covered	0.45	0.45

TABLE 15. (cont.)

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2
106	Pervomajskaya, 150 m NE of 105	Grass covered	0.45	0.40
107	Pervomajskaya/Sovetskaya, 300 m NE of 105	Grass covered	0.40	0.35
109	Sovetskaya, 100 m S of 107	Grass covered	0.35	0.30
110	Sovetskaya, 200 m S of 107	Grass covered	0.35	0.35
111	Sovetskaya, 300 m S of 107, opposite 104	Grass covered	0.45	0.45

Indoor dose rates were mostly in the range from 0.1 to 0.45 μSv/h (Table 24). The exceptions are buildings under construction at the time of the accident (see Table 24, Sites 9z, 3s and 4s) with elevated levels $\leq$0.63 μSv/h. The highest value, 1.5 μSv/h, was found in a stone dwelling. Many buildings were fitted with new roofs in the post-accident phase.

Since the fallout pattern in this town is extremely heterogeneous, the data on the officially provided map for the total caesium deposition (Fig. 38) can be considered to be in reasonable agreement with the outdoor dose rate data as measured by the international team (Tables 22 and 23; Fig. 39).

(3) *Daleta:* Outdoor dose rate values are rather uniform and low (under 0.5 μSv/h), reflecting the relatively low fallout deposition in the area. The indoor values are also low and are within the range of the natural background (under 0.2 μSv/h).

Figure 40 shows the official Soviet data for the dose rate outdoors and, for comparison, the corresponding data collected by the international team. There is satisfactory agreement between both data sets.

3.2.2. Soil Sampling

Soil sample columns (diameter: 5 cm) for depth profiles from 0 to 15 cm were collected in areas of Bragin and Polesskoe. Caesium and cobalt isotopes were analysed with conventional Ge(Li) gamma spectrometers; cerium and antimony isotopes were analysed with anticoincidence shielding in order to reduce the Compton background of some higher energy photons.

The sample descriptions are listed in Table 27. No equivalent sets of Soviet data were provided to the international team. The following radionuclides could be detected in the soil: ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{60}Co, ^{106}Ru and ^{125}Sb, with the Cs isotopes predominant ($\leq$170 kBq/kg; Fig. 41).

With regard to the depth distribution, four out of five soil columns show a maximum activity concentration at a depth of 2–3 cm. The decrease below this depth is close to exponential; only in soil column 14 (river flood area) is the maximum to be found in the uppermost layer, probably owing to runoff phenomena and sedimentation.

3.2.3. Field Gamma Spectrometry

Field gamma spectrometry was carried out at eight sites outdoors in Bragin and Polesskoe with a HPGe detector (18.5% relative efficiency) at 1 m above ground, collecting spectra in the interval 50–4000 keV (measurement period: 60 min). Full absorption peak count rates were converted to activity on the ground (kBq/m^2) and dose rate (μSv/h) using calibration factors of the HPGe detector and exponential source distribution parameters that were determined from the gamma spectra obtained.

In Table 28, the results of the in situ gamma spectrometric measurements are compared with the officially reported Soviet data. There is satisfactory agreement between the total deposition, as measured by the international team, and the official Soviet data.

3.2.4. Indoor Radon and Gamma Dose Rate Measurements

For radon measurements, electret detectors (type E-PERM^{TM}/Rn) with exposure periods of up to three months were used in order to determine long term averages [16]. The environmental background radiation was accounted for by using a second set of electret detectors (type E-PERM^{TM}/background), sealed in a foil bag impermeable to radon. Detectors from this second set

TABLE 16. Bragin: Dose Rates Over Asphalt Covered Sites
(Sampling conducted by the international team) [*Source: H. Lettner and team*]

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2
61	Dairy plant	Asphalt	0.23	
81	Sovetskaya, 150 m N of Bank Street	Asphalt	0.30	
131	Partizanskaya/Sovetskaya crossing	Asphalt	0.20	
151	Partizanskaya 6, on street	Asphalt	0.30	
211	Mampkina, milk market	Asphalt	0.25	
221	Mampkina, bus station	Asphalt	0.15	
311	Partizanskaya 11	Asphalt	0.35	
331	Partizanskaya 19, street	Asphalt	0.25	
351	Shapoval, S Oktyabr'skaya 8/4[a]	Asphalt entrance	0.29	
431	Astrejko, N Kooperativnaya 19/1, front of house[a]	Partly asphalt	0.55	
361	Partizanskaya 37, street	Asphalt	0.24	
411	Partizanskaya NW crossing, street	Asphalt	0.35	
431	Zelenaya 7, street	Asphalt	0.24	
481	Machinery park/collective farm, street	Asphalt	0.19	
501	Zelenaya/Kalininaya, crossing on street	Asphalt	0.18	
521	Kalininaya 8, street	Asphalt	0.32	
541	Kalininaya/Pionerskaya, crossing	Partly paved	0.26	
561	Pionerskaya, opposite 35, on street	Asphalt	0.28	
581	Pionerskaya/Berezka, crossing	Asphalt	0.24	
611	Pionerskaya 14, street	Asphalt	0.27	
641	Pionerskaya, store, outside pavement	Sidewalk	0.23	
661	Pionerskaya, main street near store, on street	Asphalt	0.23	
771	Gagarina, on street	Asphalt	0.21	
801	Pervomajskaya 9, on street	Asphalt	0.32	
851	Komsomol'skaya 15, on street	Asphalt	0.20	
891	Komsomol'skaya 44, on street	Asphalt	0.33	
911	Komsomol'skaya 47, street, entrance to dairy	Asphalt	0.24	
26z	Mampkina, bus station	Asphalt	0.14	
8z	Lenin Square, Town Hall	Asphalt	0.15	
39z	Lenin Square 6	Flower bed+stone block pavement	0.52	
46z	In front of TV tower	Stone, sand, concrete	0.14	
10s	Sovetskaya/Avaresar	Asphalt	0.14	
17s	Sovetskaya 149/176	Asphalt	0.10	0.17
30s	Sovetskaya 13	Asphalt	0.14	0.16
37s	Sovetskaya, opposite 12, street	Asphalt	0.14	
5g	Kirova, public water supply	Asphalt paved	0.35	0.35
102g	Path 150 m SE of 101	Paved path	0.90	0.55
103g	Path/Kriav 300 m SE of 101	Paved path/road, grass covered	0.90	0.70

[a] Home of an individual given a personal dosimeter as part of the independent dose assessment task.

TABLE 17. Bragin: Dose Rates Over Undisturbed Areas [*Source: H. Lettner and team*]

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2
21	Sovetskaya, parking place	Ploughed	0.80	
101	Sovetskaya, uninhabited house	Uncultivated garden	0.35	
141	Partizanskaya 2, garden	Uncultivated	0.30	
241	Mampkina, behind bus station	Birchyard	1.00	
281	Skorokhoda, S of bus station	Meadow, unploughed	0.60	
291	Skorokhoda, S of bus station	Meadow, unploughed	1.40	
351	Partizanskaya 37, uninhabited garden	Uncultivated	0.59	
471	Collective farm, machinery park	Sandy soil	0.35	
531	Kalininaya 8, garden	Uncultivated	0.47	
811	Pervomajskaya crossing	Under trees	0.54	
821	Pervomajskaya crossing	Stinging nettle field	0.51	
861	Komsomol'skaya 23, garden	Uncultivated	0.43	
871	Komsomol'skaya, cemetery	Under trees	0.47	
24s	Komsomol'skaya, same as 23, garden	Uncultivated	0.52	0.61
37/bs	Komsomol'skaya, opposite 21, garden	Uncultivated		0.45
46s	Komsomol'skaya, same street No. 109/80	Meadow	0.28	0.22
46/cs	Komsomol'skaya, same as 46/s, chicken yard	Soil	0.40	0.43
17g	Komsomol'skaya, between 15 and 16	Uncultivated garden		0.55
28g	Zinovicha 21, 100 m off road	Uncultivated garden	1.30	1.15
28ag	Same as 28	—	0.90	0.80
34g	Oktyabr'skaya 5	Uncultivated garden	0.60	0.85
34ag	—	—	1.05	1.05
51g	Kirova, 100 m off road	Uncultivated riverside		0.25
57g	Cemetery 400 m from 52	Uncultivated	0.60	0.70
59g	Krasnoarmejskaya, 200 m SW of 49	Uncultivated garden/potato field	0.55	0.50
70g	Lenin Square 2, 100 m off road	Uncultivated riverside		0.90
77g	Side street 50 m SW of 76, playground 30 m off road	Unpaved	0.40	0.40
87g	Chaliaze, cemetery 50 m off road	Uncultivated	1.5	3.0
88g	Chaliaze 44, 200 m W of 85	Garden/fence, cemetery	0.90	1.10
89g	Chaliaze 54, 300 m W of 85	Garden/fence, cemetery	1.00	0.75
108g	Sovetskaya, 100 m N of 107	Uncultivated field/garden	0.35	0.40

TABLE 18. Bragin: Dose Rates Over Cultivated Sites (Gardens and Fields) [*Source: H. Lettner and team*]

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2
1l	Ivanenko L., Naberezhnaya 59[a]	Cultivated garden	0.22	
19l	Romanyuk V., Ignatienko 13[a]	Garden entrance, cultivated	0.23	
7l	Sovetskaya, 150 m N of bank garden	Cultivated	0.50	
11l	Sovetskaya, house, back yard potato field	Cultivated	0.35	
16l	Partizanskaya 6, garden	Cultivated	0.50	
26l	Skorokhoda 17, garden	Cultivated	1.10	
44l	Zelenaya 7, garden	Cultivated	0.36	
71l	700 m SW of meadow W of main street	Rape field, ploughed	0.51	
72l	700 m SSW of meadow W of main street	Potato field	0.41	
19l	Partizanskaya 18, garden	Cultivated	0.52	
53l	Kalininaya 19, garden	Cultivated	0.37	
54l	Pionerskaya 39, garden	Cultivated	0.39	
4s	Sovetskaya 89, garden	Cultivated	0.30	0.35
7/bs	Sovetskaya 118, garden	Cultivated	0.30	0.33
12s	Sovetskaya 144, garden	Cultivated	0.38	0.32
18s	Sovetskaya 141, garden	Cultivated	0.36	0.40
25s	Potato field	Cultivated	0.24	
26/as	Sovetskaya, meadow	Cultivated	0.30	0.40
32/bs	Sovetskaya 27, garden	Cultivated	0.30	
32/cs	Sovetskaya 27, strawberry field	Cultivated	0.36	0.44
32/ds	Sovetskaya 27, grape vines	Cultivated	0.46	0.44
36/as	Vostonyar 37, garden	Cultivated	0.32	0.32
36/es	Vostonyar 39, garden	Cultivated	0.30	0.40
46/as	Vostonyar 80, garden	Cultivated	0.40	0.44
46/es	Same as 46/d, garden	Cultivated	0.44	0.44
53g	Kirova	Garden/field	0.25	0.30
54g	Kirova 71	Cultivated garden	0.40	
60g	Krasnoarmejskaya, 300 m SW of 49	Cultivated garden	0.40	0.35
68g	Pushkina 8	Garden/potato field	0.35	0.40
78g	Side street, 100 m SW of 76/5	Cultivated garden	0.80	0.75
79g	Side street, 200 m SW of 76/11	Cultivated garden	0.60	0.70
80g	Side street, 300 m SW of Chaliaze 76	Cultivated garden	0.90	0.70
82g	Chaliaze, 100 m NW of 80	Garden/industrial area	0.60	0.30
83g	Chaliaze 16, 200 m NW of 80	Potato field	1.20	1.10
86g	Chaliaze, 100 m W of 85	Cultivated garden	1.20	1.00
90g	Chaliaze 62/47, 400 m W of 85	Cultivated garden	0.60	0.80
91g	Chaliaze, 500 m W of 85, end of village	Cultivated garden	0.80	0.55
92g	Chaliaze, 600 m W of 85, 5 m in field	Cultivated field	0.90	1.15
94g	Chaliaze 54, 100 m off road	Potato field	1.30	1.20
95g	Chaliaze 40, 50 m off road	Cultivated garden	1.40	1.35
96g	Chaliaze 25	Ploughed/unploughed field	1.35	2.2
98g	Aerodromnaya, 100 m E of 97, dead end	Potato field	1.10	0.70
43g	Kirova 4	Cultivated garden	0.80	—
48g	Kirova 24	Cultivated garden	0.50	—
49l	Pionerskaya 45[a]	Cultivated garden	0.27	0.37

[a] Home of an individual given a personal dosimeter as part of the individual dose assessment task.

TABLE 19. Bragin: Various Other Sites [*Source: H. Lettner and team*]

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2
791	Pervomajskaya 9, sidewalk	Sand covered		0.24
7/as	Sovetskaya 118, roof		0.20	0.20
13/bs	Sovetskaya 148, roof		0.38	0.37
16s	Sovetskaya 141	Soil	0.34	0.34
21/as	Sovetskaya, mud hole on the street	Soil	0.10	
26/bs	New sand road	Sand covered	0.10	
32/as	New sand road, No. 27, in the yard	Soil		0.27
36/bs	Vostonyar 37, straw roof		0.60	0.81
36/cs	Vostonyar 39, courtyard	Soil	0.20	0.25
36/ds	Vostonyar 39, hayloft		0.30	0.30
37/as	Vostonyar 21, courtyard	Soil	0.36	0.30
37/ds	Vostonyar 21, roof		0.40	0.40
50/as	Same as 50, roof		0.32	
45g	Kirova, side street between 8 and 10	Unpaved	1.00	
56g	Kirova, side street	Unpaved	0.40	0.50
101g	Path, 150 m E of 100	Unpaved path	1.89	1.50
471	Collective farm: outside machinery park	Partly grass, sand	0.22	0.39
581	outside, in front of cereal depot		0.30	0.36
591	inside depot		0.14	0.19
601	outside depot		0.25	0.38
611	hay store		0.24	0.39
621	hay from 1989		0.29	0.36
631	wooden stable		0.42	0.50

were exposed simultaneously with the radon detectors. In addition, a portable rate meter was used for dose rate measurements at the same locations. All E-PERM™ detectors were read at the measurement site upon completion of the exposure.

No equivalent sets of Soviet data were provided to the international team. The results of the analysis are summarized in Table 29 and show that the ^{222}Rn concentration indoors in Bragin covers a wide range, from 9 to 470 Bq/m^3 (mean 139 $\pm$ 183 Bq/m^3). However, if sites 8–10 are excluded, assuming that there was low ventilation and the detector was manipulated, the variation decreases significantly. The mean concentration is lowered to 28 $\pm$ 13 Bq/m^3. This is of a magnitude comparable with that of the results of ^{222}Rn measurements in Daleta (mean: 19 $\pm$ 20 Bq/m^3; Table 29).

Indoor gamma dose rate values, derived from integrating measurements over a period of about three months with E-PERM™/background type detectors, ranged from 0.16 to 0.38 μSv/h for Bragin and 0.14 to 0.46 μSv/h for Daleta. These ranges correspond well with values determined during the detailed independent dose rate surveys (see Section 3.2.1). A comparison of the mean values (n = number of measurements) obtained with E-PERM™/background detectors (mean (n=17): 0.24 $\pm$ 0.09 μSv/h) and with a portable rate meter (mean (n = 15): 0.23 $\pm$ 0.15 μSv/h) shows almost perfect agreement between the two methods.

Text cont. on p. 160

TABLE 20. Bragin: Dose Rate Measurements in Wooden Buildings [*Source: H. Lettner and team*]

Sample No.	Location		Dose rate (μSv/h) Instrument No. 1	No. 2
121	Sovetskaya, inside house		0.25	
171	Partizanskaya 6, indoors		0.20	
271	Skorokhoda 17, indoors		0.40	
451	Zelenaya 7, house		0.25	
621	Pionerskaya 8, indoors		0.21	
34z	Skorokhoda 8		0.23	
36z	Skorokhoda 6		0.28	
52z	Kalininaya 19		0.12	
481	Collective farm, repair shop, ground floor		0.21	0.27
21	Naberezhnaya 59[a]:	entrance	0.18	0.26
31		living room	0.14	0.20
41		bedroom	0.14	0.14
121	Sovetskaya 127[a]:	kitchen	0.13	0.15
131		living room	0.14	0.20
141		bedroom	0.13	0.19
151		bedroom	0.12	0.22
161	Makhova 119[a]:	kitchen	0.12	0.15
71		living room	0.07	0.14
181		bedroom	0.08	0.18
501	Pionerskaya 45[a]:	kitchen	0.23	0.27
511		living room	0.15	0.24
521		bedroom	0.12	0.17
531		bedroom	0.11	0.24
641	Soboli[a]:	kitchen	0.19	0.19
651		living room	0.14	0.20
661		bedroom	0.10	0.20
671	Soboli[a]:	kitchen	0.14	0.17
681		living room	0.08	0.11
691		bedroom	0.07	0.07
13s	Soboli 148		0.18	0.22
18as	Soboli 141		0.10	0.13
32/esx	Soboli 127		0.10	0.13
36/fsx	Vostonyar 39		0.08	0.10
36/gsx	Vostonyar 35		0.10	0.10
37/csx	Vostonyar 21		0.10	0.11
46/bsx	Same as 46/a		0.10	0.13
46/dsx	Same street, No. 107			0.18
48ag	Kirova 24		0.30	
53ag	Kirova 59			0.15
54ag	Kirova 71		0.30	
96ag	Chaliaze 25			0.40

[a] Home of an individual given a personal dosimeter as part of the independent dose assessment task.

TABLE 21. Bragin: Dose Rate Measurements in Masonry Buildings [*Source: H. Lettner and team*]

Sample No.	Location	Dose rate (μSv/h) Instrument No. 1	No. 2
41	Sovetskaya, bank building	0.20	
231	Mampkina, shop at the bus station	0.50	
631	Pionerskaya, store, stone building	0.17	
781	Kooperativnaya, public baths	0.17	
27z	Mampkina, bus station	0.14	
28z	Mampkina, storehouse	0.15	
19s	Sovetskaya, food shop		0.10
71	Laboratory	0.15	0.18
81	Reconstruction site, brick	0.08	0.12
91	Cheese production hall, brick	0.11	0.19
101	Metal repair shop, brick building	0.08	0.20
111	Office	0.09	0.09
201	Living room	0.10	0.07
211	Bedroom	0.07	0.08
221	Kitchen	0.12	0.13
241	Polyclinic, entrance hall	0.11	0.15
251	Polyclinic, 1st floor	0.16	0.27
261	Polyclinic, 2nd floor	0.17	0.16
271	Astrejkho, office in 'Raissa' Polyclinic[a]	0.12	0.23
281	Rudenok, chemist shop in 'Lyudmilla' Polyclinic[a,b]	0.19	0.27
291	X ray room behind protective shielding[c]	95	
301	Shapoval, 'Svetlana' dental surgery[a]:	0.10	0.13
311	work room	0.10	0.16
321	living room, kitchen	0.13	0.13
331	Oktyabr'skaya 8/4: living room	0.08	0.13
341	bedroom	0.11	0.18
361	Lilyakhrilova 2/8[a]: bedroom	0.10	0.14
371	kitchen	0.08	0.13
381	living room	0.09	0.18
391	Kooperativnaya 19/1[a]: entrance	0.07	0.08
401	bedroom	0.10	0.13
411	living room	0.12	0.10
421	kitchen	0.08	0.09
441	Krilova 15/5[a]: sleeping/living room	0.10	0.12
451	kitchen	0.16	0.20
461	sleeping/living room	0.08	0.15
541	Zelenaya 8[a]: entrance	0.13	0.18
551	kitchen	0.12	0.15
561	living room	0.8	0.14
571	bedroom	0.17	0.16

[a] Home of an individual given a personal dosimeter as part of the independent dose assessment task.
[b] Dosimeter was kept there permanently.
[c] X ray in operation.

TABLE 22. Polesskoe: Outdoor Dose Rates, Mainly Grass Covered Sites [*Source: H. Lettner and team*]

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2	No. 3
1z	Park in front of Town Hall	Grass covered	0.84		
2z	Cemetery	Grass covered	2.05		
3z	Vladimirskaya 38, garden	Grass covered	1.82		
4z	Same as 3, on ground	Grass covered	8.2		
6z	Shchorsa 32	Grass covered	0.73		
8z	Corner Gogol/Shchorsa	Grass covered	0.38		
10z	Gogol	Grass covered, uncultivated	1.10		
11z	Gor'kij 1	Grass covered	0.39		
15z	1st cross street W of Gor'kij	Small park, grass covered	1.30		
16z	Zhostneva 20	Grass covered	0.41		
17z	2nd cross street W of Gor'kij	Grass covered	1.24		
18z	Gor'kij 25	Grass covered	0.64		
19z	Gor'kij 35	Grass covered	0.72		
20z	3rd cross street W of Gor'kij	Grass covered	1.23		
21z	Kotovskaya	Grass covered	1.05		
22z	Volya 40	Grass covered	0.67		
23z	Field outside town, by river	Grass covered, uncultivated	2.30		
1s	Bereznaya 2		0.60	0.40	0.75
2s	Bereznaya 4	Grass covered	1.0	1.0	0.8
3s	Bereznaya 8	Grass covered	0.9	0.8	0.6
4s	Bereznaya 8	Marked hot spot	1.3	1.2	1.2
5s	Bereznaya 8	Hot spot on the ground	2.0	2.0	2.0
6s	Bereznaya 10	Grass covered	0.6	0.6	0.6
7s	Bereznaya 14	Grass covered	0.9	0.7	0.4
8s	Bereznaya 16	Grass covered	0.65	0.5	0.65
9s	Volya 79	Grass covered	1.0	0.7	0.8
14s	Volya 67	Grass covered	1.0	1.0	0.7
15s	Volya 65	Grass covered	0.8	0.6	
20s	Volya 53		0.9	0.5	
21s	Volya 46	Grass covered	0.9	0.75	
24s	Volya 33		0.75	0.7	0.6
25s	Volya 9	Grass covered	0.6	0.35	0.5
27s	Same street, No. 69		0.3	0.27	0.3
28s	Naderzhnaya/Proletarskaya crossing	Grass covered	0.4	0.35	0.4
29s	Cemetery		0.65	0.6	0.8
30s	Cemetery		0.7	0.7	0.5

TABLE 22. (cont.)

Sample No.	Location	Description of site	Dose rate (μSv/h)		
			Instrument		
			No. 1	No. 2	No. 3
31s	Cemetery		1.2	1.2	1.1
32s	Proletarskaya 80	Grass covered	0.6	0.4	0.4
33s	Proletarskaya 70	Grass covered	0.5	0.35	0.5
34s	Rechnaya 1	Grass covered			0.45
35s	Proletarskaya 64	Grass covered	0.4	0.5	
37s	Proletarskaya 46	Grass covered	0.6	0.5	0.5
38s	Proletarskaya 32	Grass covered	0.7	0.5	0.5
39s	Proletarskaya 28	Grass covered			0.8
41s	Proletarskaya 16	Grass covered	0.8	0.6	0.7
44s	Proletarskaya 4	Grass covered	0.6	0.4	0.4
45s	Shevchenko 1	Grass covered	0.7	0.5	
46s	Shevchenko 9	Grass covered	0.8	0.7	0.5
47s	Shevchenko 18	Grass covered	0.65	0.4	0.6
48s	Shevchenko 22	Grass covered	0.55	0.35	
49s	Between Shevchenko and Proletarskaya	Grass covered	0.6	0.4	
53s	Shevchenko 25	Grass covered			0.7
54s	Shevchenko 35	Grass covered			0.8
56s	Shevchenko 43	Grass covered	0.5	0.4	0.45
57s	Shevchenko 53	Grass covered	0.5	0.4	0.5
58s	Shevchenko 65	Grass covered	0.6	0.45	0.45
59s	Proresnaya 62	Grass covered	0.7	0.5	0.4
60s	Proresnaya 54	Grass covered	0.7	0.5	0.5
61s	Proresnaya 44	Grass covered	0.6	0.4	0.45
62s	Proresnaya 67	Grass covered	0.7	0.5	0.5
63s	Proresnaya 32	Grass covered	0.8	0.6	0.75
64s	Proresnaya 24	Grass covered	1.0	0.85	0.85
65s	Proresnaya 18	Grass covered	0.8	0.6	0.6
66s	Travin 3	Grass covered	0.9	0.7	1.1
67s	Travin 6	Grass covered	0.7	0.7	0.6
68s	Travin 23	Grass covered	0.7	0.5	0.45
78s	Travin 53	Grass covered	1.1	1.1	1.2
79s	Travin 69	Grass covered	0.6	0.6	0.7
80s	Travin 83	Grass covered	0.6	0.4	0.4
81s	Travin 95	Grass covered	0.6	0.5	0.7
84s	Travin 107	Grass covered	1.0	1.0	0.6
85s	Travin side street 1	Grass covered	0.6	0.5	

TABLE 22. (cont.)

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2	No. 3
86s	Travin side street 6	Grass covered			0.5
87s	Travin side street 10	Grass covered	0.7	0.5	0.7
88s	Travin side street 9a	Grass covered	1.0	0.9	
90s	Kiev–Minsk road	Grass covered	1.3	1.4	0.9
91s	Same as 90	Grass covered	1.5	1.6	
92s	Lugovaya 70	Grass covered			0.4
93s	Lugovaya 60	Grass covered	0.5	0.3	0.35
94s	Lugovaya 56	Grass covered	0.6	0.6	0.7
95s	Lugovaya 40	Grass covered	0.5	0.4	0.4
96s	Lugovaya 12	Grass covered	1.1	0.7	
0.797s	Lugovaya 2	Grass covered	1.0	0.65	0.9
1g	West cemetery	Grass, uncultivated	1.40		
2g	West cemetery, N boundary	Grass, uncultivated	2.00		
3g	West cemetery, W boundary	Grass, uncultivated	1.75		
4g	West cemetery, S boundary	Grass, uncultivated	2.50		
5g	West cemetery, E boundary	Grass, uncultivated	2.30		
6g	West cemetery, E part	Grass, uncultivated	50		
7g	West cemetery, hot spot	Grass, uncultivated	>100		
8g	Field opposite (E of) 1	Uncultivated field	0.75		
9g	Vladimirskaya 70 m E of 8	Uncultivated field	0.80		
10g	Vladimirskaya/Khovtneva crossing	Uncultivated field	0.90		
11g	Vladimirskaya/Khovtneva crossing	Unpaved sidewalk	0.70		
12g	Vladimirskaya 50 m from 11	Unpaved sidewalk	0.60		
13g	Vladimirskaya/Kolkhoznik crossing	Unpaved sidewalk	0.80		
14g	Kolkhoznik 6, 50 m S of 13	Unpaved sidewalk	0.80		
15g	Kolkhoznik, opposite side of street	Unpaved sidewalk	0.90		
16g	Kolkhoznik 16	Unpaved sidewalk	0.50		
17g	Kolkhoznik/Kopkhoznik crossing	Unpaved	1.20		
18g	Kopkhoznik 15	Unpaved sidewalk	0.70		
19g	Meadow 20 m S of 18	Grass, uncultivated	0.70		
20g	Kopkhoznik/Kotovskogo crossing	Unpaved sidewalk	0.90		
21g	Kopkhoznik/Kotovskogo crossing	Unpaved sidewalk	0.90		
22g	Kopkhoznik/Kotovskogo crossing	Grass, uncultivated	1.1		
23g	Street connecting 10 and 20, 70 m N of 20	Unpaved sidewalk	1.1		
24g	Connecting street, opposite 23	Field boundary, uncultivated	0.9		

TABLE 22. (cont.)

Sample No.	Location	Description of site	Dose rate (μSv/h)		
			Instrument		
			No. 1	No. 2	No. 3
25g	Vladimirskaya/Gor'kij crossing, opposite 1	Uncultivated field	1.3		
26g	Vladimirskaya/Gor'kij crossing, sidewalk	Unpaved sidewalk	0.65		
27g	Vladimirskaya 70 m E of 26	Unpaved sidewalk	0.75		
28g	Vladimirskaya 8/Khovtneva crossing	Unpaved sidewalk	1.10		
29g	Vladimirskaya 18, opposite corner	Unpaved sidewalk	0.70		
30g	Vladimirskaya/Kotovskogo crossing	Unpaved sidewalk	0.75		
31g	Vladimirskaya/Kotovskogo crossing, opposite corner	Unpaved sidewalk	0.30		
32g	Vladimirskaya 4, 70 m E of 31	Unpaved sidewalk	0.90		
33g	Volya/Pionerskaya crossing	Grass, cultivated	0.30		
34g	Volya 140, opposite 33	Grass sidewalk	0.50		
35g	Volya 101, 100 m NW of 34	Grass sidewalk	0.60		
36g	Volya, opposite 35	Grass sidewalk	0.65		
37g	Volya/8-Marga crossing, E corner	Grass sidewalk	0.50		
38g	Volya/8-Marga crossing, S corner	Grass sidewalk	0.60		
39g	Volya/8-Marga 80 crossing, W corner	Unpaved sidewalk			
40g	8-Marga/Kotovskogo crossing, corner 70 m W of 39	Grass sidewalk	0.65		
41g	8-Marga/Kotovskogo 47 crossing, E corner	Grass sidewalk	0.35		
42g	8-Marga/Khovtneva crossing, N corner 50 m W of 40	Grass sidewalk	0.65		
43g	8-Marga/Khovtneva 51 crossing, E corner	Grass sidewalk	0.35		
49g	8-Bereznaya/Khovtneva 51 crossing, S corner, 70 m E of 48	Grass sidewalk	0.35		
50g	8-Bereznaya/Khovtneva crossing, E corner	Grass covered yard	0.65		
51g	8-Bereznaya/Khovtneva crossing, N corner	Paved yard	0.35		
52g	8-Bereznaya/Khovtneva crossing, W corner	Paved yard	0.30		
11	Shchorsa 32, Vasilij Cherneshov	Uncultivated garden	0.60		
61	Gogol 1b	Barren land	0.34		
51	Gogol 1	Cultivated garden, under trees	0.49		
13	Gogol 13	Cultivated garden, not used now	0.97		
161	Gogol 26	Cultivated garden	0.42		
221	Kotovskogo 27	Cultivated garden	0.68		
101	Volya 79	Garden	1.0	0.8	
121	Volya 76	Garden			1.9
161	Volya 65	Garden	1.3	1.1	
181	Volya 54	Garden			1.8
221	Volya 46	Round the wooden house	1.4	1.3	

TABLE 22. (cont.)

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2	No. 3
231	Volya 46	Reed thatch	1.75	1.7	
361	Place between Proletarskaya and Shevchenko	Cultivated garden	0.9	0.85	
401	Proletarskaya 22	Uncultivated garden	1.0	0.8	1.0
421	Proletarskaya 12	Uncultivated garden	1.0	0.9	
501	Same as 49	Cultivated garden	0.7	0.5	
511	Same as 49	Uncultivated garden	0.9	0.75	
551	Shevchenko 32	Uncultivated garden	0.8	0.5	
691	Travin 27	Cultivated garden	1.2	1.3	
711	Travin 29	Cultivated garden	1.0	0.8	1.2
731	Travin 21	Garden			0.7
741	Travin 33	Uncultivated garden	1.3	1.3	1.3
751	Travin 33	Uncultivated garden	0.85	0.95	1.7
771	Travin 31	Uncultivated garden	0.8	0.8	
821	Travin	Near hospital	0.3	0.3	0.3
891	Travin side street 9a	Cultivated garden	0.9	0.85	

TABLE 23. Polesskoe: Dose Rates at Various Other Sites
(Sampling conducted by the international team) [*Source: H. Lettner and team*]

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2	No. 3
121	Gor'kij 11, front yard	Concrete covered	0.42		
71	Gorgova/Proresnaya crossing	Asphalt covered, middle of road	0.31		
121	Gor'kij 7	Garden, at the fence	0.32		
201	Gostneva, middle of street	Asphalt	0.41		
211	Gostneva crossing	At the fence			0.49
231	Volya 40, main drainage	Under the roof	1.00		
261	Shevchenko side street 2	Asphalt	0.35	0.3	0.45
44g	8-Marga/Khovtneva crossing, W corner	Paved front yard	0.35		
45g	8-Marga/Khovtneva crossing, W corner	Paved front yard	0.35		
51g	8-Bereznaya/Khovtneva crossing, N corner	Paved yard	0.35		
52g	8-Bereznaya/Khovtneva crossing, W corner	Paved yard	0.30		

TABLE 24. Polesskoe: Dose Rates in Dwellings *(Sampling conducted by the international team)* [*Source: H. Lettner and team*]

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2	No. 3
		(a) Wooden houses			
141	Gor'kij 13	Wooden dwelling: living room	0.27		
151	Gor'kij 13	kitchen	0.22		
131	Volya 76	Wooden building			1.5
171	Volya 65	Wooden building	0.25	0.27	
		(b) Brick and/or stone houses			
5z	Vladimirskaya 38	Wooden floor	0.19		
7z	Shchorsa 32	Wooden floor of stone house	0.65		
9z	Gogol, indoors	Unfinished house structure	0.52		
14z	Gor'kij 11, indoors	Stone building	0.10		
2z	Vasilyj Cherneshov, Shchorsa 32:	Kitchen	0.42		
3s		Living room	0.63		
4s		Children's room	0.58		
10	Khovtneva 2:	Bedroom	0.08		
11s		Bedroom	0.15		
17s	Khovtneva 26:	Living room	0.21		
18s		Bedroom	0.18		
19s		Living room	0.18		
24s	Volya 40:	Living room, drainage	0.25		
25s		Living room	0.18		
26s		Kitchen	0.18		
11s	Volya 79		0.2	0.2	
19s	Volya 54				0.45
43s	Proletarskaya 12		0.2	0.27	0.35
52s	Shevchenko		0.4	0.4	
70s	Travin 27		0.3	0.3	
72s	Travin 21				0.25
76s	Travin 31		0.2	0.25	0.3
83s	Travin	Hospital	0.1	0.1	0.2

TABLE 25. Daleta: Dose Rate Measurements [*Source: H. Lettner and team*]

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2	No. 3	No. 4
		(a) Dwellings				
31	Kulish	Wooden dwelling	0.15	0.18		
111	Aleknovich	Wooden dwelling	0.12			
181	Site, schoolroom	Wooden/stone building	0.11	0.09		
191	Same site, staff room		0.09	0.09		
221	Wooden house, village boundary	Kitchen, bedroom	0.25	0.25		
271	Wooden house	Kitchen, bedroom	0.20	0.20		
361	Wooden house	Kitchen, bedroom	0.20	0.20		
371	Wooden house	Kitchen, bedroom	0.30	0.30		
151	Bus station	Asphalt road/concrete wall	0.16	0.18	0.24	
		(b) Hay and straw lofts				
51	Beside the road	Hay loft from 1988	3.0	3.1	3.2	3.4
61	Beside the road	Straw loft from 1990	0.5	0.6		
81	Kulish	Fresh hay loft from 1990	0.5			
		(c) Outdoors				
11	Kulish	Grass, garden	0.46	0.32	0.36	0.34
21	Kulish	Grass, garden	0.29			
41	Road	Sand, grass covered	0.24	0.22	0.21	
71	Next road	Sand, grass covered	0.45	0.5		
91	Kulish	Grass, garden	0.26			
101	Garden	Garden, fruit	0.21	0.22	0.29	
121	Aleknovich	Meadow, grass	0.35			
131	Road	Sand, grass	0.18	0.20		
141	Road	Near fence, grass covered	0.36	0.34		
161	Close to 11	Vegetable garden	0.24	0.25		
171	Forest adjacent	Under trees	0.29			
201	Bend of road	Sand/grass, meadow	0.23	0.24		
21g	Village boundary	Cultivated meadow	0.35			
23g	Village boundary	Mud/cultivated meadow	0.40			
24g	Field	Potatoes, cultivated	0.25			
25g	Garden	Cultivated	0.30			
26g	Field	Grain, cultivated	0.25			
28g	Field	Grain, vegetables, cultivated	0.35			
29g	Field	Potatoes, cultivated	0.40			

TABLE 25. (cont.)

Sample No.	Location	Description of site	Dose rate (μSv/h) Instrument No. 1	No. 2	No. 3	No. 4
30g	Field	Grain, cultivated	0.30			
31g	Forest	Trees, undergrowth, uncultivated	0.30			
32g	Field	Grain, cultivated	0.35			
33g	Field	Vegetables, grain, cultivated	0.35			
34g	Meadow	Grass, uncultivated	0.35			
35g	Forest	Trees, undergrowth, uncultivated	0.40			
38g	Meadow	Grass, sand, uncultivated	0.30			
39g	Meadow	Grass, sand, uncultivated	0.30			
40g	Horse pasture	Grass	0.20			
41g	Meadow	Grass, sand, uncultivated	0.20			
42g	Meadow	Grass, sand, uncultivated	0.40			
43g	Sidewalk	Sand, unpaved	0.35			
44g	Sidewalk	Sand, unpaved	0.40			
45g	Field	Potatoes, cultivated	0.45			
46g	Meadow	Grass, cultivated	0.30			

3.2.5. Hot Particles

Two hot particles were separated in the fourth layer (3–4 cm) of sample column 16 taken in a private garden in Polesskoe. As an example, the results of the analysis of one particle are shown in Fig. 42. In addition to the other radionuclides already identified in the soil samples, Eu isotopes were present. No equivalent sets of Soviet data were presented to the international team.

3.3. Survey of Control Settlements

Environmental surveys were carried out in the six settlements that were chosen to represent areas with insignificant quantities of fallout contamination (control settlements; under 37 kBq of $^{137}Cs/m^2$). This categorization was based on the official Soviet maps. The following control settlements were investigated:

— *In the UkrSSR:* Trokovichi and Krasilovka.
— *In the BSSR:* Kirovsk and Khodosy.
— *In the RSFSR:* Unecha and Surazh.

For each survey, the dose rate was determined with portable equipment (approximately 1 m above ground) in several sectors of each settlement and its nearby surroundings. In addition, grab samples of soil (per sector) and local food were taken. Fresh vegetables and milk were donated by individuals in the town. In all cases these were grown or produced locally. It was impossible to ascertain the source of the bread, meat and tinned foods. All samples were analysed for ^{137}Cs and ^{134}Cs by gamma spectrometry. The results of the measurements are shown in Tables 30–32.

Mean dose rates for the different settlements are low and range from 0.06 to 0.22 μSv/h, reflecting the low fallout deposition; this is confirmed by the relatively low ^{137}Cs surface activity (under 16 kBq/m^2). In many cases these values are of the same magnitude as those of the natural background radiation. Generally, there is no significant difference between indoor and outdoor readings. Also, the variation between different sites for a given settlement is small, as reflected in the small standard deviation of the mean values.

Concentrations of ^{137}Cs in food samples from these areas are frequently below the limit of detection (LD) or

TABLE 26. Characteristic Statistical Parameters for Indoor and Outdoor Dose Rate Measurements in Bragin, Polesskoe and Daleta *(Sampling conducted by the international team)* [*Source: H. Lettner and team*]

Measurement site	No. of measurements	Dose rate (μSv/h)				
		Mean	Standard deviation	Median	Min.	Max.
Bragin						
Grass covered sites (mainly)	329	0.46	0.25	0.40	0.14	1.92
Asphalt covered sites	33	0.23	0.07	0.24	0.10	0.35
Undisturbed areas	45	0.72	0.47	0.59	0.22	3.0
Gardens, fields	72	0.61	0.37	0.44	0.24	2.2
Detached wooden buildings (indoors)	68	0.17	0.07	0.15	0.07	1.4
Brick and stone buildings (indoors)	72	0.14	0.06	0.13	0.07	0.50
Polesskoe						
Grass covered sites (mainly)	290	0.95	2.91	0.70	0.27	50
Brick and stone buildings (indoors)	32	0.28	0.15	0.23	0.08	0.65
Daleta						
Outdoors (grass, sand, gardens, fields)	46	0.31	0.08	0.30	0.18	0.50
Wooden, stone or concrete buildings (indoors)	18	0.18	0.67	0.19	0.09	0.30

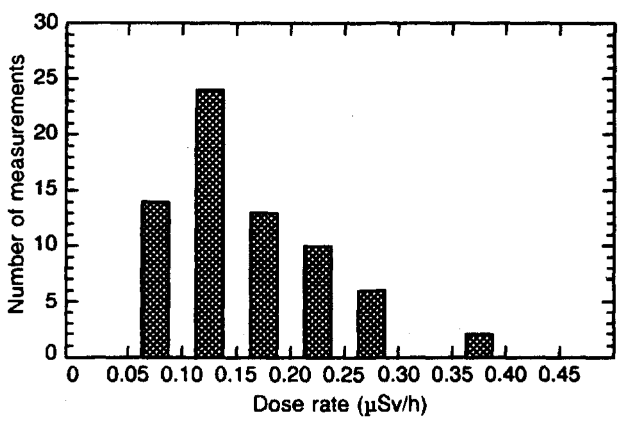


FIG. 33. Dose rate distribution in wooden buildings in Bragin. [Source: H. Lettner and team]

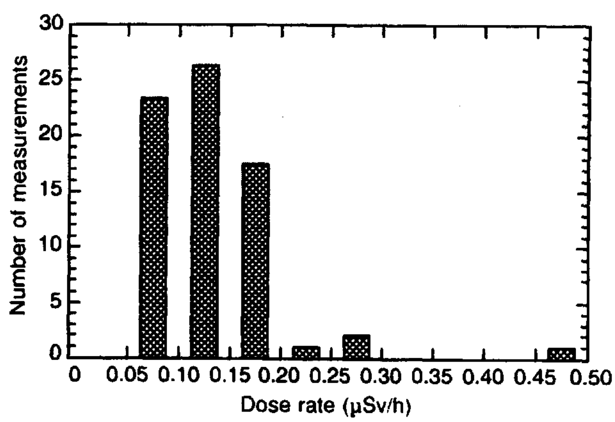


FIG. 34. Dose rate distribution in masonry buildings in Bragin. [Source: H. Lettner and team]

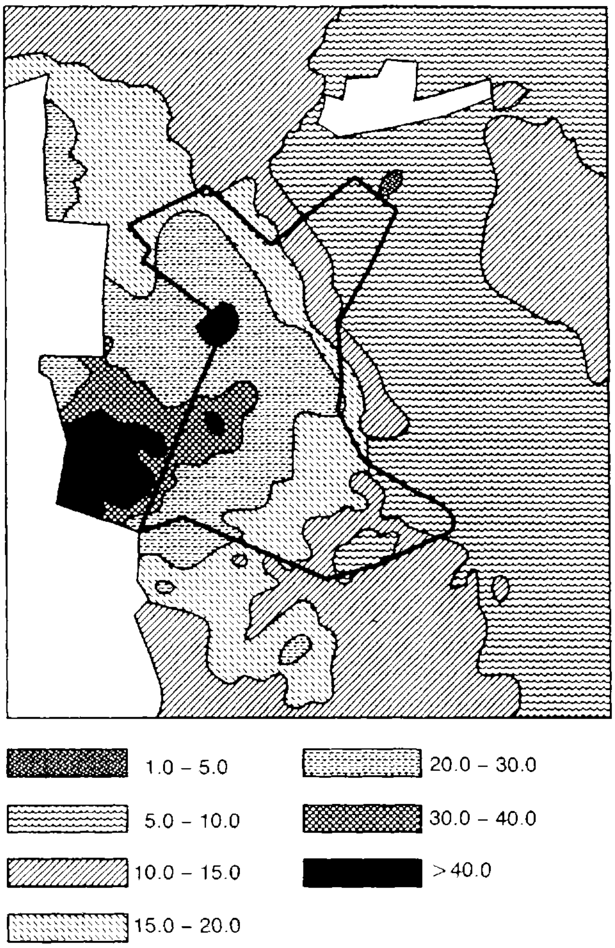


FIG. 35. Total caesium (^{134}Cs and ^{137}Cs) deposition (in Ci/km^2) in the Bragin region based on data from 1989 and compiled by the All-Union Institute for Agricultural Radiology, BSSR Branch, Gomel.

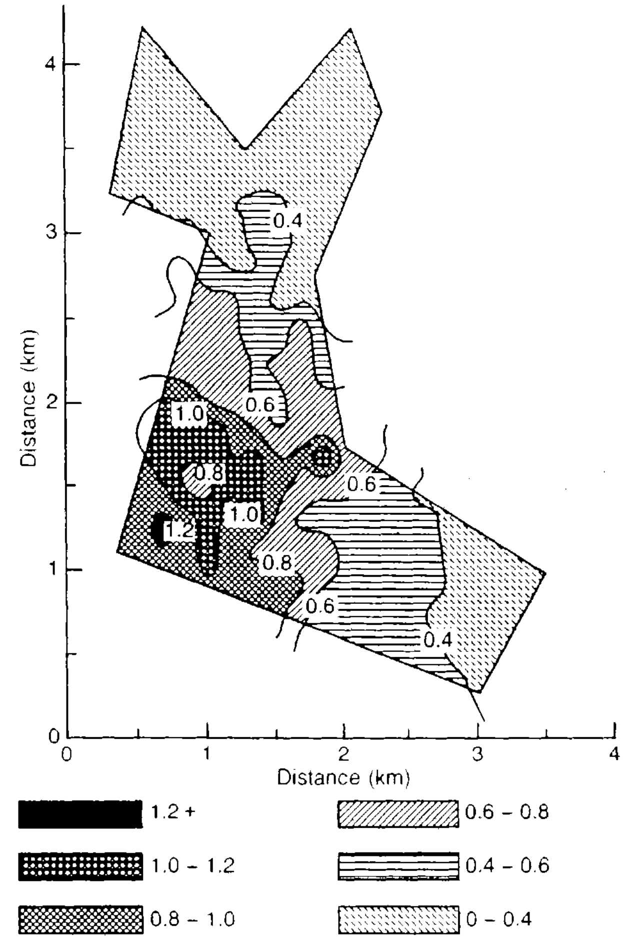


FIG. 37. Dose rate data for Bragin (isopleths), in μSv/h, based on the international team survey. [Source: H. Lettner and team]

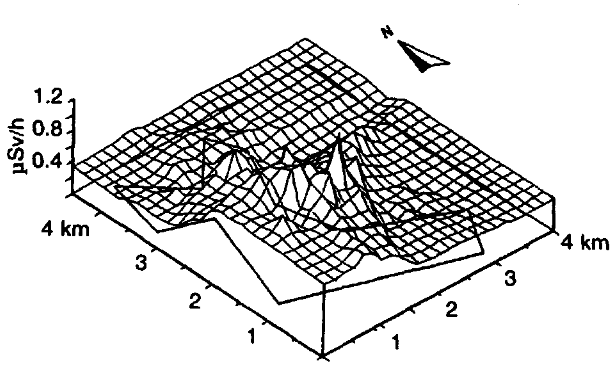


FIG. 36. Dose rate data for Bragin (three dimensional map) based on the international team survey (the polygon approximates the settlement borders). [Source: H. Lettner and team]

just slightly above (e.g. for cabbage). Corresponding values for meat or sausage samples cover a relatively wide range (LD to 126 Bq/kg wet weight), influenced by the origin of the animal fodder and the feeding practice.

In summary, the control settlements and their surroundings can be considered to be areas generally unaffected by fallout, with only low levels of fallout contamination in some isolated cases.

3.4. Dose Rate Profiles Along Roads in the Area of Gomel, BSSR

A vehicle mounted detector system was used to monitor continuously the areas adjacent to roads in the surroundings of Gomel. The objective of these measurements was to identify localized areas of increased radionuclide deposition (hot spot areas) in the vicinity of roads.

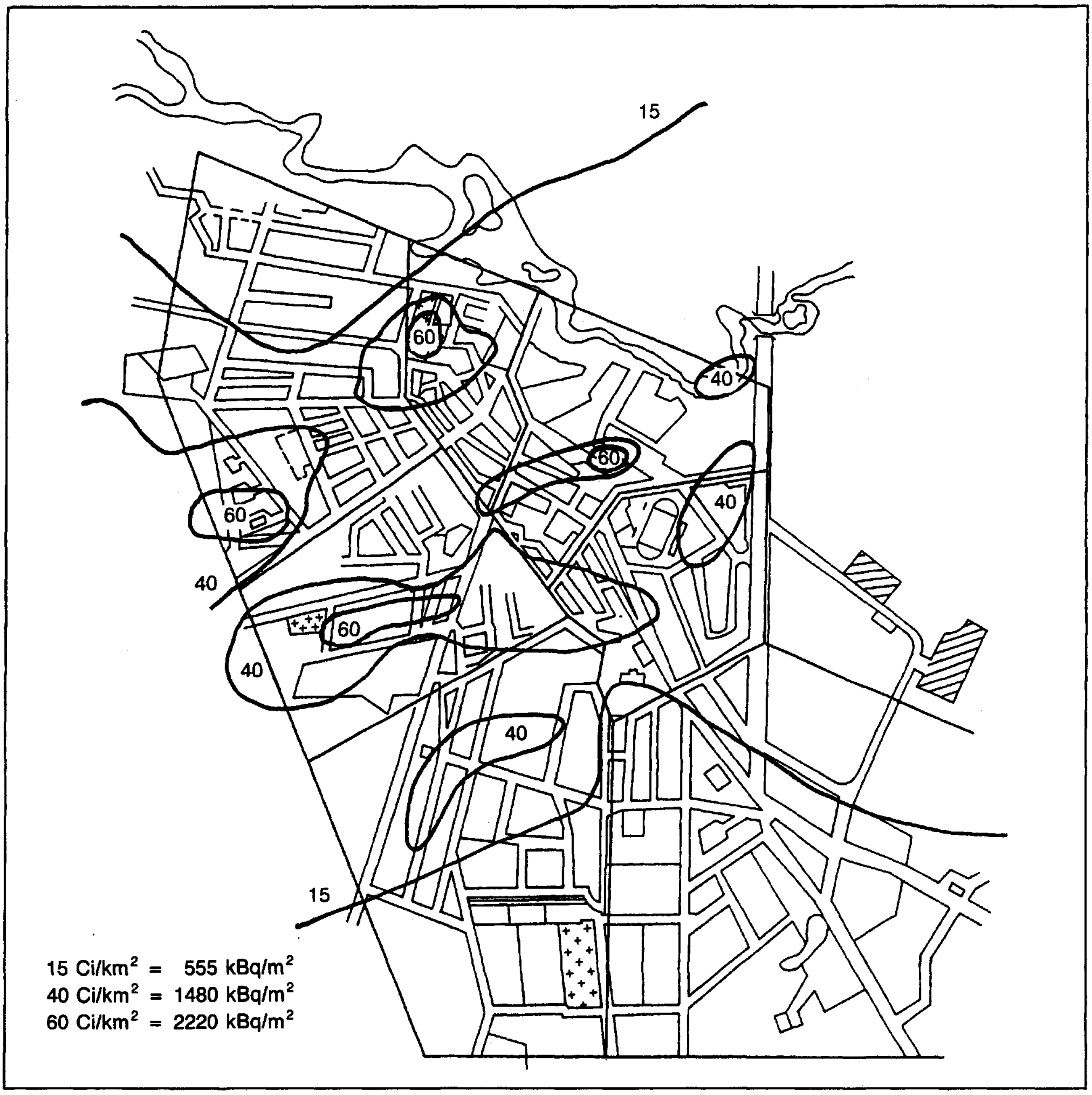


FIG. 38. Total caesium (^{137}Cs and ^{134}Cs) deposition (in Ci/km^2) in Polesskoe (official Soviet map).

The monitoring system consists of two plastic scintillation detectors (3 in × 4 in (7.8 cm × 10.2 cm)) and a rate meter. The detectors, mounted 1.5 m above the ground and separated by a 3 cm thick Pb shielding, are calibrated for ^{137}Cs measurements. This method permits differentiation between the external dose rate resulting from radionuclides below, to the right side and to the left side of the vehicle (up to 3 m on each side of the road). The sensitivity of the system is such that over a road segment 8 m in length an increase in the external dose rate by a factor of 3 (from 0.05 μSv/h to 0.15 μSv/h) can be detected at a vehicle speed of 30 km/h. Altogether, approximately 500 km of roads were tested along three routes (Table 33).

The results from the survey show that the external dose rate is mostly low (under 0.16 μSv/h) over large distances. Only occasionally were elevated levels (≤3.8 μSv/h) registered, e.g. between Chojniki and

FIG. 39. Dose rate outdoors (in μSv/h) for Polesskoe, based on the international team survey.
[Source: H. Lettner and team]

Komarin, between Novozybkov and Gomel, and near Ozov'e. No equivalent sets of Soviet data were presented to the international team.

3.5. Radionuclide Levels in Soil-Grass-Milk Ecosystems

Ecosystems were studied in more detail in three regions: Novozybkov, Bragin and Ovruch. The overall objective was the indirect corroboration of the official Soviet assessment of environmental contamination levels in the affected areas, using the soil-grass-milk system as a relative indicator.

Soil and grass samples were collected from undisturbed grassland (pastures and forests). Sampling procedures for soil and grass followed the recommended IAEA protocol [17]. Milk was sampled from humans and cows. The analysis of samples was carried out by gamma spectrometry, alpha spectrometry and standard radiochemical methods. An intercomparison exercise was conducted by the two analytical laboratories to

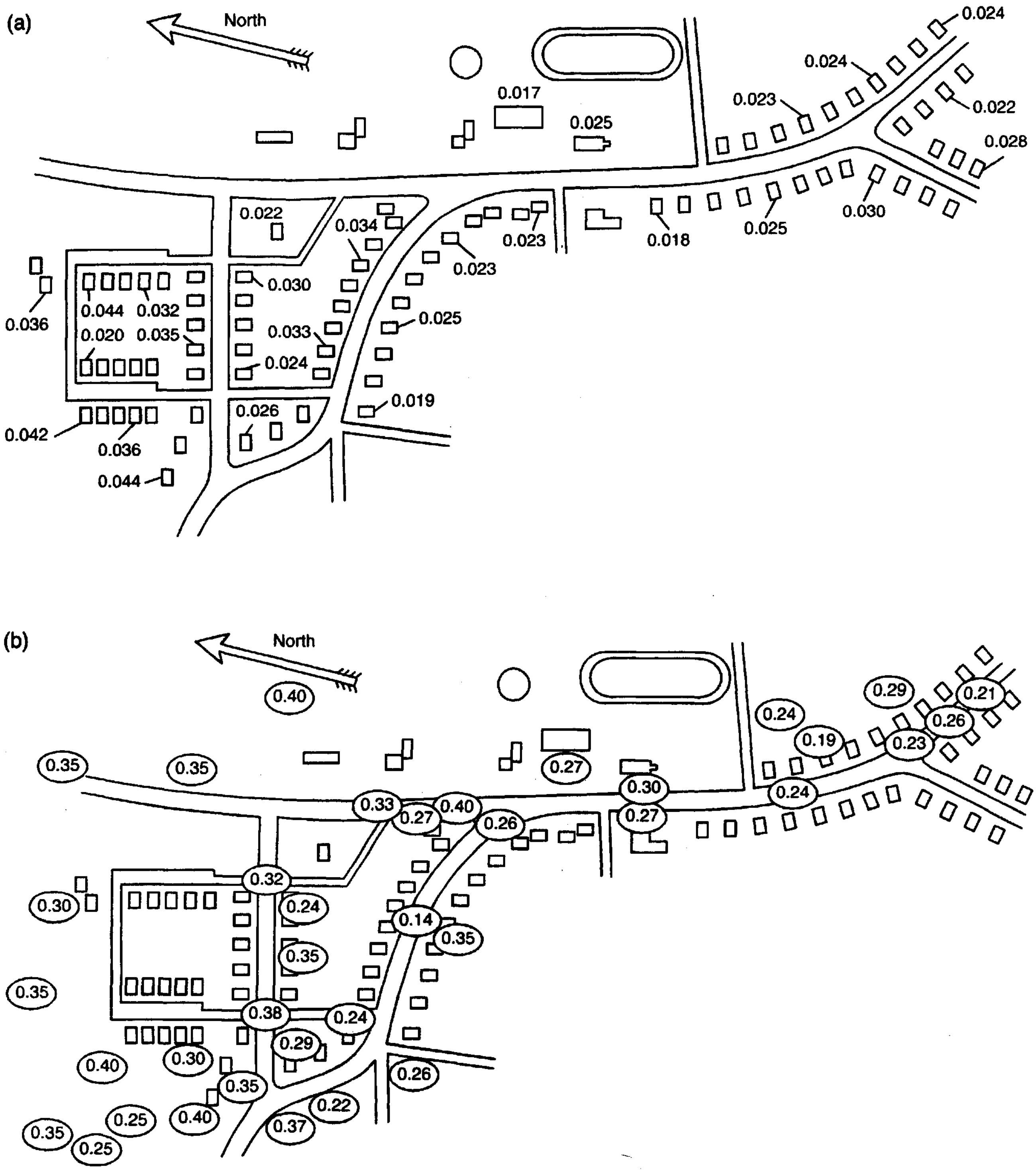


FIG. 40. Comparison of (a) the official Soviet data for the dose rate outdoors (in mR/h); and (b) the corresponding data from the international team survey in Daleta (in μSv/h). [Source: F. Steinhäusler and M. Dreicer; H. Lettner and team]

TABLE 27. Description of Soil Samples Taken in Bragin and Polesskoe *(Sampling conducted by the international team)* [*Source: H. Lettner and team*]

Sample No.	Place of origin	Sample (cm layer)	Weight (g)
2-1	Bragin, Hydromet Station	0–1	20.82
2-2			
2-3		1–2	26.40
2-4		2–3	27.64
2-5		3–4	26.34
2-6		4–5	31.54
		5-15	268.34
3-1	Bragin, Skorokhoda	0–1	21.59
3-2		1–2	27.89
3-3		2–3	25.78
3-4		3–4	32.13
3-5		4–5	32.41
3-6		5–6	30.03
12-1	Polesskoe, town area	0–1	23.07
12-2		1–2	39.01
12-3		2–3	25.35
12-4		3–4	26.88
12-5		4–5	28.59
12-6		5–15	249.20
14-1	Polesskoe, flood area by Uzh River	0–1	16.89
14-2		1–2	15.40
14-3		2–3	20.06
14-4		3–4	25.55
14-5		4–5	34.87
16-1	Polesskoe, private garden in Vladimirskaya	0–1	18.06
16-2		1–2	18.75
16-3		2–3	27.81
16-4		3–4	29.48
16-5		4–5	31.24
16-6		5–15	344.37

ensure quality control and comparability of individual results (Table 34).

The analysis of the samples showed the following results (Tables 35–38; Fig. 43):

Novozybkov Region

The levels of ^{137}Cs determined in soil–grass ecosystem samples from three different locations are in agreement with Soviet data on surface contamination, as supplied by the All-Union Scientific Research Institute of Agricultural Radiology (Obninsk).

The presence of ^{144}Ce and ^{241}Am in the samples can be used as an indicator of the occurrence of ^{239}Pu and ^{240}Pu in the environment, provided that the environmental distribution processes are the same.

Bragin Region

The official Soviet Pu estimate for Bragin is less than 0.1 Ci/km^2 (3.7 kBq/m^2). Under the assumption that most of the Pu is contained in the top 5 cm of the soil and grass mat, this corresponds to about 80 Bq of Pu/kg. The Pu analysis of the soil sample taken during this study revealed 17 Bq/kg. Taking into account the very limited number of samples taken in this project, this can be interpreted as corroboration of the official Soviet estimate.

Values for ^{137}Cs and ^{134}Cs in cow's milk (Table 38) are in general agreement with results obtained by Soviet counterparts (Table 39). With regard to the ^{90}Sr concentration, official Soviet data for 1988 (5.6 Bq/L) and 1989 (6.4 Bq/L) were supplied to the experts; for comparison, data of the international team for milk in 1990 (6.9 Bq/L) are in satisfactory agreement.

Ovruch Region

Caesium levels in cow's milk were in fair agreement with results obtained from the Soviet counterparts (Table 40), except for the Soviet data on ^{103}Ru, which must have decayed by 1990. Owing to the high transfer factor in this area, individual ^{137}Cs levels in human milk can be elevated significantly as compared with those in the other two regions investigated (Fig. 43).

3.6. Environmental Assessment Using Biomonitors

Some plants are known to accumulate significant amounts of radionuclides. These plants can be used as biomonitors to provide a relative measure of the radionuclides present in the environment. The biomonitoring programme was initiated to complement physicochemical methods in the assessment of the radiological situation in the fallout affected areas.

A total of 200 lichen (*Parmelia sulcata*) samples, together with the substrate bark (approximately 1.5 m above ground) and 65 soil samples were taken. The

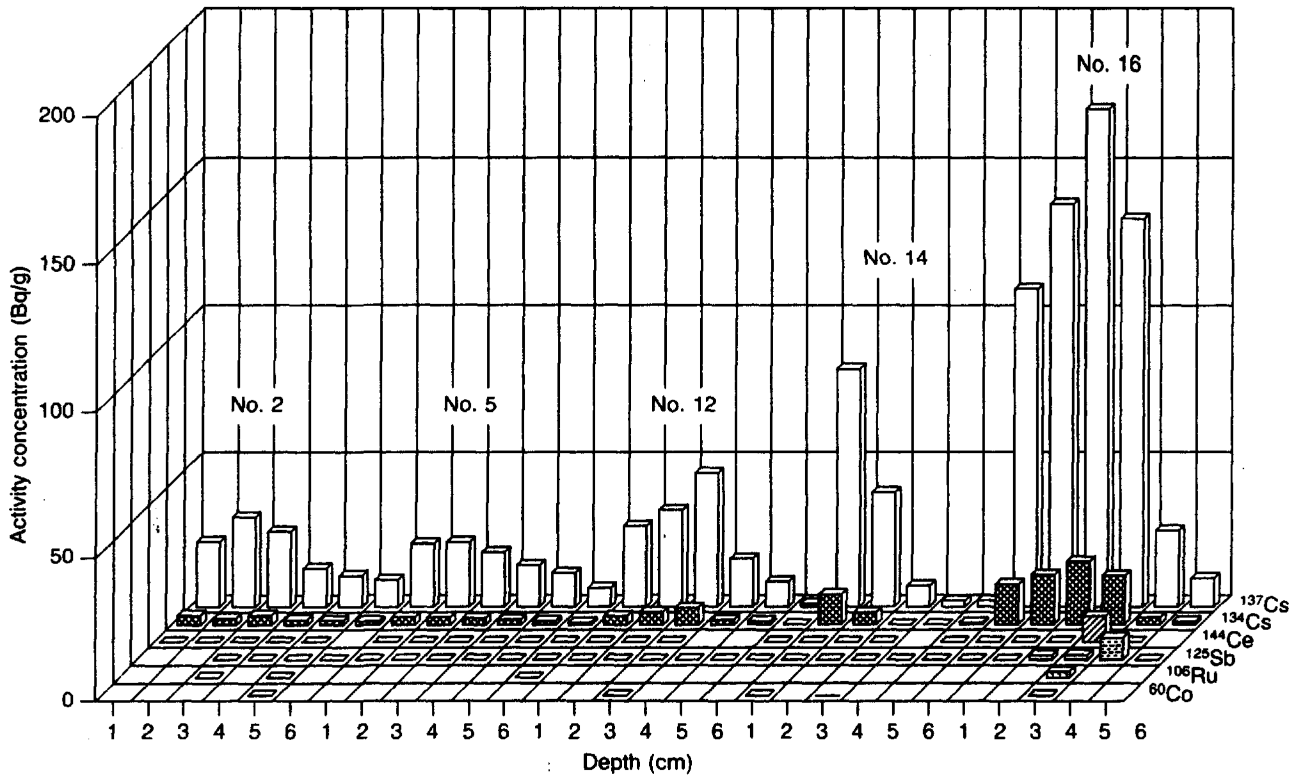


FIG. 41. Depth distribution of gamma emitters in soil columns from Bragin and Polesskoe. Radionuclide concentrations in different layers of soils 2–16. [Source: P. Zombori]

sampling sites were in the Novozybkov, Bragin and Ovruch regions. Lichens were separated from the bark, washed, ground and freeze dried. Soil samples were dried at 50°C and then ground.

All samples were analysed for ^{137}Cs by gamma spectrometry with a well type Ge detector (9.8% efficiency). The results are summarized in Figs 44 and 45. The data indicate a correlation between the Soviet ground deposition values (see Table 1) for ^{137}Cs and the ^{137}Cs concentrations in lichen sampled from the corresponding area, although it is of low statistical significance. The data from independent soil sampling did not fit well with the Soviet soil classification.

3.7. Water Sampling Programme

Radionuclides deposited on the ground can affect the surface water quality by runoff and the groundwater quality by leachate penetration into the aquifers. Therefore water samples were taken at different sites in 16 settlements in the fallout affected areas. The sites chosen were hand dug wells, public water supply systems, ponds, lakes, drainage channels, streams and rivers. In addition, sediment core samples were also taken and sectioned for the assessment of the nuclide depth distribution. Water samples were filtered with cellulose nitrate filters (pore size: 0.45 μm). Sediment samples were dried at 105°C. All samples were analysed for ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{106}Rh and ^{125}Sb using Ge gamma spectrometry (detector efficiency up to 30%).

The results of the analysis of the water samples are summarized in Table 41. No equivalent sets of Soviet data were presented to the international team. In most cases the concentration of the aforementioned radionuclides is below the limit of detection (LD). Exceptions are the results for samples from three ponds in Mikulichi, Rakitnoe and Novye Bobovichi which contained ^{137}Cs (up to 7.3 $\pm$ 0.6 Bq/L) and ^{134}Cs (up to 1.1 $\pm$ 0.2 Bq/L); all other nuclide levels were also below the LD.

The results of the analysis of the residue of filtered water samples are shown in Table 42. In general, the radionuclide concentration is below LD. Only two samples from filtered pond water in Novye Bobovichi and Rakitnoe and one from a hand dug well in Novye Bobovichi showed elevated caesium concentrations (^{137}Cs up to 470 mBq/L and ^{134}Cs up to 88 mBq/L).

Gamma spectrometry analysis of the sediment samples showed that mostly only Cs isotopes (^{134}Cs and ^{137}Cs) could be detected (Table 43). Samples from the Gden, Malozhin and Novye Bobovichi areas with signi-

TABLE 28. Comparison of the In Situ Results for the Caesium Inventory in Bragin and Polesskoe as Measured by the International Team with the Officially Reported Values shown in the Soviet Maps
[*Source: H. Lettner and team*]

Location	Site	Activity concn		
		Measured		Official
		(kBq/m²)	(Ci/km²)	(Ci/km²)
Bragin	Sports ground:			
	Cs-134	54	1.5	
	Cs-137	351	9.5	
	Total	405	11	15–20
	Hydromet Station:			
	Cs-134	122	3.3	
	Cs-137	844	23	
	Total	966	26	20–30
	Memorial Park:			
	Cs-134	85	2.3	
	Cs-137	569	15	
	Total	654	18	15–20
	Cemetery:			
	Cs-134	169	4.6	
	Cs-137	1170	32	
	Total	1339	36	20–30
Polesskoe	Outside town, flood area or Uzh River:			
	Cs-134	184	5	
	Cs-137	1110	30	
	Total	1294	35	15–40
	West cemetery:			
	Cs-134	150	4.5	
	Cs-137	1100	30	
	Total	1250	34	40–60
	North cemetery:			
	Cs-134	50	1.4	
	Cs-137	340	0.2	
	Total	390	11	<15
	By the road to Ovruch:			
	Cs-134	84	2.3	
	Cs-137	580	16	
	Total	664	18	15–40

ficantly elevated Cs concentrations in the sediments also contained other radionuclides above LD, such as ^{144}Ce (up to 59 Bq/kg), ^{106}Rh (up to 157 Bq/kg) and ^{125}Sb (up to 116 Bq/kg). The isotope ^{137}Cs was identified in the top layers of all sediment samples, ranging from 5 to 11 800 Bq/kg, i.e. reflecting the Cs ground deposition in the relevant areas. On the basis of the depth profile analysis, most of the Chernobyl related fallout is usually contained in the upper layer of the sediments (down to 10 cm); below 10 cm the nuclide concentration decreases rapidly. Exceptions were the samples from a lake in Novozybkov which had not been decontaminated. In this case, ^{137}Cs fallout, presumably from nuclear weapons tests before the Chernobyl accident, could be found in the 10–35 cm layer (up to 39 Bq/kg), below the ^{137}Cs fallout due to the Chernobyl accident (up to 40 Bq/kg).

3.8. Soil and Vegetation Sampling Programme

The uptake of radionuclides by plants at the present time is dependent mainly on the amount of fallout available to the root system. In order to describe present soil contamination and nuclide behaviour in the soil-vegetation ecosystem, an extensive sampling of soil depth profiles was undertaken. In addition, vegetation was sampled in some selected areas.

Soil depth profiles were taken from undisturbed areas, meadows, ploughed fields, gardens, forest areas, areas near water supplies and public places. Altogether, more than 100 soil profiles (soil depth 30 cm each) were sampled in 15 settlements. The material was dried at 100°C and analysed for ^{134}Cs and ^{137}Cs by gamma spectrometry. In some selected samples, ^{90}Sr, ^{239}Pu and ^{240}Pu contents were also determined using radiochemical procedures [18, 19].

3.8.1. Caesium in Soil and Vegetation

The results for soil samples are summarized in Table 44. while examples are given in Figs 46 and 47.

TABLE 29. Indoor Radon Concentrations in Bragin and Daleta [*Source: E. Wehrstein-Werner*]

Site No.	Measurement site	Rn-222 concn (Bq/m^3)	Dose rate (μSv/h)	
			E-PERM™/background	Rate meter
		Bragin		
1	Sanitary office, 2nd floor	18	0.16	0.08
2	Sanitary office, 1st floor	18	0.38	0.34
3	Kindergarten	41	0.29	0.6
4	Private house on riverside	39	0.18	0.15
5	Kravchenka 11	38	0.19	0.33
6	Hospital, lab. rest room	35	0.16	0.26
7	Hospital, lab. 2nd floor	9	0.24	0.21
8	Hospital[a], Epidem. Lab.	420	0.19	0.15
9	Police station[b]	470	0.24	0.12
10	Spetna 4[c]	300	0.31	0.50
		Daleta		
42	Kulish, Mikhail	35	0.14	0.18
		58	0.39	
43	School	2	0.17	0.18
		7	0.46	
44	Starovojd, Nikolaj D., teacher	16	0.21	0.10
45	Germanchuk, Maria	8	0.23	0.16
46	Lesh, Petr. I.	6	0.17	0.14

[a] Old brick building (dosimeter kept in small store room).
[b] Old brick building (dosimeter kept in small store room).
[c] Possibly opened and touched.

Note: Bragin mean (± standard deviation), all measurements: 139 (±183);
Bragin mean (± standard deviation), excluding Nos 8-10: 28 (±13);
Daleta mean (± standard deviation): 19 (±20).

In most of the soil samples from areas undisturbed by human activities (such as agriculture or gardening), the maximum ^{137}Cs contamination was found in the top soil layer (0–2.5 cm). However, in some cases there has been significant downward migration into deeper layers. Concentration values range from 1.6 Bq/g (Ovruch) to 29 Bq/g (Starye Bobovichi) and correlate with the initial fallout deposition at the sampling sites, i.e. about 150 kBq/m^2 in Ovruch and over 1500 kBq/m^2 in Starye Bobovichi.

A similar pattern can be seen for soil samples from public areas, as well as pastures, meadows and forests, where most of the ^{137}Cs is usually found in the top 5 cm layer of the soil. The range of concentration values is comparable with that for undisturbed areas, with lower values in public areas and higher values in forests.

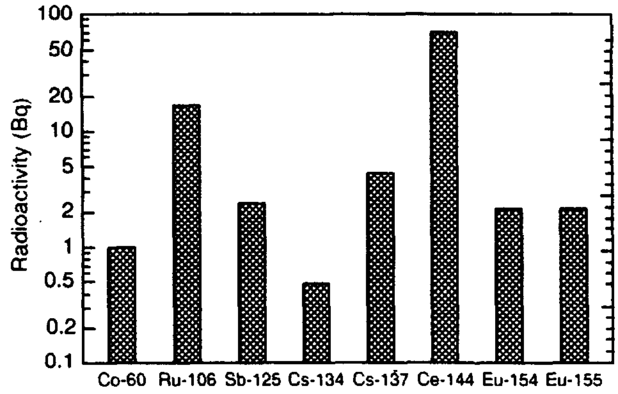


FIG. 42. Radionuclide composition of a hot particle collected from the soil in Polesskoe. [Source: P. Zombori]

TABLE 30. Dose Rates Outdoors and Indoors in Control Settlements [*Source: F. Steinhäusler, M. Dreicer and E. Henrich*]

Location	No. of measurements	Dose rate (μSv/h) Min.	Max.	Mean (± standard deviation)
Trakovichi				
Outdoors	8	0.12	0.24	0.20 ± 0.04
Indoors	5	0.18	0.25	0.22 ± 0.03
Krasilovka				
Outdoors	10	0.11	0.15	0.13 ± 0.01
Indoors	2	0.15	0.18	0.13 ± 0.01
Kirovsk				
Outdoors	19	0.04	0.12	0.07 ± 0.02
Indoors	18	0.04	0.12	0.08 ± 0.02
Khodosy				
Outdoors	9	0.06	0.09	0.07 ± 0.01
Indoors	10	0.06	0.11	0.08 ± 0.01
Unecha				
Outdoors	15	0.04	0.10	0.06 ± 0.02
Indoors	13	0.04	0.10	0.07 ± 0.02
Surazh				
Outdoors	16	0.04	0.18	0.08 ± 0.04
Indoors	16	0.04	0.15	0.08 ± 0.03

TABLE 31. ^{137}Cs Surface Activity in Control Settlements [*Source: E. Henrich*]

Location	Surface activity (kBq/m^2)
Unecha	10–12
Surazh	6–9
Kirovsk	6–16
Khodosy	4–14

An example of the effect of decontamination techniques applied in agriculture is shown in Fig. 46 for two sites with comparable fallout deposition. At an undisturbed site at a collective farm the maximum Cs concentration is found in the top 5 cm soil layer and no Cs is detectable below 10 cm (Fig. 46(a)). The decontamination of a pasture results in a shift of this Cs maximum to lower soil layers, in this particular case to a soil depth of 15 to 20 cm, thereby reducing Cs availability to grass roots (Fig. 46(b)).

The caesium concentration of the soil sample from a hot spot in Svyatsk (a ^{137}Cs content of 12 717 kBq/m^2) is significantly elevated, with a maximum specific ^{137}Cs activity of 220 Bq/g at a soil depth of 2.5–5 cm (Table 44).

In addition to the Cs concentration in the soil, the ^{137}Cs surface activity was determined in selected settlements (Table 44). In the following, the range of the corresponding official Soviet data for these settlements (Hydromet database (H-DB), Ref. [20]) is compared with the international team (IT) data.

— *Bragin region (Bragin, Mikulichi, Gden, Komarin, Malozhin):*
Soviet data (H-DB): 74–999 kBq/m^2;
IT data: 15–2915 kBq/m^2.

— *Novozybkov region (Novozybkov, Starye Bobovichi, Novye Bobovichi, Svyatsk):*
Soviet data (H-DB): 600–1763 kBq/m^2;
IT data: 52–3398 kBq/m^2 (excluding the hot spot area).

The range of data from the international team covers the range of the Soviet data sufficiently well in view of the inherent difference between the two data sets, i.e. the Soviet data represent mean values based on comprehensive surveys over several years, while the data from the international team are a few single values derived from grab sampling. However, at the upper end of the range the systematic exclusion of hot spot areas in accordance with the official methodology is evident, i.e. single locations with surface activity exceeding the official maximum values are possible. This is also the case in Slovechno and Kortsevka.

Analytical results for the ^{137}Cs concentration in samples of grass and the underlying mat region (0–3 cm) are presented in Tables 45 and 46. The ^{137}Cs concentration in grass samples can cover a wide range for a given location; for example, in Bragin results differ by a factor of 8 for different sampling sites, indicative of the heterogeneous fallout deposition even over relatively small areas. Differences in the ^{137}Cs concentration are just as

TABLE 32. ^{137}Cs Concentrations in Food Samples from Control Settlements
[*Source: M. Makarewicz and E. Henrich*]

Measurement site	Cs concn (Bq/kg wet weight)
Trakovichi	
Milk, bread, corn, meat, gherkins, green peppers, potatoes, tomatoes (canned)	LD
Cabbage	17
Krasilovka	
Potatoes	LD
Meat	LD
Beetroot	9
Cabbage	10
Unecha	
Milk	LD
Bread	LD
Meat	LD–126
Sausage	13
Potatoes, beetroot, carrots, cabbage	LD
Surazh	
Milk, butter	LD
Bread, meat	LD
Potatoes, carrots, beetroot, cabbage	LD
Kirovsk	
Milk, cheese	LD
Bread	LD
Meat, sausage	LD–10
Potatoes, cabbage	LD
Fish	LD
Khodosy	
Bread	LD
Meat	LD
Sausage	LD
Potatoes, onions	LD

Note: LD: limit of detection (≤7 Bq/kg wet weight).

TABLE 33. Continuous Dose Rate ($\dot{H}$) Measurements Along Roads in Contaminated Areas [*Source: M. Heinzelmann and F. Schirmer*]

Route / Dose rate ($\dot{H}$) category (μSv/h)	Relative length of road (in %) of total road length surveyed					
	<0.25	0.25–0.50	0.50–1.0	1.0–1.5	1.5–2.5	>2.5
Direction of Vetka	6	48	44	2	—	—
Bragin region	66	19	12	1	1	1
Novozybkov region	2	30	40	27	2	—
Novozybkov–Gomel	47	6	12	22	13	—
Ovruch region	98	2	—	—	—	—
Ovruch–Kalinkovichi	56	34	10	<1	—	—
Total (%)	52	22	16	7	3	<1

TABLE 34. Results of the Intercomparison Exercise Between Analytical Laboratories in Yugoslavia and Czechoslovakia for Milk Samples [*Source: P. Stegnar*]

Sample No.	Radionuclide	Concn (Bq/kg dry weight)	
		Inst. Jošef Stefan, Ljubljana	Inst. of Hygiene and Epidemiology, Prague
107	Cs-137	10 070 ± 110	12 500
	Cs-134	1 660 ± 60	1 610
	Sr-90	47 ± 4	50
108	Cs-137	9 330 ± 100	10 800
	Cs-134	1 440 ± 120	1 470
	Sr-90	52 ± 5	46
109	Cs-137	4 770 ± 50	5 000
	Cs-134	700 ± 35	670
	Sr-90	34 ± 4	26
6	Cs-137	680 ± 8	820
	Cs-134	91 ± 11	104
	Sr-90	55 ± 5	61

pronounced between different locations, with values ranging from 270 Bq/kg dry weight in Malozhin to 21 890 Bq/kg dry weight in Starye Bobovichi.

The ^{137}Cs concentration in mat samples is generally higher than in corresponding grass samples, reaching up to 30 000 Bq/kg dry weight.

In Novye Bobovichi, a moss sample was taken in the local forest, since mosses are known to accumulate radionuclides. In addition to detectable amounts of ^{144}Ce, ^{154}Eu, ^{125}Sb and ^{106}Ru (each under 2140 Bq/kg dry weight), the Cs concentration (values in Bq/kg dry weight) was found to be significantly elevated (^{134}Cs: 107 400 Bq/kg; ^{137}Cs: 697 200 Bq/kg).

3.8.2. Strontium and Plutonium in Soil and Vegetation

In Bragin, grass samples were also analysed for ^{90}Sr and soil/mat samples from undisturbed grassland for

^{239}Pu and ^{240}Pu (Table 47). The results show a nuclide distribution pattern similar to that for ^{137}Cs, i.e. significantly variable ^{90}Sr levels at a given location (Bragin: 141–1867 Bq/kg dry weight) and also between different areas (Daleta: 234 Bq/kg dry weight; Polesskoe: up to 1289 Bq/kg dry weight), depending on the amount of fallout deposited initially. Results for ^{239}Pu and ^{240}Pu are available for a soil/mat and soil sample from undisturbed grassland in Bragin (Table 47). As with Cs nuclides, in this type of environment ^{239}Pu and ^{240}Pu are found mainly in the top soil/mat layer (0–5 cm) and only at considerably lower concentrations in the 5–10 cm layer (0.5 Bq/kg dry weight, Fig. 48).

Selected soil samples from Bragin, Daleta and Polesskoe were analysed with regard to the determination of the Pu and Sr surface activity in the top soil layer (0–1 cm) and the soil depth distribution. The results for ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{90}Sr are shown in Table 48 and Fig. 48. In the samples from Bragin, the surface activity ranges from 36 to 740 Bq/m^2 for Pu and from 5400 to 38 600 Bq/m^2 for ^{90}Sr, with higher values in the undisturbed areas. Owing to the very limited number of ^{90}Sr data from the international team, the $^{90}Sr/^{137}Cs$ ratio could not be assessed. This was also the case for the Pu/Ce ratio.

A typical example for the soil depth distribution of Pu isotopes is shown in Fig. 48. In undisturbed soil, practically all radionuclides were found in the top 5 cm layer, with a pronounced maximum in the top 1 cm layer, as is the case for Cs isotopes.

The official values for the surface activity in Bragin, reported to have been based on direct measurements (^{90}Sr 37 000–74 000 Bq/m^2; ^{239}Pu and ^{240}Pu less than 3700 Bq/m^2), are shown in the maps issued with the Overview to this Project. The results from the soil sampling programme of the international team correspond with official Soviet data for Pu, with the potential for overestimation of the actual ^{90}Sr surface activity in the official Soviet data. It must be stressed though that the validity of comparing Pu concentrations in soil samples, which are not exactly the same in terms of sampling procedure, is limited.

TABLE 35. Radionuclide Concentrations in Soil–Grass Ecosystem Samples, Novozybkov Region (in Bq/kg Dry Weight) [*Source: P. Stegnar*]

	Cs-137	Cs-134	Ru-106	Sb-125	Ce-144	K-40	Eu-154	Eu-155	Am-241
				No. 1. Starye Bobovichi[a]					
Grass, 2 m^2	21 890	3 050	43	55	32	800			
Mat, 0–2 cm	30 000	4 500	710	315	100	490	13		
Root soil, 2–6 cm	8 170	1 260	240	170	40	370			
Soil, 6–10 cm	1 570	238	76	50		357			
				No. 2. Gatka[b]					
Grass, 1 m^2	6 660	1 040				550			
Mat, 0–3 cm	10 000	1 480	150	115	30	290			
Root soil, 3–6 cm	10 400	1 590	200	160	40	295			
Soil, 6–9 cm	740	130		20		330			
				No. 3A. Novye Bobovichi[c]					
Coarse organic matter, 0–1 cm	237 600	36 600	4460	5600	460	160	125	120	37
Soil organic matter, 0–1 cm	38 000	5 900	1080	1000		270	13		
Soil, 1–4 cm	1 015	155	165	96		262	1.2		

[a] Starye Bobovichi — undisturbed meadow; gamma dose rate: 200–300 μR/h (2–3 μGy/h). Surface contamination: 40–45 Ci/km^2 of Cs-137 (1.48–1.66 MBq/m^2).

[b] Gatka — undisturbed meadow; gamma dose rate: 80–100 μR/h (0.8–1.0 μGy/h). Surface contamination: 15–20 Ci/km^2 of Cs-137 (0.55–0.75 MBq/m^2).

[c] Novye Bobovichi — (Rosa) forest; gamma dose rate around 500 μR/h (5 μGy/h). Surface contamination: 60–75 Ci/km^2 of Cs-137 (2.2–2.8 MBq/m^2).

TABLE 36. Radionuclide Concentrations in Soil–Grass Ecosystem Samples, Bragin Region (in Bq/kg Dry Weight) [*Source: P. Stegnar*]

	Cs-137	Cs-134	Ru-106	Sb-125	Ce-144	K-40	Eu-154	Eu-155	Am-241	Co-60
				No. 5. Malozhin[a]						
Grass, 1 m^2	270	40			7	890				
Mat, 0–3 cm	125	16		2	4	370				
Root soil, 3–8 cm	90	17		3	10	440				
Soil, 8–11 cm	150	30		3	<5	370				
				No. 6. Gden[b]						
Grass, 1 m^2	120	22				800				
Mat, 0–3 cm	16 660	2460	2610	360	3600	230	134	135	33	14
Root soil, 3–6 cm	190	22	38	14	33	184	3.6	2.2		
Soil, 6–10 cm	41	5.8		5.9		170	1.5			
				No. 7. Bragin[c]						
Mat + soil, 0–5 cm	5 950	890	550	130	1430	150	39	38	13	
Soil, 5–10 cm	39	3		7		200				

[a] Malozhin — undisturbed meadow; gamma dose rate around 10 μR/h (0.1 μGy/h).
Surface contamination around 2 Ci/km^2 of Cs-137 (0.1 MBq/m^2). Sr-90 0.4 Ci/km^2.
[b] Gden — undisturbed meadow; gamma dose rate: 10–15 μR/h (0.1–0.15 μGy/h).
Surface contamination: 5–6 Ci/km^2 of Cs-137 (0.2 MBq/m^2). Sr-90 1.6 Ci/km^2.
[c] Bragin — undisturbed grassland; gamma dose rate up to 15 μR/h (0.15 μGy/h).
Possible surface contamination by Pu-239, Pu-240: around 0.15 Ci/km^2 (5.5 kBq/m^2).

TABLE 37. Radionuclide Concentrations in Soil–Grass Ecosystem Samples, Ovruch Region (in Bq/kg Dry Weight) [*Source: P. Stegnar*]

	Cs-137	Cs-134	Ru-106	Sb-125	Ce-144	K-40	Eu-154	Eu-155	Am-241	Co-60
				No. 8. Milcha (Daleta)[a]						
Mat, 0–3 cm	560	72		6	17	100				
Soil, 3–8 cm	220	31		2	8	56				
				No. 9. Rakitnoe[b]						
Grass, 1 m^2	1470	224				470				
Mat, 0–3 cm	8630	1345	80	110	160	120				
Soil, 3–8 cm	422	65		12		90				
				No. 10. Machul'nya[c]						
Mat, 0–3 cm	9840	1490	385	140	600	160	31	30	13	8
Soil, 3–8 cm	145	23	40		5	165				

[a] Milcha — near Daleta; low ground and high food contamination by Cs-137 and Cs-134.
Surface contamination around 5 Ci/km^2 of Cs-137 (0.2 MBq/m^2).
[b] Rakitnoe — high ground and high food contamination.
Surface contamination up to 15 Ci/km^2 of Cs-137 (0.6 MBq/m^2).
[c] Machul'nya — low ground and low food contamination.

TABLE 38. Concentrations of ^{137}Cs, ^{134}Cs and ^{90}Sr in Human and Cow's Milk from the Novozybkov, Bragin and Ovruch Regions
[*Source: P. Stegnar*]

	Cs-137 (Bq/L)	Cs-134 (Bq/L)	Sr-90 (Bq/L)
Novozybkov region			
Human milk, mean (range) (5 samples)	8.0 (1.9–14.1)	—	—
Bragin region			
Human milk, mean (range) (8 samples)	10.6 (3.1–18.2)	—	—
Cow's milk (1 sample)	85	11.8	6.9
Ovruch region			
Human milk, mean (range) (7 samples)	18.9 (3.7–61.2)	—	—
Cow's milk, mean (range) (3 samples)	1068 (645–1410)	152	5

Note: Daleta: pooled private milk.
Rakitnoe: pooled private milk.
Slovechno: pooled milk from collective farms.

3.9. Air Sampling Programme

Fallout deposited on the ground is subject to resuspension processes due to meteorological phenomena (e.g. wind) and human activities (e.g. ploughing and traffic). Resuspension of radioactive particles contributes to the inhalation dose of residents and workers and can also cause contamination of exposed surfaces in the contaminated areas. In order to quantify the occurrence of resuspended particles, an air sampling programme was initiated in selected settlements, mostly in areas where surveys of other radiological components had also been carried out.

Air samples were taken in 11 settlements in the Bragin and Ovruch areas using high volume air samplers (sample volume: 5–30 m^3) and cellulose acetate filters (pore size: 1.2 μm). Sampling sites were mainly outdoors, i.e. public sites, playgrounds and agricultural areas where resuspension seemed likely. In addition, a few indoor measurements were carried out. However, owing to high precipitation during the investigation period, together with seasonal coverage of soils with vegetation, the representativity of these air samples is limited. Conditions may be different during extended periods of dry weather and thinner vegetation cover. The exposed filters were analysed for gamma emitters by the use of gamma spectrometry and for alpha emitters by radiochemical separation and alpha spectrometry.

Results are given in Table 49. No equivalent sets of Soviet data were presented to the international team. Generally, atmospheric nuclide levels outdoors and indoors were found to be low during the period of investigation: the Cs concentration was below 0.3 Bq/m^3 (the limit of detection for gamma spectrometry) and alpha emitters ranged from 0.07 to 0.51 mBq/m^3.

3.10. Food Sampling Programme

As part of the nutritional study carried out within the framework of the assessment of clinical health effects from radiation exposure and evaluation of the general health situation (Part F), a food sampling programme was carried out (for details, see Section 1 in Part F).

Food samples that were representative of the total dietary intake were taken from 11 selected settlements. All samples were blended and homogenized. Aliquots were sealed and frozen for subsequent analysis. Radionuclide concentrations (^{134}Cs and ^{137}Cs) were determined by gamma spectrometry.

The results of the analysis of the total diet samples are presented in Table 50 and show significant variation in Cs values within a given region and also between different regions. For example, in the Novozybkov region, the ^{137}Cs concentration in total diet samples ranges from insignificantly low values in Malozhin (maximum concentration: 63 Bq/kg dry weight) to elevated levels in Starye Vishkov (maximum concentration: 3930 Bq/kg dry weight).

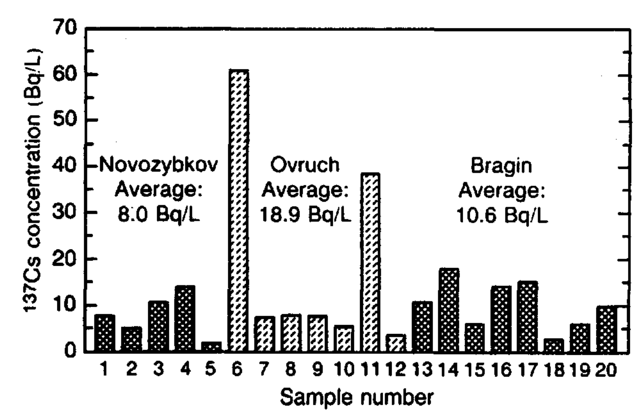


FIG. 43. Concentration of ^{137}Cs in human milk from the Novozybkov, Bragin and Ovruch regions. [Source: P. Stegnar]

Text cont. on p. 185

TABLE 39. Official Soviet Data on ^{137}Cs Concentrations in the Environment and Agricultural Products in 1989 for the Bragin Region

	Contamination of agricultural land by Cs-137 and Cs-134		
	1-5 Ci/km^2	5-15 Ci/km^2	15-40 Ci/km^2
Agricultural land (%)	54.1	32.3	13.6

	Contamination of agricultural land by Sr-90		
	0-1 Ci/km^2	1-3 Ci/km^2	3 Ci/km^2 and over
Agricultural land (%)	42.5	49.4	8.1

Contamination of towns and settlements by Cs-137 and Sr-90		
	Cs-137 (Ci/km^2)	Sr-90 (Ci/km^2)
Bragin	27.0	2.1
Mikulichi	17.0	0.95
Malozhin	2.0	0.4
Gden	5.6	1.6

Contamination of agricultural products by Cs-137		
Milk	up to 1 × 10^{-8} Ci/L	- 87%
Potatoes	up to 2 × 10^{-8} Ci/kg	-100%
Hay	up to 5 × 10^{-8} Ci/kg	- 67%
Silage	up to 2.5 × 10^{-8} Ci/kg	- 71%
Grass silage	up to 2.5 × 10^{-8} Ci/kg	- 46%
Cereals	up to 1 × 10^{-8} Ci/kg	-100%
Root crops	up to 2 × 10^{-8} Ci/kg	-100%

Note: 1 Ci = 37 GBq.

TABLE 40. Official Soviet Data on Radionuclide Concentrations in Milk for the Ovruch Region
Results of spectrometric studies on milk collected from towns and settlements, 16 and 17 July 1990
[*Source: P. Stegnar*]

Site	Type and No. of sample	Isotope	Activity	
			Bq/L	Ci/L
Slovechno	Milk, collecting point, public	Cs-137	341	9.2×10^{-9}
Machul'nya	Public, private sector	Cs-134	74	2.0×10^{-9}
		Cs-137	317	8.6×10^{-9}
		Σ	391	1.06×10^{-8}
		Ru-103	435	1.2×10^{-8}
		Ra-226	52	1.4×10^{-9}
Korchevka	Public, private sector —			
	Sample No. 1	Cs-134	118	3.2×10^{-9}
		Cs-137	629	1.7×10^{-8}
		Σ	747	2.0×10^{-8}
	Sample No. 2	Cs-137	606	1.6×10^{-8}
	Sample No. 3	Cs-134	140	3.8×10^{-9}
		Cs-137	850	2.3×10^{-8}
		Σ	990	2.68×10^{-8}
Rakitnoe	Public, private sector	Cs-137	1200	3.29×10^{-8}
	Collective farm	Cs-137	470	1.22×10^{-8}
	Private sector	Cs-134	185	5×10^{-9}
		Cs-137	1369	3.7×10^{-8}
		Σ	1554	4.2×10^{-8}
Daleta	Private sector —			
	Sample No. 1	Cs-134	73	2.0×10^{-9}
		Cs-137	1180	3.2×10^{-8}
		Σ	1253	3.4×10^{-8}
		Ru-103	436	1.2×10^{-8}
		Ra-226	53	1.4×10^{-9}
	Private sector —			
	Sample No. 2	Cs-134	247	6.7×10^{-9}
		Cs-137	1710	4.6×10^{-8}
		Σ	1957	5.27×10^{-8}
	Sample No. 3	Cs-134	351	9.5×10^{-9}
		Cs-137	2553	6.9×10^{-8}
		Σ	2904	7.85×10^{-8}

Note: The studies were carried out over the 550-850 keV energy range (the range for caesium isotopes) but were not performed for the whole spectrum. Probability = 95%; relative error = 3.6–11.3%. The studies were carried out by P.V. Kolyadko, an engineer from the Ovruch Epidemiological Station, on the AI-1024-95-17 pulse analyser No. 709, certified on 29 Nov. 1989.

1 Ci = 37 GBq.

TABLE 41. Nuclide Concentrations in Water Samples [*Source: F. Maringer and team*]

Location (sampling site)	Nuclide concn (Bq/L)				
	Cs-134	Cs-137	Ce-144	Rh-106	Sb-125
		Bragin			
Drainage, well, public water supply (F)	LD	LD	LD	LD	LD
		Daleta			
Well (F)	LD	LD	LD	LD	LD
		Gatka			
Well (F)	LD	LD	LD	LD	LD
		Gden			
Tap water (UF)	LD	LD	LD	LD	LD
		Komarin			
Well (F)	LD	LD	LD	LD	LD
Public water supply (UF)	LD	LD	LD	LD	LD
		Korchevka			
Well (F)	LD	LD	LD	LD	LD
		Malozhin			
Standing surface water (F)	LD	LD	LD	LD	LD
		Mikulichi			
Pond (UF)	1 ± 0.2	7 ± 1	LD	LD	LD
Well	LD	LD	LD	LD	LD
		Novoe Mesto			
Well (F)	LD	LD	LD	LD	LD
		Novozybkov			
Lake	LD	LD	LD	LD	LD
		Novye Bobovichi			
Well (F)	LD	LD	LD	LD	LD
Pond (F)	LD	6 ± 1	LD	LD	LD
Public water supply (UF)	LD	LD	LD	LD	LD
		Ovruch			
River, lake, well (F)	LD	LD	LD	LD	LD
		Rakitnoe			
Well (F)	LD	LD	LD	LD	LD
Well (UF)	LD	LD	LD	LD	LD
Pond (F)	LD	2 ± 0.3	LD	LD	LD
		Savichi			
Lake, well (F)	LD	LD	LD	LD	LD

TABLE 41. (cont.)

Location (sampling site)	Nuclide concn (Bq/L)				
	Cs-134	Cs-137	Ce-144	Rh-106	Sb-125
		Slovechno			
Stream, well (F)	LD	LD	LD	LD	LD
Well (UF)	LD	LD	LD	LD	LD
		Starye Bobovichi			
Well, river (F)	LD	LD	LD	LD	LD
Public water supply (UF)	LD	LD	LD	LD	LD
		Svyatsk			
Well (F)	LD	LD	LD	LD	LD
Public water supply (UF)	LD	LD	LD	LD	LD

Note: F: filtered sample; UF: unfiltered sample. Nuclide specific limit of detection (LD) for water (Bq/L): Cs-134: 0.3; Cs-137: 0.3; Ce-144: 1.8; Rh-106: 2.5; Sb-125: 0.8.

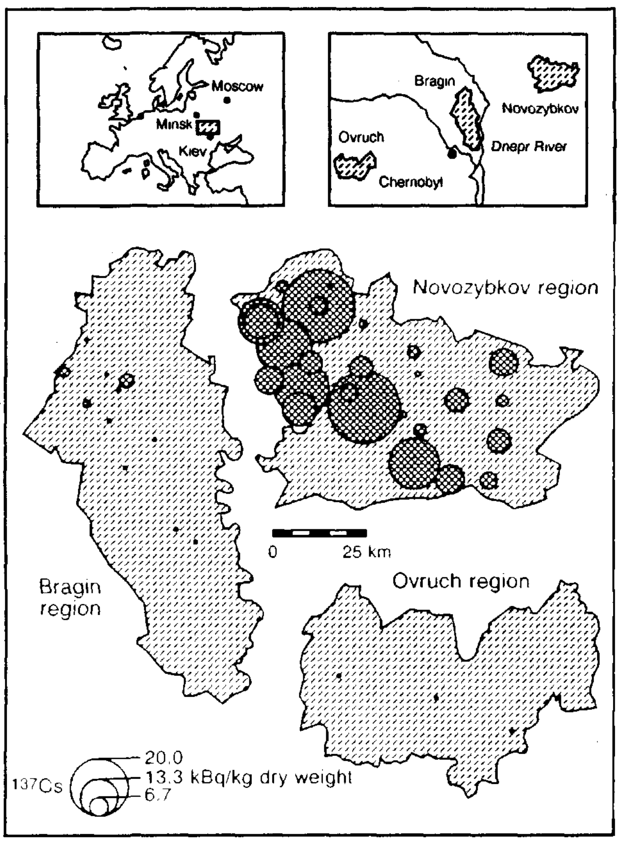


FIG. 44. Concentration of ^{137}Cs in soil samples from the Bragin, Novozybkov and Ovruch regions. [Source: G.J. Van Den Berg and team]

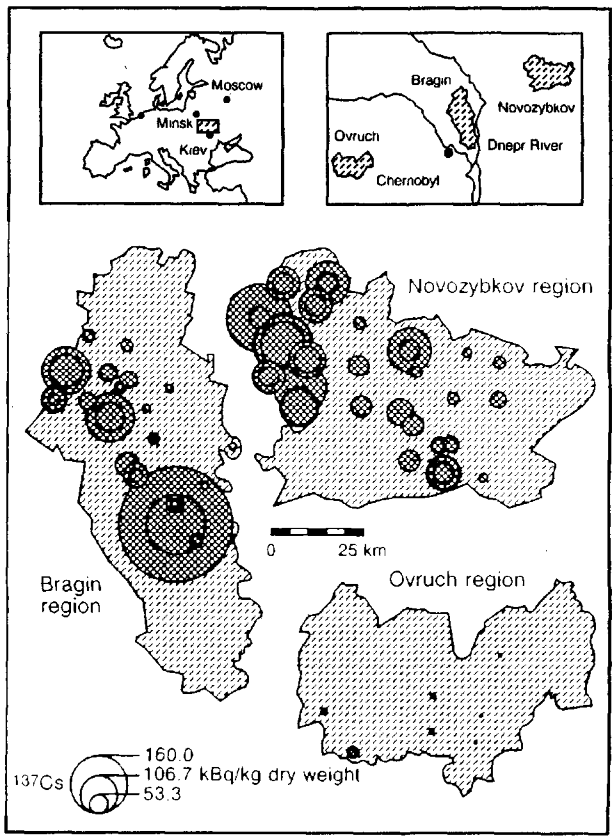


FIG. 45. Concentration of ^{137}Cs in lichen samples (*Parmelia sulcata*) from the Bragin, Novozybkov and Ovruch regions. [Source: G.J. Van Den Berg and team]

TABLE 42. Nuclide Concentrations in the Residue of Filtered Water Samples [*Source: F. Maringer and team*]

Location (sampling site)	Nuclide concn (mBq/L)				
	Cs-134	Cs-137	Ce-144	Rh-106	Sb-125
		Bragin			
Drainage	LD	3 ± 1	LD	LD	LD
Well, public water supply	LD	LD	LD	LD	LD
		Daleta			
Well	LD	LD	LD	LD	LD
		Gatka			
Well	LD	LD	LD	LD	LD
		Komarin			
Well	LD	LD	LD	LD	LD
		Korchevka			
Well	LD	LD	LD	LD	LD
		Malozhin			
Standing surface water	LD	25 ± 7	LD	LD	LD
		Mikulichi			
Well	LD	LD	LD	LD	LD
		Novoe Mesto			
Well	LD	LD	LD	LD	LD
		Novozybkov			
Lake	LD	78 ± 11	LD	LD	LD
		Novye Bobovichi			
Pond	88 ± 14	470 ± 42	LD	LD	LD
Well	41 ± 11	234 ± 23	LD	LD	LD
		Ovruch			
River, lake, well	LD	LD	LD	LD	LD
		Rakitnoe			
Well	LD	LD	LD	LD	LD
Pond	LD	68 ± 15	LD	LD	LD
		Savichi			
Lake	LD	44 ± 9	LD	LD	LD
Well	LD	LD	LD	LD	LD
		Slovechno			
Stream, well	LD	LD	LD	LD	LD
		Starye Bobovichi			
Well, river, public water supply	LD	LD	LD	LD	LD
		Svyatsk			
Well	LD	LD	LD	LD	LD

Note: Nuclide specific limit of detection (LD) for filter residue (mBq/L): Cs-134: 10.0; Cs-137: 9.0; Ce-144: 61.0; Rh-106: 84.0; Sb-125: 36.0.

TABLE 43. Depth Distribution of Radionuclides in Sediments [*Source: F. Maringer and team*]

Location (sampling site)	Depth (cm)	Nuclide concn (Bq/kg)				
		Cs-134	Cs-137	Ce-144	Rh-106	Sb-125
			Gden			
River bank	0–5	1740 ± 95	11 800 ± 690	53 ± 9	157 ± 20	116 ± 8
	5–10	485 ± 28	3 370 ± 200	LD	LD	LD
	10–15	113 ± 7	810 ± 49	LD	LD	LD
	15–20	5 ± 1	36 ± 3	LD	LD	LD
	20–25	LD	10 ± 1	LD	LD	LD
			Korchevka			
Pond	0–5	LD	6 ± 1	LD	LD	LD
			Malozhin			
Surface water	0–5	22 ± 2	180 ± 11	LD	36 ± 8	LD
	5–15	5 ± 1	32 ± 2	LD	LD	LD
			Mikulichi			
Pond	0–5	218 ± 13	1 480 ± 88	LD	LD	LD
	5–10	323 ± 18	2 200 ± 130	59 ± 10	LD	38 ± 6
	10–15	30 ± 2	220 ± 13	LD	LD	LD
			Novozybkov			
Lake	0–5	LD	40 ± 3	LD	LD	LD
	5–10	LD	9 ± 1	LD	LD	LD
	10–24	LD	39 ± 3	LD	LD	LD
	24–29	LD	10 ± 1	LD	LD	LD
	29–35	LD	4 ± 1	LD	LD	LD
			Novye Bobovichi			
Pond	0–1	831 ± 46	5 690 ± 340	LD	109 ± 37	LD
	1–18	34 ± 2	231 ± 14	LD	LD	LD
	18–20	LD	3 ± 1	LD	LD	LD
			Ovruch			
Lake	0–12	40 ± 3	255 ± 16	LD	LD	LD
	2–7	51 ± 3	309 ± 18	LD	LD	LD
	7 ± 12	37 ± 2	238 ± 14	LD	LD	LD
	12 ± 17	11 ± 1	82 ± 5	LD	LD	LD
			Rakitnoe			
Pond	0–1.5	16 ± 1.5	110 ± 8	LD	LD	LD
	1.5–6	10 ± 1	70 ± 5	LD	LD	LD
	6–11	LD	4 ± 1	LD	LD	LD
			Savichi			
Lake	0–2	135 ± 10	977 ± 61	LD	LD	LD
	2–15	15 ± 12	119 ± 8	LD	LD	LD
			Slovechno			
Stream	0–2	LD	5 ± 1	LD	LD	LD
			Starye Bobovichi			
River	0–5	207 ± 12	1 420 ± 83	LD	LD	LD
	5–13	7 ± 1	50 ± 3	LD	LD	LD
	13–24	LD	3 ± 1	LD	LD	LD

Note: Nuclide specific limit of detection (LD) for sediments (Bq/kg): Cs-134: 1.4; Cs-137: 1.9; Ce-144: 12.0; Rh-106: 17.0; Sb-125: 4.2.

TABLE 44. **^{137}Cs Concentrations in Soil Samples** [*Source: K. Buchtela*]

Area (No. of samples) [*centred titles*], sample type	Cs-137 deposition (kBq/m^2)	Max. specific Cs-137 activity (Bq/g) at depth (cm)
	Bragin (n=5)	
Undisturbed area	930	16 (0–5)
Ploughed area, garden	552–2915	4.5–24 (10–20)
Decontaminated garden	138	0.3 (5–10)
	Daleta (n=8)	
Garden/pasture/meadow	214–398	1.4–9.1 (0–10)
Potato/oat field	277–386	2.3–2.7 (5–10)
Undisturbed area	82	2.1 (0–2.5)
Forest	130	3.0 (0–2.5)
	Gden (n=6)	
Pasture	340–415	14–17 (0–2.5)
Rye field	221	0.7 (10–15)
Garden	121–356	2.4–4.4 (0–10)
Forest	74	1.3 (0–2.5)
	Komarin (n=5)	
Garden	158–160	0.7–1.5 (5–15)
Potato/rye field	72–93	0.3–0.5 (0–2.5)
Forest	100	1.8 (0–2.5)
	Korchevka (n=6)	
Garden/pasture/meadow	117–283	1.4–3.3 (0–5)
Field	235	0.9 (10–15)
Near well	179	2.6 (0–2.5)
Forest	87	1.1 (0–2.5)
	Malozhin (n=5)	
Pasture	27	0.6 (0–2.5)
Near pond	160	2.5 (2.5–5)
Oat field/orchard	15–42	0.2–0.3 (0–2.5)
Forest	38	1.8 (0.–2.5)
	Mikulichi (n=6)	
Pasture, meadow	123–1378	1.3–28 (0–5)
Rye/oats field	1101–1554	5.8–6 (5–15)
Decontaminated meadow	155	2.2 (0–2.5)
	Novozybkov (n=11)	
Pasture	696	14 (0–2.5)
Field	558–1855	1.6–9.2 (0–15)
Near lake	673	27 (0–2.5)
Undisturbed area	899	13 (0–2.5)
Near hot spot	1448	13 (2.5–5)
Forest	748–1109	13–19 (0–2.5)
	Novye Bobovichi (n=6)	
Garden/field	665–1117	3.9–5 (5–10)
Meadow/pasture	1756–2060	20–38 (0–10)
Forest	1428	36 (0–2.5)

TABLE 44. (cont.)

Area (No. of samples) [*centred titles*], sample type	Cs-137 deposition (kBq/m^2)	Max. specific Cs-137 activity (Bq/g) at depth (cm)
	Ovruch (n=6)	
Garden/pasture	143–153	0.9–2.1 (0–2.5)
Field	116–195	0.5–0.8 (0–5)
Undisturbed area	101–153	1.6–2.8 (0–2.5)
	Rakitnoe (n=8)	
Near school/park	363–441	7.9–14 (0–2.5)
Garden/meadow	108–477	1.1–4.3 (0–5)
Orchard/field	232–930	1.4–1.7 (0–5)
Undisturbed area	240	4.5 (0–2.5)
Forest	49	2.4 (0–2.5)
	Savichi (n=6)	
Meadow	419	2.9 (5–10)
Garden	199–909	0.8–13 (0–5)
Rye field	187	0.8 (2.5–15)
Decontaminated field	32	0.7 (0–2.5)
	Slovechno (n=7)	
Field	82–90	0.3–0.4 (2.5–15)
Garden/pasture	92–122	0.8–1.5 (0–5)
Near well	169	2.7 (0–2.5)
Undisturbed area	52–171	0.5–1.7 (0–15)
	Starye Bobovichi (n=5)	
Forest	1049	38 (0–2.5)
Meadow	910–1574	8–18 (0–5)
Undisturbed area	1564	29 (0–2.5)
Garden	1214	28 (0–2.5)
	Svyatsk (n=8)	
Pasture, garden	1528–2845	7.8–9.2 (5–10)
Decontaminated garden	3398	15 (5–10)
Decontaminated meadow	150	2.2 (0–2.5)
Forest	572	16 (0–2.5)
Undisturbed area	28	5.2 (2.5–10)
Hot spot	12717	220 (2.5–5)

TABLE 45. ^{137}Cs Concentrations in Grass Samples [*Source: P. Stegnar and E. Lovranich*]

Location	Nuclide concn (Bq/kg dry weight)
Bragin	131–1 080
Malozhin	270
Starye Bobovichi	21 900
Daleta	2 890
Gatka	6 660
Polesskoe	1 380–7 710
Rakitnoe	1 470

Note: Total number of samples n = 16.

TABLE 46. ^{137}Cs Concentrations in Mat (Grass) Samples [*Source: P. Stegnar*]

Location	Nuclide concn (Bq/kg dry weight)
Milcha	560
Malozhin	125
Starye Bobovichi	30 000
Gatka	10 000
Gden	16 700
Rakitnoe	8 630
Machul'nya	9 840

Note: Total number of samples n = 7.

TABLE 47. ^{90}Sr, ^{239}Pu and ^{240}Pu Concentrations in Grass and Soil/Mat Samples [*Source: A. Ghods and P. Stegnar*]

Location	Sample type	Nuclide concn (Bq/kg dry weight)	
		Sr-90	Pu-239/Pu-240
Bragin	Grass	141–1870	
	Soil/mat	—	16.9
Daleta	Grass	234	—
Polesskoe	Grass	161–1290	—

Note: Total number of samples n = 12.

TABLE 48. ^{90}Sr, ^{238}Pu, ^{239}Pu and ^{240}Pu Surface Activity in Top Soil Layer (0–1 cm) in Bragin, Daleta and Polesskoe [*Source: A. Ghods, P. Zambori and J. La Rosa*]

Location (sampling site)	Surface activity (Bq/m^2)		
	Pu-238	Pu-239/Pu-240	Sr-90
	Bragin		
Public area	36	65	5 400
Yard	—	—	6 700
Undisturbed area	410	740	38 600
	Daleta		
Field	—	—	5 500
	Polesskoe		
Field (near road)	—	113	6 800
Field (near river)	—	—	8 500
Undisturbed area	—	—	4 400
		1020	30 000

TABLE 49. Radionuclide Concentrations in Air Filter Samples [*Source: E. Wehrstein-Werner and J. La Rosa*]

Location	Sampling site	Nuclide concn		
		Cs-134 (Bq/m^3)	Cs-137 (Bq/m^3)	α emitters (mBq/m^3)
Bragin	Indoors	LD	LD	0.14
	Outdoors	LD	LD	0.08–0.43
Ovruch	Indoors	—	—	0.01
	Outdoors	—	—	0.12–0.19
Daleta	Outdoors	LD	LD	0.07–0.35
Gden	Outdoors	—	—	0.12
Komarin	Outdoors	—	—	0.08
Korchevka	Outdoors	—	—	0.33–0.51
Malozhin	Outdoors	—	—	0.07–0.10
Mikulichi	Outdoors	—	—	0.06
Savichi	Outdoors	—	—	0.11
Rakitnoe	Outdoors	—	—	0.07–0.33
Sovenichi	Outdoors	—	—	0.27–0.51

Note: Total number of samples n = 28.
LD: limit of detection.

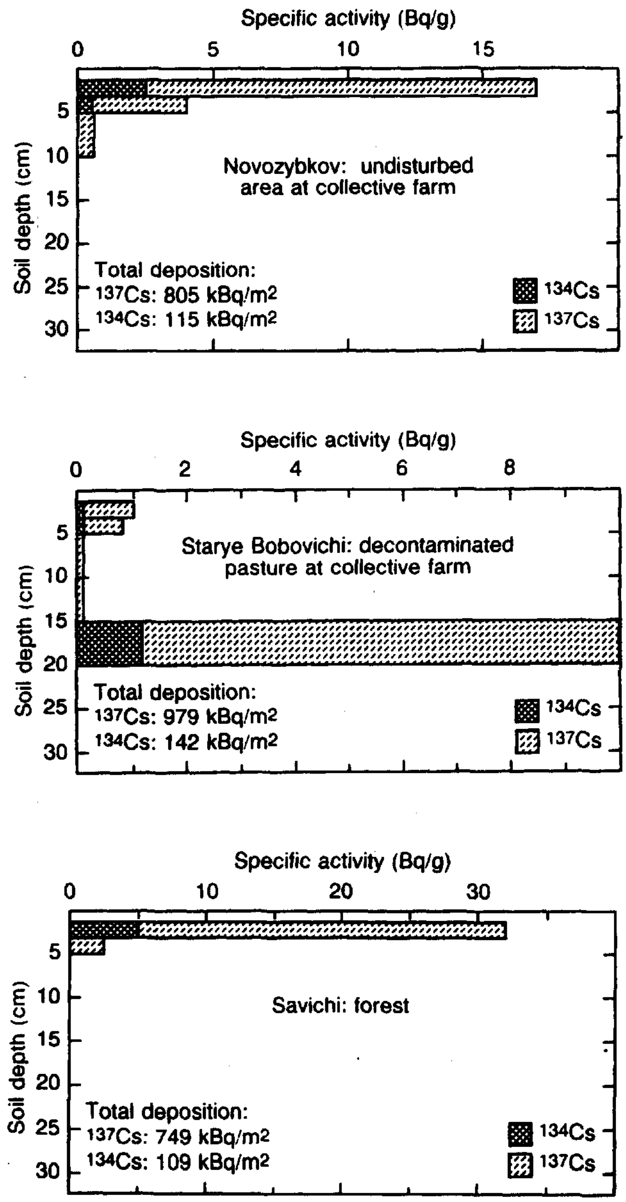


FIG. 46. Depth distribution of ^{137}Cs and ^{134}Cs in soil samples from areas used for agriculture and forestry. [Source: K. Buchtela]

The difference observed in the Cs concentration of total diet samples between regions is influenced not only by the amount of fallout initially deposited, but also by local radioecological conditions. For instance, in Daleta, an area reporting elevated transfer from the soil to plants, but relatively low environmental radioactivity (dose rate outdoors: under 0.5 μSv/h), total diet samples have the highest Cs concentration in this study (up to 6370 Bq/kg dry weight). This is also reflected in the corresponding results from the independent whole body counting programme (for details, see Section 2 in Part E).

Official Soviet data are not available for Cs contamination in total diet samples. However, Cs concentrations were measured in a large number of different foods in 1990 and analytical results are stored in the Soviet database developed by the USSR State Committee on Hydrometeorology (H-DB) (see Ref. [20]; for detailed references, see Part E, Annex 2). Although the Soviet data and independently collected food data are not directly comparable (food assortment compared with total diet samples; time of year), it can be concluded that the caesium (^{134}Cs + ^{137}Cs) ranges from the independent study are generally lower than the corresponding ranges from H-DB:

— *Bragin region:*
  H-DB: 222–1110 Bq/kg wet weight;
  Independent study: under 5 to 91 Bq/kg wet weight;
— *Novozybkov region:*
  H-DB: 74–5550 Bq/kg wet weight;
  Independent study: under 3 to 717 Bq/kg wet weight.

The corresponding range of caesium (^{134}Cs + ^{137}Cs) data for total diet samples from the Ovruch region (15–914 Bq/kg wet weight) is of the same order of magnitude as for the Novozybkov region. Soviet food data have not been made available for comparison.

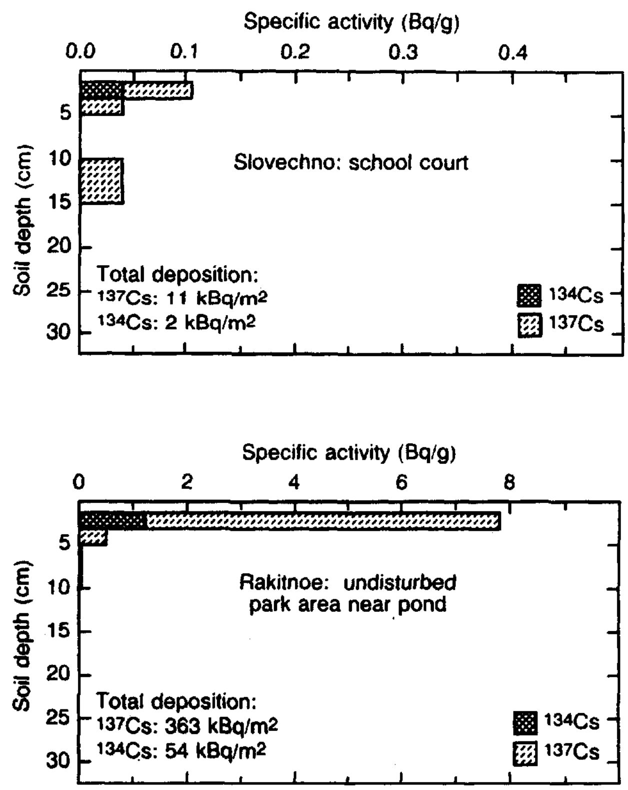


FIG. 47. Depth distribution of ^{137}Cs and ^{134}Cs in soil samples from public areas. [Source: K. Buchtela]

In addition, a few samples of wild food (berries and mushrooms) and other food (vegetables, fruits, butter, bread and fish; commercial and private sources) were taken at random in the Bragin, Novozybkov and Ovruch regions (Tables 51 and 52). As was to be expected, the ^{137}Cs concentration in wild food was significantly elevated (e.g. mushrooms ≤131 000 Bq/kg dry weight), whereas the nuclide concentration in the other food samples is considerably lower (≤349 Bq/kg dry weight) and corresponds to the results obtained for the total diet samples.

TABLE 50. ^{134}Cs and ^{137}Cs Concentrations in Total Diet Samples [*Source: M. Makarewicz and R. Schelenz*]

Location	Nuclide concn (Bq/kg dry weight)	
	Cs-134	Cs-137
	Bragin region	
Bragin	11	70
Gden	LD-52	8-420
Mikulichi	LD-11	29-60
	Novozybkov region	
Karkhovka	11-130	<53-540
Malozhin	LD-8	16-63
Novozybkov	LD-45	31-290
Starye Bobovichi	LD-78	14-1160
Starye Vishkov	LD-540	54-3930
Svyatsk	LD-15	37-101
	Ovruch region	
Daleta	190-870	1350-6370
Rakitnoe	14-510	100-3600

LD: limit of detection.
Note: LD for Cs-134 is ≤7 Bq/kg dry weight.
LD for Cs-137 is ≤19 Bq/kg dry weight.

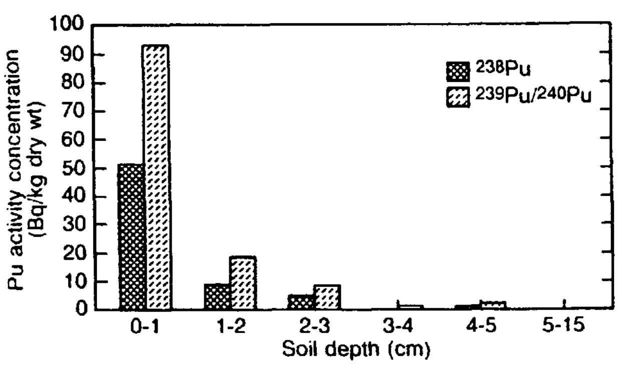


FIG. 48. Depth distribution of ^{238}Pu, ^{239}Pu and ^{240}Pu in undisturbed soil (Bragin). [Source: J. La Rosa and P. Zombori]

TABLE 51. ^{137}Cs Concentration in Samples of Wild Edibles [*Source: M. Makarewicz*]

Sample and location	^{137}Cs concn (Bq/kg)
Blueberries	
Bragin[a]	740
Novozybkov[a]	1 240
Mushrooms	
Bragin[a]	1 320
Savichi[b]	131 000
Daleta[b]	20 800

[a] Wet weight.
[b] Dry weight.

TABLE 52. ^{137}Cs Concentration in Selected Food Samples [*Source: M. Makarewicz*]

Sample and location	^{137}Cs concn (Bq/kg wet weight)
Bragin region	
Vegetables	<25
Fruit	<9
Garlic	27
Butter	14
Fish	170
Novozybkov region	
Vegetables	<14
Fruit	≤12
Corn	23
Bread	<6
Ovruch region	
Vegetables	<1 to 102
Corn	180
Meat	6
Fish	340
Milk	<4 to 2070

4. Discussion of Results for the Corroboration of Soviet Environmental Radiation Data

4.1. Results of the Review of Databases, Sampling Techniques, Analytical Procedures, Instrumentation and Mapping Procedures

On the basis of the review by the international expert team, presented in Section 2, it can be concluded that the USSR has a well developed infrastructure for the sampling and analysis of the radioactivity of foodstuffs and environmental materials. The staff engaged in the work in the three Republics and at the All-Union level were generally found to be experienced and competent. However, a few problems were identified by the teams. In several cases, lack of information impeded the satisfactory assessment of the situation.

There was great variability in the participation of the institutions visited by the experts for this task. Some institutions were most co-operative in providing copies of manuals on their laboratory procedures, while others provided them reluctantly and some refused absolutely.

It was not possible to review the quality assurance programmes (QAP) of the individual laboratories. The documentation for these programmes was not provided. In particular, the role of the 'Typhoon' Scientific Production Association (Obninsk) in an All-Union QAP is unclear, since only very limited information was provided. This, together with the lack of information on which data were contributed by which institution, makes it impossible to quantify the uncertainty associated with officially published Soviet data on environment and foodstuffs.

4.1.1. Databases

The collection of official radiological data, together with official non-radiological information on the environment, is well organized and data are stored in a central database in Moscow and in various databases at the Republic level. All are updated frequently. However, detailed information is lacking on the qualifying criteria for using data as input into them. Furthermore, it is unclear to what extent data are exchanged between these databases. No quantitative information was provided on the relative contribution of each laboratory that was visited to the various databases used for the assessment of the environmental contamination. It is evident that the institutions range from small laboratories checking regularly on compliance in selected products for a limited geographical area to research organizations with the potential for major contributions to the databases. An indication of the importance of each institute can be gauged by its participation in the intercomparison exercise organized by the IAEA (for details, see Section 2.5), since the IAC requested that the participants in the exercise should represent the main contributors to the total Soviet data collection used for all subsequent assessments. In summary, it is not possible to quantify the uncertainty and degree of completeness of the data sets stored in the databases in Moscow and in the Republics.

4.1.2. Sampling Programmes

The deliberate discrimination against hot spots in accordance with the methodology that was reported to be used for the choice of soil sampling locations, in contrast to the otherwise elaborate soil sampling procedures, limits the usefulness of the soil sampling techniques. For large scale average assessments of surface deposition, these methods can be considered adequate. However, the representativeness of results for a given area on a smaller scale remains unclear. This influences the uncertainty associated with contour lines of surface deposition (isopleths) presented in fallout maps. Owing to the lack of adequate information, this uncertainty cannot be quantified at present.

Extensive water sampling programmes have been implemented for surface water and, to a lesser extent, for groundwater and soil water. Water samples are analysed routinely for ^{137}Cs and ^{90}Sr; no data on Pu isotopes were received by the experts. The main problem with these sampling programmes is the significant potential for cross-contamination during water sampling and/or analytical procedures. This can lead to a possible overestimation of the actual water contamination owing to incomplete separation of particulate matter.

The insufficiency of information on air sampling methodology and equipment precludes a valid assessment.

Vegetation sampling programmes can be considered to be adequate for providing representative averages for a given area.

Food sampling programmes emphasize the monitoring of commercial production and supply and are generally satisfactory. Despite the widespread use of privately produced food and edibles collected, for example, in forests, this sector is generally not part of the elaborate food monitoring system designed for the commercial sector. Further technical information is needed in order to evaluate the performance of the screening methods developed by the Soviet authorities.

4.1.3. Analytical Procedures and Instrumentation

The equipment and analytical procedures used for gamma spectrometry were generally adequate. Most of the laboratories used calibration standards from the same reference laboratory (Khlopin Radium Institute, Leningrad) and spectral analysis was performed mostly with computer based software. Since the calibration standards used were frequently solutions or resins, they were not necessarily representative of the different sample matrices being analysed. This can contribute to the overall uncertainty associated with the analytical data.

Radiochemical methods and laboratory practices used for ^{90}Sr and Pu analysis were subject to criticism in several cases. In a number of laboratories there was evidence of poor sample management and potential cross-contamination problems. Some laboratories also reused glassware in the analyses without conducting appropriate testing for successful decontamination and they did not separate high or low level samples. The problem was compounded by the frequently observed lack of blank determinations which could detect cross-contamination. Concern was also raised about the potentially inadequate dissolution procedures for soil samples, permitting at present only the analysis of exchangeable components, thereby potentially underestimating the total radionuclide concentration.

4.1.4. Mapping Procedures

The Soviet method for producing the environmental contamination maps used a combination of aerial surveys at different heights and soil sampling in settlements. This method is suitable for producing a reliable description of the average fallout deposition on the ground for a given area. On the basis of information obtained from aerial surveys and soil sampling programmes, a spatial resolution of the order of several hundred metres can be assumed for the official maps. Official information quantifying the uncertainties associated with these maps was not available.

4.2. Results from the Intercomparison Exercise

In what follows the major results obtained are discussed with regard to the performance of the laboratories in analysing soil, milk powder and air filters for the three most important nuclides (^{137}Cs, ^{90}Sr and ^{239}Pu). It is emphasized that on the basis of past experiences with similar international exercises, laboratories participating in intercomparison exercises take extra care during the whole sequence of measurement and analysis in order to arrive at the closest possible agreement with the recommended value. Therefore, deviations from the recommended value observed during such an exercise usually represent the minimum value of the potential deviation of a result obtained during routine operations. The reason for larger uncertainties associated with routine measurements is usually the need for a higher sample throughput, resulting in a shorter measurement time and fewer checks on analytical procedures.

For this assessment it has been assumed, on the basis of a personal communication [14], that the laboratories that responded to this exercise provided most of the data used by the Soviet authorities in the relevant databases. The relative contribution of each of these participants to the various databases has not been documented. Only about 20% of the laboratories nominated by the Soviet authorities as potential participants in this exercise submitted their results by the deadline for this Report (December 1990).

The results from participating Soviet laboratories for ^{137}Cs concentrations in *soil* can be considered to be reliable. The values reported for the analysis of ^{239}Pu and ^{90}Sr in soil have a general tendency toward partly significant overestimation of the actual value.

The values for the higher level ^{137}Cs contamination in *milk* generally have low uncertainties, but the values for the concentrations in the lower level samples of ^{137}Cs in milk display significant overestimation of the actual value. This is also the case for ^{90}Sr in milk powder, particularly for lower concentrations. These findings indicate that the actual radionuclide concentration in milk may frequently be lower than is indicated by the analysis.

The analytical results of participating Soviet laboratories for ^{137}Cs and ^{210}Pb on *air* sampling filters are of adequate quality. However, in the case of ^{90}Sr, ^{133}Ba and ^{60}Co, the data cannot be considered to be satisfactory.

In the case of *vegetation*, the actual ^{137}Cs concentration may be higher than the official analytical result, whereas ^{90}Sr results are more likely to be representative of the actual value.

Repeated tests indicated that most environmental samples taken by the participating Soviet institutions fulfilled the criteria of *homogeneity*, a necessary requirement for the production of reference materials.

4.3. Results from the Independent Environmental Surveys

For the independent field surveys of the environmental radiological situation in *settlements in the contaminated areas* of concern, different methods were used selectively: external gamma dose rate surveys, in situ gamma spectrometry, sampling programmes for soil, water, air and food, and biomonitoring. The results obtained by all methods corroborated to varying degrees the general validity of the categories for ^{137}Cs surface deposition used in official Soviet fallout maps (1-5 Ci/km^2 (37-185 kBq/m^2); 5-15 Ci/km^2 (185-555 kBq/km^2); 15-40 Ci/km^2 (555-1480 kBq/m^2); and more than 40 Ci/km^2 (> 1480 kBq/m^2)). Localized hot spots which were neither listed in official tables, nor shown on fallout maps in accordance with officially approved Soviet methods, were found in some settlements during these surveys. The reason for this approach is reportedly the apparent insignificance of the exposure resulting from such hot spot areas as compared with the overall exposure of the residents in a given area. Provided that the appropriate long term marking of the perimeter of a hot spot area is ensured, and the local authorities are informed of their existence, this approach can be considered to be adequate.

With regard to the corroboration of the official data on *^{90}Sr and Pu surface deposition*, it is emphasized that owing to severe constraints on the time and manpower available, only a few grab samples could be analysed for this Report. However, taking into account these limitations, Pu analysis of independently collected soil samples yielded data that generally corresponded to the official Soviet results. Independent ^{90}Sr data are indicative of a potential overestimation of the actual environmental conditions in the Soviet data.

Outdoors, the degree of environmental radioactive contamination by ^{137}Cs in the areas investigated ranged from levels comparable with the surface deposition in, for example, Alpine regions of Austria (up to 46 kBq/m^2) to levels almost 60 times higher.

Indoors, the exposure is largely due to the main components of the natural radiation environment (NRE), i.e. external gamma radiation from construction material and atmospheric radon. In the above settlements these NRE components are of the same order of magnitude as in many other countries (the worldwide mean indoor radon concentration is 55 Bq/m^3; the worldwide mean absorbed dose rate indoors is about 70 nGy/h) [21]. Transfer of outdoor contamination into the indoor environment by occupants could not be detected at the time the surveys were conducted.

The analysis of *soil and vegetation* samples emphasized further the problem already mentioned of the heterogeneous fallout deposition pattern in the affected areas. Migration of ^{137}Cs, ^{90}Sr and Pu in the soils sampled reflects the nuclide specific behaviour as a function of soil type, as well as its possible modification by human activities. From the limited number of samples it is not feasible to draw detailed conclusions. However, a general pattern is indicated, such as that in undisturbed areas (meadows and forests), where the maximum concentrations of ^{137}Cs and Pu can be found towards the top soil layer, and they are present only at considerably lower concentration in lower layers.

The occurrence of *hot particles* in the environment of the affected areas could be corroborated. However, constraints on the manpower and time available prevented the experts from carrying out an assessment in depth of this component, such as different modes of behaviour for the various types of hot particles identified earlier.

The analytical results of *water* samples from wells, lakes and rivers showed that generally they are not contaminated with any of the five radionuclides investigated in the analysis. However, owing to the somewhat significantly elevated ^{137}Cs levels in the sediment samples, the long term impact of runoff processes (rain and melting snow) on the aquatic environment (e.g. enhanced nuclide uptake by fish) requires further monitoring. This is indicated by the ^{137}Cs concentrations in the few fish samples analysed for this project (see Table 52), which is slightly elevated compared with most other foodstuffs.

The results for the *air* samples in the contaminated settlements and surroundings show that during the period of investigation ^{137}Cs and alpha emitters could be detected. Concentration values were found to be low for both categories of nuclides (up to 3.2 Bq/m^3 for ^{137}Cs and up to 0.51 mBq/m^3 for alpha emitters). However, these data cannot be considered as being necessarily representative for long term averages owing to specific boundary conditions during air sampling (frequent rain showers or seasonal soil coverage by vegetation). During extended periods of dry and windy weather, certain population groups (e.g. agricultural workers tilling and harvesting) could be exposed to higher atmospheric nuclide levels since the occurrence of resuspension phenomena cannot be excluded on the basis of the data obtained.

Food sampled in the affected areas frequently showed radiocaesium (^{134}Cs + ^{137}Cs) concentration values below 700 Bq/kg dry weight, i.e. the concentration in the product ready for consumption would be significantly lower. For comparison, these nuclide levels are below the derived intervention levels of the Commission of the European Communities for different foodstuffs (up to 740 Bq/kg wet weight; details are given in Part G). The exceptions to this are edibles collected in forests, for example, and food produced in areas with high soil-plant nuclide transfer factors. Such foodstuffs can show significantly elevated nuclide concentration levels (e.g. ^{137}Cs concentrations in mushrooms from Savichi, up to 131 kBq/kg dry weight; milk from Ovruch, up to 2070 Bq/kg wet weight).

Independent field surveys of the environmental radiological situation were also carried out in *control settlements*. These are settlements in areas in which the official estimate for the ^{137}Cs surface deposition is less than 37 kBq/m^2. This categorization was corroborated by independent surveys, consisting of external gamma dose rate measurements, in situ gamma spectrometry and soil sampling. Generally, no significant radiological consequences of the Chernobyl accident could be detected in terms of elevated levels of gamma dose rate indoors or outdoors. Also, the available food supply was largely unaffected.

Part D

References

[1] Long-Term Radiological Impact of the Chernobyl Accident on the USSR, Report submitted to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Moscow (1987).

[2] Environmental Contamination Following a Major Nuclear Accident (Proc. Symp. Vienna, 1989), IAEA, Vienna (1990).

[3] BEGICHEV, S.N., et al., "Radioactive releases due to the Chernobyl accident", paper presented at the ICHMT Int. Sem. on Fission Product Transport Processes in Reactor Accidents, Dubrovnik, 1989.

[4] IL'IN, L.A., et al., Radiocontamination patterns and possible health consequences of the accident at the Chernobyl nuclear power station, Radiol. Prot. **10** (1990) 13–29.

[5] BELEZKY, Y.A., BUKA, N.N., CHERBANIUK, B.S., CHEBURNOY, N.D., Structure of an Integrated Database for the Zone Affected by the Chernobyl Power Plant, Rep. UDK-681/322/067.

[6] BORZILOV, V.A., 'Typhoon' Scientific Production Association, USSR State Committee for Hydrometeorology, Institute of Experimental Meteorology, Obninsk, personal communication, 1991.

[7] Instructions for Soil Sampling Procedures in Contaminated Areas, USSR State Committee on Hydrometeorology (Goskomgidromet), Moscow (1987).

[8] Instructions and Methodological Advice on the Assessment of the Radiological Situation in a Contaminated Area, USSR State Committee on Hydrometeorology, (Goskomgidromet), Moscow (1989).

[9] Express Method for Measuring Mean Radiation Energy and Specific Activity of an Unknown Mixture of Beta-Emitting Radionuclides, Report, All-Union Scientific Research Institute of Agricultural Radiology, Obninsk (1990).

[10] Technique for Measuring Gamma-Emitting Radionuclide Activities in Soil and Biological Samples Using a Semiconductor Gamma Spectrometer, Report, All-Union Scientific Research Institute of Agricultural Radiology, Obninsk (1990).

[11] Technique for ^{238}Pu, ^{239}Pu Radionuclide Detection in Samples of Soil, Plants and Milk Contaminated after the Chernobyl Nuclear Power Station Accident, All-Union Scientific Research Institute of Agricultural Radiology, Obninsk (1990).

[12] SHEPARD, J., in Proc. 23rd Natl AMS Conf., 1968, pp. 517-523.

[13] FRANKE, T., NIELSON, G., Int. J. Num. Methods Eng. **15** (1980) 1961-1704.

[14] BUSSURIN, Y., USSR Ministry of Nuclear Power and Industry, International Relations Department, Moscow, personal communication, 1991.

[15] ENVIRONMENTAL MEASUREMENTS LABORATORY, Procedures Manual, Rep. EML-540, United States Department of Energy, New York, NY (1991).

[16] KOTRAPPA, P., DEMSEY, J.C., RAMSEY, R.W., STEIFE, L.R., A practical E- PERM^{TM} (electret passive environmental radon monitor) system for indoor ^{222}Rn measurement, Health Phys. **58** (1990) 461–467.

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Measurement of Radionuclides in Food and the Environment, Technical Reports Series No. 295, IAEA, Vienna (1989).

[18] ZHU, S., et al., Interference of ^{91}Y with the rapid determination of ^{90}Sr originating from the Chernobyl fallout debris, Radiochim. Acta (in press).

[19] LAROSA, J., et al., "Analysis of plutonium in some natural matrix materials", Environmental Contamination Following a Major Nuclear Accident, (Proc. Symp. Vienna, 1989), Vol. 2, IAEA, Vienna (1990) 457.

[20] Data on Radiation Contamination in Settlements of (a) the Ukrainian SSR, (b) the Byelorussian SSR, (c) the Russian SFSR by Caesium-137 and Strontium-90, USSR State Committee on Hydrometeorology (Goskomgidromet), Moscow (1989).

[21] UNITED NATIONS, Sources, Effects and Risks of Ionizing Radiation (Report to the General Assembly), Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), UN, New York (1988).

Annex 1

Frequently Used Sampling Procedures for the Assessment of Chernobyl Fallout in the USSR

1-1. Soil Sampling Procedures in Undisturbed Areas

1-1.1. 'Disc Shaped' Samples

Step 1

Prior to sampling the site is tested for the occurrence of hot spots by carrying out two independent gamma dose rate measurements with an unshielded dose rate meter:

$Gamma_1$ is a measurement 2–5 cm above the ground;
$Gamma_2$ is a measurement 100 cm above the ground.

If the ratio $gamma_1$: $gamma_2$ does not exceed 1.5, the site is defined as being suitable for subsequent soil sampling.

Step 2

(a) One or two sampling sites are selected inside the area representing the highest gamma dose rates, whenever the gamma dose rate of all selected sampling sites inside the area is less than 25–100 μR/h.[1]
(b) Alternatively, five sampling sites are chosen along the contours of an envelope shaped area (the 'envelope' technique), representing the 'most frequent gamma dose rate values' (no statistical selection criteria), taking into consideration the nature of the sampling site (sod cover or flat area at least 20 m away from roads).
(c) In case the gamma dose rates exceed the most frequent gamma dose rate values by 200% or more, a sixth sample is taken at the site with the highest gamma dose rate value.
(d) Locations representing 'low gamma dose rate values' (no statistical selection criteria), as compared with the average rates of the particular area, are defined as being unsuitable for subsequent soil sampling.

[1] 1 röntgen (R) = 2.58×10^{-4} C/kg.

Step 3

Disc shaped soil samples are taken by using steel rings. In the initial post-accident phase, the sampling ring collected a soil disc with a diameter of 14 cm and a thickness of 5 cm.

More recently, this steel ring has been changed to take samples to a depth of 10 cm. For sandy soils, samples are taken to a depth of 15 cm in order to account for nuclide migration.

1-1.2. 'Brick Shaped' Samples

Step 1

Use of a shielded dose rate meter to survey a 100 m × 100 m plot, using a grid size of 5 m × 10 m or 10 m × 10 m. The instrument records the gamma dose rate from a 10 cm × 20 cm area at a height of 30 cm.

Step 2

Determination of an average value.

Step 3

Five representative brick shaped soil samples are taken with the dimensions 10 cm × 20 cm × 6 cm (width × length × thickness).

1-2. Soil Sampling Procedure for Agricultural Soils (Arable Areas)

1-2.1. Sampling Criteria

Samples are taken from areas exhibiting 'severe contamination' (undefined term), representing the main types of soil and specific topology.

1-2.2. Number of Mixed Samples

The maximum number of samples taken is a function of the surface contamination (e.g. one sample per region in areas with levels under 1 Ci/km^2 (37 kBq/m^2); one sample per farm in areas with levels between 7 and 15 Ci/km^2 (259-555 kBq/m^2)).

Step 1. Mixed soil sample preparation

Each mixed soil sample consists of at least ten individual samples 'distributed uniformly' (undefined term) throughout the area of interest. Where appropriate, samples are taken at the depth of the cultivated horizon (e.g. a ploughing depth of 18-22 cm). After mixing the bulk material from the individual samples, one mixed sample (mass 2 kg) is prepared.

Step 2. Elementary plot sample

In farms, soil samples from elementary plots are added to represent areas where only one type of crop is grown.

1-3. Vegetation Samples

Principle: The envelope technique (see Sections 1-1 and 1-2, this Annex) is used for samples of grass, corn and soybean.

Sampling area:	1 m^2,
Number of samples:	5 per m^2,
Sampling procedures:	vegetation is cut not less than 3 cm above the ground to obtain a mixed sample (minimum mass: 1 kg wet weight).

1-4. Milk

In order to monitor the caesium content in milk, the tank of each milk delivery truck is investigated with a NaI detector in the form of a stick, connected to a rate meter. For a volume of 3 m^3, the associated error ranges from 30 to 50%. The limit of detection for ^{137}Cs using this method is 37 Bq/L. In addition, fresh milk samples are taken at the milk production sites for subsequent laboratory analysis.

1-5. Meat

Animals selected for slaughter are screened at State farms with a stick type NaI detector in conjunction with a calibrated rate meter. If the Cs levels are above the applicable limits, animals are fed with uncontaminated fodder prior to slaughter.

A second measurement is carried out at the assembly line of meat processing plants. Each cut of meat is checked with a stick type NaI detector attached to a calibrated rate meter before it enters the food market. Meat with caesium levels below the limits are marked individually by a controller.

In addition, the laboratories established at the meat processing plants carry out spot checks of the processed meat. They use an NaI detector connected to a single channel analyser. The sum of ^{137}Cs and ^{134}Cs is measured and reported.

Subsequently, a random check is carried out on the finished product by the State Sanitation Supervision Epidemiology Station.

Annex 2

Institutions Visited for Reviewing Sampling Procedures, Analytical Methods, Instrumentation Used in Routine Laboratory Work and Mapping Procedures

All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

'Typhoon' Scientific Production Association,
Branch of the USSR State Committee
on Hydrometeorology,
Institute of Experimental Meteorology,
Obninsk, RSFSR

Institute of Nuclear Research,
Academy of Sciences of the Ukrainian SSR,
Kiev, UkrSSR

Radiological Laboratory,
Institute of Nuclear Research,
Academy of Sciences of the Ukrainian SSR
Kiev, UkrSSR

All-Union Scientific Research Institute
of Agricultural Radiology,
Ukrainian Branch,
Kiev, UkrSSR

Special Bureau of Mathematical Machines and Systems,
Glushkov Institute of Cybernetics,
Kiev, UkrSSR

All-Union Institute of Agricultural Biology,
Branch for the Byelorussian SSR,
Gomel, BSSR

Laboratory of Radiation Hygiene,
Branch of the Institute of Radiation Hygiene, Leningrad,
Novozybkov, RSFSR

State Sanitation Supervision Epidemiology Station,
Novozybkov, RSFSR

Department of Dosimetry and Radiation Hygiene,
All-Union Scientific Centre for Radiation Medicine,
Kiev, UkrSSR

Meat Processing Plant,
Gomel, BSSR

Evolutionary Morphology Centre,
Chernobyl, UkrSSR

Division of Environmental Radioactivity,
All-Union Scientific Research Institute
of Agricultural Radiology, Ukrainian Branch,
Kiev, UkrSSR

Ukrainian Research Institute of Hydrometeorology
and Control of the Environment,
Kiev, UkrSSR

Institute of Geological Sciences,
Academy of Sciences of the Ukrainian SSR,
Kiev, UkrSSR

Institute of Physics and Chemistry of Minerals,
Academy of Sciences of the Ukrainian SSR,
Kiev, UkrSSR

Radiobiology Institute,
Academy of Sciences of the Byelorussian SSR,
Minsk, BSSR

Dosimetry and Radiometry Laboratory,
Branch of the Radiobiology Institute,
Minsk, BSSR

Radiochemistry Laboratory,
Branch of the Radiobiology Institute,
Kiev, UkrSSR

Part D

Annex 3

Review of Equipment, Calibration and Quality Control Methods in the Major Laboratories Visited

3-1. Institute A, RSFSR

3-1.1. Laboratory for Soil Analysis and Air Sampling

3-1.1.1. Equipment

- HPGe gamma spectrometers,
- NaI(Tl) gamma spectrometers,
- Beta spectrometer,
- Beta/gamma spectrometer.

3-1.1.2. Calibration and Quality Control

Artificially prepared average soil standards have the same geometry as the samples. These standards are used for calibration and are supplied by the USSR State Committee for Standardization, All-Union Institute of Physical, Technical and Radiotechnical Measurements.

An energy calibration and efficiency check (for ^{137}Cs) is performed daily; complete efficiency calibrations for various energies and all geometries are performed yearly; there is regular participation in intercomparison exercises.

3-1.2. Radiochemical Analysis Section and Counting Laboratory

3-1.2.1. Equipment

- Plastic scintillators for beta activity measurements,
- 4π gas flow proportional counters,
- Alpha/beta/gamma counting system,
- Beta spectrometer with organic scintillator,
- Alpha spectrometer.

3-1.2.2. Calibration and Quality Control

Samples are spiked with a Sr carrier and ^{242}Pu tracer. Dissolution is in 6 mol/L of HCl and Sr separation is by precipitation. The method of acid sample leaching does not even approach complete dissolution of the sample.

Inadequate sample management and poor control of contamination in laboratory areas increases the potential for undefined cross-contamination of low activity samples by neighbouring high activity samples.

3-1.3. Water Laboratory

3-1.3.1. Equipment

- Alpha spectrometer,
- Beta spectrometer with and without anti-coincidence shielding,
- Liquid scintillation spectrometer,
- HPGe gamma spectrometer.

3-1.3.2. Calibration and Quality Control

It was reported that staff participated successfully in a ^{90}Sr intercomparison organized by the IAEA.

With regard to groundwater sampling, more attention needs to be paid to contamination problems, since the activity level in groundwater is expected to be very low in comparison with that in surface water and soil particles suspended in surface water.

The same glassware is used for processing both high and low activity level samples, with the potential for cross-contamination. Blank sample tests are not run routinely.

Adequate water filtration of sample water prior to the determination of the activity concentration of the purely dissolved fraction should be emphasized.

3-2. Institute B, RSFSR

3-2.1. Radiometry Laboratory

3-2.1.1. Equipment

- Gamma spectrometers.

3-2.1.2. Calibration and Quality Control

Gamma spectrometers calibrated for six different geometries (122 keV to 1488 keV) using a ^{152}Eu standard solution.

No correction for summing effects is made for the efficiency calibration.

No routine quality assurance is performed and the quality assurance data are not recorded for later analysis and review.

The NaI(Tl) gamma spectrometer is calibrated with a Cs standard of density 1.0.

No absorption correction or quality assurance record is kept.

The same method is used for analytical methods for Sr and Pu.

Lack of contamination control is noticeable, as well as poor sample storage practices. However, owing to lower levels of activity and the better overall condition of facilities, the contamination problem is less serious.

3-3. Institute C, UkrSSR

3-3.1. Radioelemental Analysis Laboratory

3-3.1.1. Equipment

— HPGe gamma spectrometers,
— Ge(Li) gamma spectrometers,
— Alpha spectrometers,
— Shielded proportional counters,
— Si(Li) and Ge planar detector systems.

3-3.1.2. Calibration and Quality Control

It was indicated that in the early post-accident phase there were serious quality control problems with samples. At present, calibration is reportedly carried out regularly, using self-made multiradionuclide standards and standards supplied by the Radium Institute. In addition, staff reportedly participated in intercomparison exercises. Neither the results from the calibration nor those from the intercomparison runs could be reviewed owing to the fact that the systems were largely disassembled and not in an operating condition. Gamma spectrometric analysis of soil samples is performed by averaging the results from a sample counted on both sides.

Estimates of Pu and Sr levels are derived on the basis of experimentally derived correlation coefficients with ^{144}Ce. The validity of this procedure has reportedly been checked by Soviet scientists.

Information on radiochemical procedures concerning Pu and Sr analysis is limited, since the head of the laboratory was unwilling to provide detailed information. Plutonium-236 is used as a tracer and ^{90}Sr analysis is based on beta counting of the separated $SrCO_3$. Yield and purity are measured by inductively coupled plasma emission spectrometry.

The question of potential cross-contamination of samples cannot be answered satisfactorily, since it was not possible to determine whether blank controls are used properly. Dissolution procedures could not be reviewed either. Since it was also impossible for the reviewer to obtain samples and results for corroboration by the Agency's PCI Laboratory at Seibersdorf, the quality of Sr and Pu data cannot be assessed adequately.

3-4. Institute D, UkrSSR

Significance: Studies on soil–grass–animal–man ecosystems; hot particle sample bank (1200 specimens).

3-4.1. Radiometry and Gamma Spectrometry Laboratory

3-4.1.1. Equipment

— HPGe gamma spectrometers,
— Ge(Li) gamma spectrometers.

3-4.1.2. Calibration and Quality Control

Standards from the Radium Institute are used for frequent calibrations (daily checks of energy response and weekly checks of efficiency).

The laboratory is extremely clean and well maintained and there is no apparent contamination problem.

3-4.2. Radiochemistry and Soil Chemistry

3-4.2.1. Equipment

— Alpha/beta/gamma counter,
— Alpha spectrometers,
— Ge(Li) gamma spectrometer,
— Gamma scintillator with autosampler.

3-4.2.2. Calibration and Quality Control

Calibration for ^{90}Sr determination is carried out with each batch of samples using suitable blanks and standards. However, the dissolution of the samples may still cause uncertainties for the Sr and Pu results.

Laboratory management is excellent and results in a database of high quality, particularly on hot particles and crop information.

3-5. Institute E, BSSR

3-5.1. Meteorology Laboratory of Radioecology

3-5.1.1. Equipment

— HPGe gamma spectrometers.

3-5.1.2. Calibration and Quality Control

Calibration is carried out with a small mixed standard (^{134}Cs, ^{137}Cs, or ^{106}Ru). This source does not adequately represent the true sample geometry, leading to an underestimation of the radionuclide content of the sample.

Sample management requires improvement in terms of the provision of additional sample storage space to avoid the present overcrowding, with the potential for cross-contamination between samples.

Poor and outdated equipment (about 50% of the total) makes it questionable whether sensitive analytical methods can be used successfully.

3-5.2. Dosimetry and Radiometry Laboratory

3-5.2.1. Equipment

— Gamma spectrometers,
— Alpha spectrometers.

3-5.2.2. Calibration and Quality Control

Radionuclide standards are available in various geometries to simulate different samples (aqueous, point source and in Marinelli beakers). It was reported that staff participate several times a year in national intercalibration exercises.

Separation and determination of actinides and ^{90}Sr in environmental samples are carried out with standard procedures as used, for example, by the Agency's PCI Laboratory. However, there is no personal computer available to store and process data; alpha spectrometer equipment is on loan only and available in inadequate quantities.

3-6. Institute F, UkrSSR

3-6.1. Isotope Laboratory

3-6.1.1. Equipment

— Alpha spectrometers,
— Beta spectrometers,
— Gamma spectrometers.

3-6.1.2. Calibration and Quality Control

All equipment is Soviet made. There is a strong need to upgrade all experimental facilities. Appropriate filtering of water samples containing suspended material should be implemented. Blank sample runs are needed regularly to check for cross-contamination.

3-7. Institute G, UkrSSR

3-7.1. Laboratories

3-7.1.1. Equipment

— Alpha spectrometers,
— Beta counters,
— Gamma spectrometers,
— Liquid scintillation counter.

3-7.1.2. Calibration and Quality Control

No information is available on the calibration methods and quality control programme for the equipment of purely Soviet origin. Co-operation with the IAEA is sought.

3-8. Institute H, UkrSSR

3-8.1. Equipment

Experimental facilities in the laboratory are below the international standard; some of the equipment is outdated. The research ship is well equipped for the sampling of water and sediments.

3-8.2. Calibration and Quality Control

The institute co-operates with several other institutes in Obninsk and Kiev in areas of analytical service, reference standards and intercalibration. The potential for cross-contamination problems and the lack of the use of blanks for testing purposes are evident.

Annex 4

Soviet Institutions Sent Intercomparison Samples in June 1990

Institute of Experimental Meteorology,
Obninsk, RSFSR

Institute of Nuclear Research,
Academy of Sciences of the Ukrainian SSR,
Kiev, UkrSSR

All-Union Scientific Research Institute
of Agricultural Radiology,
Ukrainian Branch,
Kiev, UkrSSR

Radiobiology Institute,
Academy of Sciences of the Byelorussian SSR,
Minsk, BSSR

All-Union Scientific Research Institute
of Agricultural Radiology,
Byelorussian Branch,
Gomel, BSSR

All-Union Scientific Research Institute
of Agricultural Radiology,
Obninsk, RSFSR

All-Union Scientific Research Institute
of ExperimentalPhysics,
Arzamas,
Gor'kij Region, RSFSR

All-Union Research Institute
of Nuclear Geophysics and Geochemistry,
Moscow, USSR

Polytechnic Institute,
Geological Faculty,
Tomsk, RSFSR

Department of Activation Analysis,
Laboratory of Neutron Physics,
Joint Institute for Nuclear Research,
Dubna, RSFSR

Institute of Geochemistry and Analytical Chemistry,
Academy of Sciences of the USSR,
Moscow, USSR

Laboratory of Physics of the Atmosphere,
Institute of Physics,
Leningrad State University,
Leningrad, RSFSR

Department of Dosimetry,
All-Union Scientific Centre for Radiation Medicine,
Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

All-Union Research Institute of Marine Fisheries
and Oceanography (VNIRO),
Moscow, USSR

Institute of Physics,
Academy of Sciences of the Byelorussian SSR,
Minsk, BSSR

Research Institute of Radiation Hygiene,
Ministry of Public Health,
Leningrad, RSFSR

Institute of Botany,
Academy of Sciences of the Byelorussian SSR,
Minsk, BSSR

All-Union Scientific Centre of Radiation Medicine,
Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

P.O. Kombinat,
Chernobyl,
Kiev Region, UkrSSR

Laboratory for Environmental and Climatic Monitoring,
Moscow, USSR

Radium Institute,
Leningrad, RSFSR

Varnadsky Institute of Geochemistry and Analytical,
Chemistry,
Moscow, USSR

Laboratory of Nuclear Research,
Kiev State University,
Kiev, UkrSSR

Laboratory of the Institute of Applied Geophysics,
USSR State Committee for Hydrometeorology
and Control of the Natural Environment,
Academy of Sciences of the USSR,
Moscow, USSR

Part D

Annex 5

Soviet Institutions Sent Intercomparison Samples in October 1990

Radiochemical Department,
All-Union Research Institute for Experimental Physics,
Arzamas,
Gor'kij Region, RSFSR

Radiological Department,
Bryansk Centre Agrochemical Laboratory,
Bryansk, RSFSR

Kiev Project and Research Agricultural Station,
Chabany Settlement, UkrSSR

Veterinary Laboratory,
Chernigov District,
Chernigov, UkrSSR

Chernigov Project and Research Station of Chemical Agriculture,
Chernigov, UkrSSR

Sanitary and Epidemiological Station,
Chernigov District,
Chernigov, UkrSSR

Sanitary and Epidemiological Station,
Doubrovitaskaya Country,
Doubrovitsa,
Rovno District, UkrSSR

Radiological Department,
Gor'kij Centre Agrochemproject,
Gor'kij, RSFSR

Radiological Department,
Kaluga Centre Agrochemproject,
Kaluga, RSFSR

Kiev Meat Processing and Packing Factory,
Kiev, UkrSSR

Radiological Department and Kiev Enterprise of Dairy Production,
Kiev, UkrSSR

All-Union Scientific Centre of Radiation Medicine,
Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Republican Sanitary and Epidemiological Station,
Kiev, UkrSSR

Department of Dosimetry,
All-Union Scientific Centre for Radiation Medicine,
Academy of Medical Sciences of the USSR,
Kiev, UkrSSR
(*was also sent samples earlier*)

Radiological Department,
Republican Veterinary Laboratory,
Kiev, UkrSSR

Sanitary and Epidemiological Station, Kiev Region,
Kiev, UkrSSR

Radiological Laboratory,
Plant of Non-Alcoholic Drinks Obolon,
Kiev, UkrSSR

Radiometry Laboratory,
Kiev Pastry Plant,
Kiev, UkrSSR

Hygienic Centre,
Public Health Department of the UkrSSR,
Kiev, UkrSSR

Laboratory of the Subfaculty of Milk Processing,
Kiev Technological Institute of Food Production,
Kiev, UkrSSR

Radiological Department,
Kiev Urban Sanitary and Epidemiological Station,
Kiev, UkrSSR

Subfaculty of Nuclear Physics,
Kiev State University,
Kiev, UkrSSR

Institute of Nuclear Power,
Academy of Sciences of the Byelorussian SSR,
Minsk, BSSR

Academy of Radiobiology,
Academy of Sciences of the Byelorussian SSR,
Minsk, BSSR

Fourth Radiation Chemistry Department,
V.I. Lenin State University of the Byelorussian SSR,
Minsk, BSSR

All-Russian Institute of Projects and Research in Chemical Agriculture and Soil Reclamation,
Nemtchinovka,
Moscow District, USSR

Agrochemradiology,
Novozybkov Laboratory of Bryansk Centre,
Novozybkov,
Bryansk Region, RSFSR

Sanitary and Epidemiological Station,
Ovrouchskaya District,
Ovruch, UkrSSR

PLVSK Branch of Tula Region Project and Research Station of Chemical Agriculture,
Plavsk,
Tula Region, RSFSR

Rovno Project and Research Station of Agriculture,
Vovno Country, Shoubkov Settlement,
Rovno, UkrSSR

Rovenskaya Sanitary and Epidemiological Station,
Rovno, UkrSSR

Tula Region Project and Research Station
of Chemical Agriculture,
Tula, RSFSR

Kiev Veterinary Laboratory,
Kiev Region Veterinary Laboratory,
Vishnevy, UkrSSR

Sanitary and Epidemiological Station,
Vladimiretz Country,
Vladimiretz, UkrSSR

Project and Research Station of Chemical Agriculture,
Zhitomir, UkrSSR

Zhitomir Veterinary Laboratory,
Zhitomir, UkrSSR

Sanitary and Epidemiological Station,
Zhitomir Region,
Zhitomir, UkrSSR

Part D

Annex 6

Designated Institutions in the USSR Preparing Material for Intercalibration Exercises

Institution	Contact person	Type of sample
	BSSR	
Institute of Radiobiology, Academy of Sciences of the BSSR (Minsk)	Academician E.F. Konoplya	Undisturbed soil
USSR Institute of Agricultural Radiology, Byelorussian Branch (Gomel)	Director: S.K. Firsakova	Agricultural: soil, grass and milk
	RSFSR	
Institute of Experimental Meteorology (Obninsk)	V.A. Borzilov	Undisturbed soil Experimental
All-Union Scientific Research Institute of Agricultural Radiology (Obninsk)	Director: R.M. Aleksakhin	Agricultural: soil, grass and milk
	UkrSSR	
Institute of Nuclear Research, Academy of Sciences of the UkrSSR (Kiev)	Director: I. Vishnevsky	Undisturbed soil
USSR Institute of Agricultural Radiology, Ukrainian Branch (Kiev)	Director: N.A. Loshchilov	Agricultural: soil, grass and milk

Part E
Radiation Exposure of the Population

Contents

1. Introduction

Dose assessment may be regarded as a strictly objective procedure that uses generally recognized calculational methods with available environmental data or results of measurements of radionuclides in the body. The estimates of dose may be made from various starting points. More reliable dose estimates can be made by reducing the number of intermediate steps in the calculation, e.g. starting with measured radionuclide contents in the body rather than with concentrations in air or deposition. It is often the case, however, that the more direct measurements are insufficient, unavailable or not technically feasible.

It is inevitable that the databases required for dose calculations are incomplete. Therefore, a degree of approximation is necessary, and indirect inferences must be made. In addition to general assumptions, some more particular selection of parameters to reflect local conditions is necessary in dose estimation methods, e.g. time spent outdoors, composition of diet, consumption amounts, etc. Usually these factors are sufficiently variable to require more conservative values to be taken as representative, so that doses will not be underestimated. In addition, when projecting doses far into the future, it is necessary to extrapolate future environmental behaviour of radionuclides. For this, the generally available experience must be considered in relation to specific circumstances of the contamination. This may also be done with a varying degree of conservatism.

Some degree of overestimation of doses is to be expected; however, if the estimated doses are excessively high and unrealistic, this could lead to incorrect surmises with regard to eventual health effects or to unjustified relocation of individuals from contaminated regions. For these reasons, the dose assessment procedure must be considered rather carefully and must be continually adjusted to reflect actual measurements. While it is desirable to estimate doses as accurately as possible, it is generally considered important that these doses not be underestimated.

The objective of the dose assessment task in the international review of the radiological consequences of the Chernobyl accident is to review the methods used in the BSSR, the RSFSR, the UkrSSR and the USSR to calculate individual and collective doses from the environmental radiation measurement results. This was accomplished by examination of documented methods for dose evaluation and detailed discussion with Soviet experts regarding these methods, their choices of values for key parameters and the reasons for these choices. To corroborate the doses reported by Soviet sources, a database for a few selected settlements (visited by the environmental corroboration teams or the medical teams for their project assessments) in contaminated areas has been compiled and estimates of the doses to residents have been derived using independent methods. The members of the dose assessment team did not consider the doses to the evacuees or to the workers engaged in decontamination work following the accident.

In order to obtain the available documentation on the dose assessment and to discuss it with the Soviet experts who had developed or utilized it, two missions to the USSR were organized in the summer of 1990. Nineteen scientific institutes and ministries in the BSSR, the RSFSR, the UkrSSR and the USSR were visited. In addition, a few settlements in contaminated areas were visited in order for the experts to view personally the lifestyle of the people. The list of institutes and settlements visited by the teams of international experts is presented in Annex 1 to Part E.

The scientists at the institutes visited in the BSSR, the RSFSR, the UkrSSR and the USSR were most co-operative in discussing their dose calculation methods and results. While much information was provided, it is inevitable that some questions remain. In particular, some additional basic input data would be needed to perform adequately some independent calculations. It is recognized that an entirely satisfactory basis for calculations does not exist, particularly as regards the complex and dynamic early stages following the accident, when measurement capabilities were overextended. It is unfortunate that there was no opportunity to work through sample dose calculations during the two missions. This would have been useful to provide further clarification and understanding of some calculational details. On the whole, however, the independent experts were able to reproduce most of the Soviet calculations to a reasonable degree and were satisfied that the procedures used were scientifically sound.

2. Description of the Soviet Methodology for Dose Assessment

The principal methodology used in the USSR to estimate radiation doses from the Chernobyl accident, referred in the following as the official methodology, is contained in four documents:

- Methodological Principles for Calculating Levels of External and Internal Exposure of the Populations Living in the Territories Contaminated by Radioactive Materials as a Result of the Chernobyl Accident [1].
- Methodological Basis for Predicting the Levels of Exposure of the Population Caused by Caesium Radioisotopes for Those Residing Permanently in Areas Contaminated as a Result of the Chernobyl Accident [2].
- Methodological Principles for Prediction of Levels of Population Exposure to Strontium Radionuclides during Permanent Residence in Areas Contaminated as a Consequence of the Chernobyl Accident [3].
- Guide to the Evaluation of Thyroid Exposure Doses due to Uptake of Radioactive Isotopes of Iodine in the Human Body [4].

This methodology is presented and discussed in this section. Additional information and clarifications obtained during the missions of the international experts to the USSR are included when appropriate.

2.1. External Irradiation

2.1.1. Cloud Dose

Three different methods were used to assess the external exposure from the passing cloud carrying radionuclides released to the air in the initial days following the accident [1]:

- Measurements of the external gamma doses obtained from dosimeters installed before the accident at distances from 1.5 to 50 km around the plant as part of the routine environmental measurement programme were used to estimate the cloud gamma dose by subtracting the contribution of deposited nuclides.
- An empirical formula was derived that correlates the cloud gamma dose with the thyroid dose from inhalation measured 5 to 10 days after the accident (applicable to adults who consumed clean food only and did not use iodine tablets):

$$D_{cloud} = 0.01\, D_{thyroid,\ inhalation} \qquad (1)$$

- An empirical formula was derived that correlates the cloud gamma dose with the measurement of the exposure rate:

$$D_{cloud} = 0.1\, P_\gamma(d_0 + 15) \qquad (2)$$

where $P_\gamma\,(d_0 + 15)$ is the exposure rate (mR/h) on the 15th day after the beginning of the accident, and D_{cloud} is the cloud gamma dose (rad).

The estimates of cloud gamma doses obtained with the three methods do not exceed 20% of the external gamma dose from deposited activity delivered during the first 15 days after the accident. It is assumed by the Soviet authorities that an upper estimate of the cloud gamma doses is 10% of the first year's dose due to external irradiation from the activity deposited on the ground [1].

2.1.2. Dose from Deposited Radionuclides

The description of the methodology used to estimate whole body doses and skin doses resulting from radioactive materials deposited on the ground is provided in Refs [1] and [2] and is summarized below.

2.1.2.1. Whole Body Dose

The variation with time of the outdoor exposure rate from radionuclides deposited on the ground was derived from measurements of exposure rate at 1 m above the ground and from model predictions. The formulations of the external doses are different in Refs [1] and [2]. For the first 3 years after the accident, according to Ref. [1], the variation with time of the outdoor exposure rate, normalized to $d_0 + 15$ (15 days after the accident), is given in Table 1. For times greater than 15 days after the accident, the values presented in Table 1 can be approximated as:

$$P_\gamma(t) = 7.5\, P_\gamma(d_0 + 15)\, t^{-0.75} \qquad (3)$$

with t in days.

Annual whole body dose equivalents (taken to represent the effective doses) were calculated using the following coefficients [1]:

- 0.87 for the conversion factor from outdoor exposure rate (expressed in mR/h) to outdoor absorbed dose rate in air (expressed in mrad/h);
- 0.7 for the screening factor due to snow cover during the winter;

TABLE 1. Time Variation in External Exposure Rate and Accumulated Dose in Air Relative to an Exposure Rate Value of 1 mR/h 15 Days after the Accident [1] *[1 R = 258 μC/kg]*

Time after accident	Exposure rate (mR/h)	Accumulated dose (mGy)
1 day	3	4.3
4 days	2.5	5.7
7 days	1.7	7.2
15 days	1.0	9.0
1 month	0.55	12
3 months	0.22	17
1 year	0.074	25
3 years	0.039	34

- 0.6 for the migration of ^{137}Cs into the ground (beginning the second year after the accident);
- 0.4 for the shielding and indoor occupancy factor for individuals living in cities;
- 0.75 for the shielding and indoor occupancy factor for individuals living in the country.

The overall values of the conversion coefficients from outdoor exposure rate to effective or whole body dose are therefore:

- $0.87 \times 0.4 \times 0.7 = 0.24$ for the populations living in cities in the first year after the accident;
- $0.87 \times 0.75 \times 0.7 = 0.46$ for the populations living in the country in the first year after the accident;
- $0.87 \times 0.4 \times 0.7 \times 0.6 = 0.15$ for the populations living in cities in the second and following years after the accident;
- $0.87 \times 0.75 \times 0.7 \times 0.6 = 0.27$ for the populations living in the country in the second and following years after the accident.

According to Ref. [2], which is a document more recent than Ref. [1], the external exposure doses for the first four years after the accident (1986–1989) can be evaluated from the relationship:

$$D_{ext}(1986\text{–}1989) = K\sigma_{137} \quad (4)$$

where D_{ext} (1986–1989) is the external exposure dose for 1986–1989 in rem, σ_{137} is the deposition density of ^{137}Cs expressed in Ci/km^2, and K is a coefficient, expressed in rem per Ci/km^2. (Note: it is assumed in this report that the external exposure dose represents the whole body or effective dose.) The value of K is different in various regions of contamination. Specific values are given for the regions as follows:

Kiev	0.26
Zhitomir	0.26
Gomel (south)	0.26
Bragin	0.26
Narovlyansk	0.19
Khojniki	0.23
Gomel (north-east)	0.16
Mogilev	0.16
Bryansk	0.16

The derivation of the values of K involves the conversion coefficient from outdoor external exposure rate to effective dose. The values of the conversion coefficient from outdoor exposure rate to effective dose are given in Ref. [2] as 0.46 rem/R for villages and 0.24 rem/R for towns. Those values are numerically equal to those used in Ref. [1] for the first year after the accident but are greater than those used in Ref. [1] for the second and following years after the accident. It is stated in Ref. [2] that the individual measured doses did not exceed the calculated doses in 90% of the adults and in at least 97% of the children.

According to Ref. [2], the prediction of the doses from external irradiation for the time period 1990–2060 is made using a model derived from observations of deposition and migration of ^{137}Cs into the ground following the nuclear weapons tests of the 1960s [5]. The annual doses, $D_{ext}(t)$, for the year 1988 and beyond can be estimated as:

$$D_{ext}(t) = d_0(1988)\ (0.7\ e^{-0.3t} + 0.3\ e^{-0.024t}) \quad (5)$$

where t is the time in years beyond 1988 (t = 0 in 1988), and $d_0(1988)$ is the annual effective dose in 1988, in rem, taken to be numerically equal to $0.028\ \sigma_{137}$, where σ_{137} is the deposition density of ^{137}Cs, in Ci/km^2. Integrating the above equation over the time period 1990—2060 yields, according to Ref. [2]:

$$D_{ext}(1990\text{–}2060) = 0.32\ \sigma_{137} \quad (6)$$

2.1.2.2. Skin Dose

As indicated in Ref. [1], the radiation dose to the skin due to soil and plant contamination is estimated as:

$$P_\beta(\text{rem/d}) = 1.5 \times 10^{-3}\ \sigma(\text{Ci/km}^2) \quad (7)$$

where σ represents the total activity deposited per unit area of ground. It is assumed that the maximum energy of the beta rays is about 1 MeV per disintegration. The dose rate on skin includes the irradiation from the ground and from surface contamination of clothes and skin; it is calculated on a daily basis, as washing removes the contamination.

2.2. Internal Irradiation

2.2.1. Caesium

The methodologies for estimating internal doses from caesium were issued in 1986 and 1988 [1, 2]. Although the earlier reference has been essentially superseded, it is still contained in the official methodology, and it is of major interest, because it was the methodology that was originally used during the first two years after the accident.

2.2.1.1. Content in Milk and Diet

First year (1986 methodology [1]*)*

The official methodology states that "During the first year, caesium intake with food is determined by the contamination penetrating by routes other than plant roots." It is further assumed that the retention coefficient on pasture plants with a biomass of 1 kg/m^2 is 0.2; or the mass interception fraction is 0.2 m^2/kg. The caesium content in grass with time is assumed to follow a two component exponential decay with half-times of 3 days (70%) and 50 days (30%). Thus, the equation describing the caesium content in pasture, $q_g(t)$ in μCi/kg, is

$$q_g(t) = 0.2(0.7\, e^{-0.231t} + 0.3\, e^{-0.014t})\, \sigma_{137} \qquad (8)$$

where σ_{137} is the deposition density of ^{137}Cs in μCi/m^2 (or Ci/km^2).

It is further assumed that the pasture period is six months; hay is produced during the last three months of the pasture period; pasture consumption by the cow is 50 kg/d; the half-time of ^{137}Cs in the body of the cow is 30 days, and the fraction eliminated daily with milk is 0.13. The latter value is taken to be equivalent to 0.013 day/L with the additional assumption of an average milk yield of 10 L/d.

The caesium content in milk, $q_m(t)$ in μCi/L, before cows are transferred to stall feeding, is given by

$$q_m(t) = 0.013\, q_d\lambda_c[0.7\, (e^{-\lambda_c t} - e^{-\lambda_1 t})/(\lambda_1 - \lambda_c) + 0.3(e^{-\lambda_c t} - e^{-\lambda_2 t})/(\lambda_2 - \lambda_c)] \qquad (9)$$

where λ_c is the elimination rate of caesium from the cow, 0.023 per day, λ_1 is the elimination rate of 70% of caesium from pasture, 0.231 per day, λ_2 is the elimination rate of 30% of caesium from pasture, 0.014 per day, and q_d is the daily intake of caesium by the cow, 50 kg/d multiplied by the initial contamination of the pasture, $q_g(0)$.

When cows are removed from pasture and fed in stalls, it is assumed that the caesium concentration in hay is constant and is equal to the mean pasture (grass) content during haymaking. This is stated to be given by

$$q_g = 0.2[0.7(1 - e^{-\lambda_1 t_h})/\lambda_1 + 0.3\, (1 - e^{-\lambda_2 t_h})/\lambda_2]\, \sigma_{137}/t_h \qquad (10)$$

where t_h is the average time elapsed (days) between deposition and haymaking.

The content of ^{134}Cs in pasture and in milk is stated to be "calculated with an assumption of the ratio of its concentration in the fallout to the concentration of ^{137}Cs remaining 1:2 to 1:1.5". This latter statement is specific for the first year after the accident.

No specific advice is given on how to determine the content of caesium in foods other than milk.

Second year (1986 methodology [1]*)*

During the second year, the transfer of caesium to foods is determined by the soil–root pathway. For the Ukrainian-Byelorussian Polesye, which is stated to be the region most highly contaminated by the accident, caesium mobility in soil exceeds by "tenfolds" that in other regions of the country. (The content of caesium in milk, for example, is stated to be 1.5 to 15 times higher in the affected region than in other regions.) The advice is given that, for a particular region, one should use transfer coefficients determined from worldwide fallout unless and until newer data are obtained for Chernobyl fallout. It is stated that it is sufficient to determine an annual average content of caesium in milk. This is given by

$$q_m = K_m\sigma_{137} \qquad (11)$$

where K_m is the transfer coefficient to milk (Ci/L per Ci/km^2). (It should be noted that the units of q_m in Eq. (11) are Ci/L ,while in Eq. (9) the units are μCi/L. Also, σ_{137} in Eq. (11) is expressed in units of Ci/km^2, while Eq. (8) uses units of μCi/m^2. Numerically, the values for σ_{137} would be the same for either set of units.) During the second year and thereafter, the ratio of ^{134}Cs to ^{137}Cs is assumed to vary according to the differences in their half-lives.

For the total diet, it is stated that the content of caesium can be determined by using link coefficients for the diet as a whole or by assuming that milk determines up to 70% of the daily intake of caesium in the BSSR and up to 30% in the UkrSSR. Values for the link coefficients for the diet as a whole are stated to vary from 2×10^{-9} to 20×10^{-9} km^2/L. Example calculations are provided in Ref. [1] using a "sufficiently moderate" value of 5×10^{-9} km^2/L.

2.2.1.2. *Content in the Body*

First year (1986 methodology [1]*)*

This calculation is not specifically addressed in the 1986 methodology [1] in the section dealing with the first year. However, a general equation is provided in Ref. [1] for determining the body content under conditions when the dietary content is varying. This equation is

$$Q(t) = e^{-\lambda_e t} \int_0^t q_r(\tau)\, e^{-\lambda_e \tau}\, d\tau \qquad (12)$$

where λ_e is the elimination rate of caesium in the human body (per day), $q_r(\tau)$ is the daily intake of caesium with diet (Ci/d), and Q(t) is the content of caesium in the body (Ci).

Values of λ_e are given as 0.0063 per day for ^{137}Cs and 0.00716 per day for ^{134}Cs for adults, corresponding to a biological retention half-time of 110 days. For children, the elimination rate is given by the following:

$$\lambda_e = 0.693/[12.8(a^{0.5} - e^{-a})] \qquad (13)$$

where a is the age of the child (years) and λ_e has units of inverse days. It is stated that $q_r(\tau)$ may be given by Eq. (9) "adjusted to the diet as a whole."

Second year (1986 methodology [1]*)*

It is assumed that, beginning from the second year, the content of caesium in food is constant during the year. Then the caesium content in the body is given by

$$Q(t) = q_r(1 - e^{-\lambda_e t})/\lambda_e \qquad (14)$$

It is assumed for Eqs (12) and (14) that the fraction of caesium absorbed from the gastrointestinal tract is 1.0. Another method of calculating Q(t) is given for conditions of chronic constant intake (Ci/d). This uses an empirical relationship:

$$Q(t) = 120\, q_r \qquad (15)$$

2.2.1.3. *Internal Dose from Caesium*

First four years (to end of 1989)

In the 1986 methodology [1], the dose to soft tissues for the time interval, T, is stated to be given by the product of the integral of the body content for that period and the dose rate coefficient:

$$D(T) = d_0 \int_0^T Q(t)\, dt \qquad (16)$$

where d_0 is the dose rate coefficient (rad/d per Ci). The values for d_0 are stated to be 360 rad/d per Ci (0.13 rad/a per μCi) for ^{137}Cs and 610 rad/d per Ci (0.22 rad/a per μCi) for ^{134}Cs.

In the 1988 methodology [2], the calculation of the internal exposure doses for the period from 26 April 1986 to the end of 1989 is based on "the data on the actual content of caesium radioisotopes in the bodies of the inhabitants of specific villages as a result of direct measurements or according to intake with the diet."

Remainder of 70 year period (1990–2056) (1988 methodology [2]*)*

The critical group has been selected to be individuals who were born in the year of the accident and live in the given location for 70 years. All the data in the model are appropriate for adults, and this is stated to be a deliberate choice, so that doses to children and adolescents are overestimated.

The calculations are based upon the content of caesium in foods in 1988. In evaluating data for this use, it is stated that the 90th percentile of ^{137}Cs in milk and other products is used. Also, a conservative value for the half-time of caesium in foods of 14 years is used. The combination of these conservative factors is stated to result in overestimates of doses by a factor of at least 2.

For the calculations, it is assumed that locally produced foodstuffs are consumed. The following additional assumptions, stated to be based on results of studies in the affected areas, are made:

- The average daily intake of caesium with meat and milk is equivalent to the caesium content in 1 litre of milk.
- The consumption rate of potatoes is 630 g per day.
- The concentration of ^{137}Cs in potatoes is, for practical purposes, independent of the deposition density of ^{137}Cs in the area. The 90th percentile of the concentration in potatoes in 1988 was 0.6×10^{-8} Ci/kg.
- The intake of caesium radionuclides via potatoes is 70% of the overall intake via vegetable products.
- The caesium content of the diet remains constant during any one year.
- The ^{137}Cs content in the human body is constant during any one year.

— On the basis of observations of ^{137}Cs from global fallout, the reduction of concentrations in milk and other food products occurs from the beginning of 1988 according to a half-time of 14 years for ^{137}Cs and according to the physical decay (half-life of 2 years) for ^{134}Cs.

The prediction of internal dose is to be based on actual measurements of the concentration of ^{137}Cs in cow's milk in the summer of 1988 at private farms in villages and the value for potatoes referenced above. For those villages where there were no dairy cattle at private farms, the concentration in milk in 1988 (Ci/L) is to be predicted from the ^{137}Cs deposition density (Ci/km^2):

$$q_m = 1.5 \times 10^{-9}\ \sigma_{137} \quad (17)$$

The dose for time periods starting in 1990 is to be based upon the dose determined for the year 1988. Thus,

$$D(t) = D_0^{137}\ e^{-\lambda_{137}t} + D_0^{134}\ e^{-\lambda_{134}t} \quad (18)$$

where D(t) is the average annual dose equivalent at time t (rem/a), D_0^{137} and D_0^{134} are the average annual doses due to ^{137}Cs and ^{134}Cs in 1988 (rem/a); and λ_{137} and λ_{134} are the elimination rates of caesium from foodstuffs, 0.05 per year and 0.35 per year for ^{137}Cs and ^{134}Cs, respectively.

It is stated that the ratio in 1988 of the annual dose from ^{134}Cs to that from ^{137}Cs was 0.42. Therefore, Eq. (18) can be rewritten

$$D(t) = D_0^{137}\ (e^{-\lambda_{137}t} + 0.42\ e^{-\lambda_{134}t}) \quad (19)$$

As a result of this simplification, it is only necessary to determine the reference dose for ^{137}Cs. This is stated to be determined by

$$D_0^{137} = Q_0\ d_0 \quad (20)$$

where Q_0 is the equilibrium content of ^{137}Cs in the body (Ci) and d_0 is the dose rate coefficient, 1.31×10^5 rem/a per Ci.

The accumulation of caesium in the human body is stated to be described by the simplified equation (neglecting the short term component of the caesium elimination from the body):

$$Q(t) = q(1 - e^{-\lambda_e t})/\lambda_e \quad (21)$$

where q is the daily intake of ^{137}Cs in diet (Ci/d). The equilibrium content of ^{137}Cs in the body is thus:

$$Q_{equil} = q/\lambda_e \quad (22)$$

From Eqs (19), (20) and (22), the dose at time t is

$$D(t) = q d_0\ (e^{-\lambda_{137}t} + 0.42\ e^{-\lambda_{134}t})/\lambda_e \quad (23)$$

where D(t) has units of rem/a. The integral dose for 66 years (1990–2056) is then

$$D(66) = 18.6\ q_0 d_0/\lambda_e \quad (24)$$

or, with numerical values for d_0 and λ_e

$$D(66) = 3.87 \times 10^8\ q_0 \quad (25)$$

The parameter q_0 is taken to be the daily intake of ^{137}Cs in 1990. With the assumptions stated above, q_0 (Ci/d) is determined to be

$$q_0 = 0.9\ q_m + 0.63\ (0.6 \times 10^{-8})/0.7$$

$$= 0.9\ q_m + 0.54 \times 10^{-8} \quad (26)$$

In Eq. (26), it appears that the factor of 0.9 results from two years of decay of caesium in foodstuffs. However, a similar correction has not been applied to the value for potatoes. From Eqs (25) and (26), the 66 year dose (rem) is stated to be

$$D(66) = 21(1.7 \times 10^7\ q_m + 0.1) \quad (27)$$

where it is emphasized that q_m is the ^{137}Cs concentration in milk (Ci/L) in 1988, but the integration period for the dose is from 1990 through 2056.

2.2.2. Strontium

The procedures for calculating doses from strontium are contained in two documents of official methodology issued in 1986 and 1988 [1, 3]. These methods have been used whenever it has seemed necessary to calculate doses from the ingestion of ^{89}Sr and ^{90}Sr. However, except for highly unusual circumstances, the calculation of doses from the ingestion of strontium has not been of high priority. This is because it is generally accepted by the Soviet authorities that the dose to individuals from the ingestion of strontium is quite minor compared to the dose from the ingestion of caesium.

The 1986 methodology [1] does not contain very much information about the actual calculation of doses from strontium. Rather, the methodology contains a few general statements that can be summarized as follows:

— In the first year after the accident, the effective dose equivalent from strontium is determined by both ^{89}Sr and ^{90}Sr. In subsequent years, the effective dose equivalent is due almost entirely to ^{90}Sr alone.
— During the first year and the following few years, with a ratio of ^{137}Cs to ^{90}Sr in the fallout of 1.6:1 (which is relatively more ^{90}Sr than actually observed), the effective dose equivalent from strontium radionuclides is negligibly small in comparison which the dose from caesium radionuclides.

- The maximum concentration of ^{90}Sr in bone tissue, taking into account the expected decrease in availability, occurs 20 years after the accident.
- As a result of the above, the annual effective dose equivalent from ^{90}Sr will be several times lower than the dose from ^{137}Cs. The effective dose equivalent accumulated over 50 years from ^{90}Sr is also several times lower than the 50 year dose from caesium.

The methodology published in 1988 [3] gives specific procedures for calculating the dose from strontium. The conclusion appears to be much the same: that the dose from strontium is practically negligible compared with that from caesium. Some of the general principles considered in this document are similar to those considered for the methodology of calculating doses from caesium:

- The methodology is generally concerned with the prediction of long term doses to the population living in the contaminated zones.
- The predictions are based on data accumulated during the time period 1986–1989. (The paper was written in 1988, but is mainly concerned with calculating doses from the period of 1990 onward, so it is assumed that data from 1989 will be available.)
- The critical group is generally taken to be those individuals born in 1986 and who will live for 70 years in the contaminated area. This allows comparison with the 70 year dose limit of 350 mSv.
- The calculation is deliberately conservative, with values of the 90th percentile concentration used as a basis for prediction. Thus, the model is designed to overestimate doses by a factor of not less than 2.
- Although some consideration has been given to the dose from the inhalation of strontium, the result is that this dose is about 1% of the dose from ingestion. It is therefore neglected in any further considerations.

Other specific input data to be used for model predictions are the following:

- Values of the deposition density of ^{90}Sr are to be taken from the data of the State Committee on Hydrometeorology.
- The activity ratio of ^{89}Sr to ^{90}Sr was 10:1 at the time of the accident.
- Data on the actual content of strontium (or caesium as a surrogate) should be used for the period 1986–1989.
- The contamination of the ^{90}Sr in the diet decreases exponentially starting from 1990 with a half-time of 10 years. (This assumption is not supported or referenced in the document.)
- The average daily intake of ^{90}Sr in the diet for a deposition density of 1 Ci/km^2 during 1990 is 2×10^{-10} Ci, and the 90th percentile value is 3.5×10^{-10} Ci. (These values are not supported in the document or referenced.)

2.2.2.1. *Intake in Diet*

First four years (to end of 1989)

It is recognized that much was done in the way of protective measures to reduce the intake of radionuclides following the accident, and that there were significant regional differences in these measures. Also, during the early years, there were not so many measurements of strontium. Therefore, the actually recorded levels of caesium in residents are suggested for use as an "objective, quantitative criterion of the effectiveness of these (counter)measures". To develop the calculations, this analogy to caesium is developed further. The average equilibrium level of body content and the average levels of chronic daily intake of caesium are stated to be connected by

$$A = d_{dly}/\lambda_{ef} \tag{28}$$

where A is the body content of caesium (μCi), q_{dly} is the daily dietary intake of caesium (μCi/d); and λ_{ef} is the rate of elimination of caesium in the body (corresponding to an effective half-time of 110 days), (d^{-1}).

In estimating the daily intake of strontium, it has been assumed that its concentration in the diet is 0.01 of the concentration of caesium. The statement is made that the actual values of this ratio vary from 0.001 to 0.01, so that the assumption of the value of 0.01 is conservative. (This statement is not supported or documented.)

Considering Eq. (28), the value of the annual intake, Q_{Sr} (μCi/a), of strontium in the period 1986–1989 can be estimated by

$$Q_{Sr} = 365\ A\ \lambda_{ef} K_{Sr} \tag{29}$$

where K_{Sr} is the ratio of strontium to caesium in the diet (0.01) and the other factors are as above. Inserting the parameter values, the equation becomes

$$Q_{Sr} = 0.023\ A \tag{30}$$

The methodology [3] states that, according to many measurements made with whole body counters, the relative body contents of caesium in the residents of controlled areas during 1986, 1987, 1988 and 1989 can be described by the proportions 6:2:1.4:1. It is stated that in the strictly controlled areas where restrictive measures were applied, the actual body content of caesium measured during 1988 corresponds to an annual intake of caesium of 3.7 μCi for the rural population and 0.7 μCi for the urban population. The annual ^{90}Sr intake would be 1% of these values, according to the assumptions above. The annual intake values for the years 1986–1989 can therefore be apportioned according to the proportions given above and with the use of the normalizing values for 1988.

In the localities where restrictive measures were not applied, the following predictive relationship may be used:

$$Q_{Sr} = K_i \sigma_{Sr} \qquad (31)$$

where K_i is the time dependent proportionality constant and σ_{Sr} is the deposition density of ^{90}Sr (Ci/km^2). The values of K_i are stated to be 0.78, 0.26, 0.18 and 0.13 μCi/a per Ci/km^2 for the years 1986, 1987, 1988 and 1989, respectively.

Because of the short half-life of ^{89}Sr, the calculation of dose is meaningful only for 1986. On the basis of the ratio of ^{89}Sr to ^{90}Sr at the time of the accident, it is stated that for each unit of intake of ^{90}Sr in 1986, there were two units of ^{89}Sr intake.

Remainder of 70 year period (1990–2056)

The estimated annual intake of ^{90}Sr is given by

$$Q(t) = Q_0 e^{-\lambda t} \qquad (32)$$

where λ is the elimination rate of ^{90}Sr from diet (corresponding to a half-time of 10 years) (a^{-1}); and Q_0 is the annual intake (90th percentile) during 1990 (Ci/a), equal to 0.128 σ_{Sr}, where σ_{Sr} is the deposition density of ^{90}Sr (Ci/km^2).

2.2.2.2. Dose to Red Bone Marrow

The absorbed dose to the red bone marrow is calculated over a period of 70 years for individuals born in 1986. The calculations use retention functions of strontium in the cortical and trabecular bone, and take into account the variation of the masses of cortical and trabecular bone as a function of age. Details and parameter values are provided in Ref. [3].

2.2.3. Iodine

The official methodology [4] gives procedures used to calculate the dose equivalent to the thyroid from the beta decay of iodine isotopes in the thyroid, following an intake of radioiodine from a release from a nuclear reactor, using a single thyroid measurement, knowledge of the probable route and pattern of intake, and tabulated data. Thyroid measurements are converted, by use of an instrument calibration factor, into equivalent activities of ^{131}I in the thyroid. This conversion is corrected for the presence of other iodine isotopes in the thyroid by a factor r(t), where t is the time between the accident and the measurement. The total thyroid dose from intakes of all iodine isotopes is then calculated. Iodine uptake and retention by the thyroid are modelled as a single exponential function, with an apparent half-time appropriate to the age of the subject. Uptake and retention in vegetation and milk are modelled in a similar fashion, with the activity in milk depending on the activity in the fodder that the cows consume.

At the time of measurement, ^{131}I is usually the main radionuclide in the thyroid, but other short lived radioiodines (^{132}I, ^{133}I, ^{134}I and ^{135}I) may be present as a result of intake of those iodine isotopes and of intake of ^{132}Te. The activity of ^{131}I in the thyroid is estimated from the measured exposure rate. The presence of other iodine isotopes in the thyroid is accounted for by means of a factor r(t), which depends upon the time between the accident and the measurement. The exposure rate due to ^{131}I in the thyroid is multiplied by K (μCi per μR/s), the calibration factor for ^{131}I in the thyroid for the instrument used, to give W(t), the activity of ^{131}I in the thyroid at the time of measurement:

$$W(t) = K[P_{th}(t) - P_{bg}(t)]/r(t) \qquad (33)$$

where $P_{th}(t)$ and $P_{bg}(t)$ are the measured exposure rates at time t from the thyroid and the background, respectively.

The dose to the thyroid is then calculated in the following manner: The basic parameter is D_1, the dose that the thyroid will receive from the time of the measurement, t, onwards from W(t), the ^{131}I activity present in the thyroid at time t. This is because D_1 only depends on the iodine metabolic model used, and not on the pattern or route of intake. The value of D_1 is then used in different ways to estimate the total dose received from the different patterns and routes of intake. D_1 is obtained by multiplying W(t) by d (rem/μCi), a factor that converts the ^{131}I activity measured in the thyroid to the total dose to the thyroid from that activity from the time of measurement until it is totally cleared from the thyroid:

$$D_1 = W(t)\, d \qquad (34)$$

The value of d varies with the age of the subject, reflecting the change with age of the iodine clearance rate from the thyroid.

The dose to the thyroid prior to measurement (and after measurement, if intake continues) is then calculated according to the pattern and route of intake deduced from the questionnaire completed by the subject. All inhalations are assumed to be acute. All ingestions are assumed to be chronic. For ingestion, doses can either be calculated for chronic intakes that stop at the time of measurement, or for chronic intakes that continue after the measurement, due to the continued presence of the same activity concentration in the food-chain. For both acute inhalation and chronic ingestion, procedures are given to calculate doses from both single and multiple contamination events and for chronic ingestion cases where intake ceased some time before measurement. For simplicity, only single contamination events will be described below. Methods for calculating other contamination events are provided in Ref. [4].

2.2.3.1. Inhalation

The total ^{131}I dose equivalent to the thyroid from an inhalation, D_2, is obtained by multiplying D_1 by a factor $C(\tau, t)$, which corrects D_1 for the fraction of the total dose that has been delivered to the thyroid between the time of inhalation, τ, and the time of measurement, t. The value of $C(\tau, t)$ varies with the time between inhalation and measurement and with the iodine clearance rate from the thyroid. Values have, therefore, been tabulated (in Ref. [4]) by subject age and time from intake to measurement.

The total dose from all iodine isotopes inhaled, D_Σ, is obtained by multiplying the ^{131}I dose by a factor, s, accounting for the contribution of short lived radioiodines:

$$D_\Sigma = D_1 C(\tau, t)\, s \qquad (35)$$

The value of s depends on (a) the original composition of the radionuclide release, (b) the decay rates and relative doses per unit intake of the iodine isotopes, and (c) the time between the accident and inhalation. For a given release, points (a) and (b) are fixed, so that the value of s is only a function of the time between the accident and inhalation.

2.2.3.2. Ingestion

For both ingestion regimes, two sets of tabulated data are provided for each of two factors $g(\Theta, t)$ and $h(\Theta, t)$ (see below) for which (a) the majority of intake is from milk, or (b) the majority of intake is from vegetables. Intake by the subject is, therefore, treated as time dependent on the decrease of iodine from the food source. Only the dose from ^{131}I is considered, that from other iodine isotopes being regarded as negligible.

Doses received before and after the thyroid measurement are calculated separately. D_1 is again used as the basis of the calculation. The dose received before the measurement, D_H, is obtained by multiplying D_1 by $g(\Theta, t)$, where Θ is the time from the accident to deposition of the iodine on vegetation, and t the time from the accident to thyroid measurement. The value of $g(\Theta, t)$ is obtained on the assumption that the subject consumes a constant quantity of contaminated food from the moment the food source is contaminated to the time of the measurement, and that the activity in the food decreases in accordance with the defined elimination coefficients.

If intake stopped at the time of measurement, the total dose is given by $D_1 + D_H$. If intake continues after the thyroid measurement, the dose received after measurement, D_{oct}, is given by multiplying D_1 by $h(\Theta, t)$. This assumes that the same food source will continue to be eaten in the same quantities indefinitely, and that the activity will continue to be cleared from the body at the same rate. The total dose received is then $D_H + D_{oct}$.

If thyroid doses are to be estimated for individuals for whom no direct thyroid measurements are available, this is done by analogy with other measured individuals or by the use of a radioecological model.

3. Review of the Soviet Dose Methodology

The adequacy of the Soviet methodology for dose evaluation can be judged mainly by comparison of the dose estimates with those derived from independent means. Such a comparison will be presented in Section 6. The purpose of this section is to comment briefly on some of the equations used and parameters selected in the dose estimation procedures.

Although the documents presenting the Soviet methodology for dose assessment contain useful information on how individual doses were estimated, they are deficient in several respects:

- The documents are lacking in clarity. Occasionally, this is due to the difficulties of translation; more frequently, however, parameters or mathematical expressions are not properly defined. The lack of necessary information could lead to incorrect inferences and, thus, disagreements with the stated conclusions.
- Values for parameters tend to be given without any reference as to how those values were chosen or obtained. While accepting that it may not be practical to include all such information in these documents, it would be most helpful to give references to the source material so that such values could be checked, if desired.

3.1. External Dose

3.1.1. Cloud Gamma Dose

In order to verify the validity of the methods for estimating cloud gamma doses, detailed information would be needed on the radionuclide distributions in the air and on the ground as a function of time elapsed since the accident. This information was not made available to the international experts. It is recognized, however, that the cloud gamma dose represented in most cases a very small fraction of the total dose and that its estimation does not justify an extensive investigation.

3.1.2. Dose from Deposited Radionuclides

The conversion factor from absorbed dose in air to effective dose equivalent is not mentioned and, therefore, seems to have been taken as 1. The UNSCEAR 1988 Report [6] assumes a value of 0.7 for this conversion factor. The value of the screening factor due to snow cover could not be verified. It is generally believed to be of less significance, particularly as applied to the annual absorbed dose rate in air. If the conversion factor is adopted and the screening factor is neglected, the two factors compensate for one another.

The measurements of external radiation carried out as part of the environmental corroboration task by the international expert team in Novozybkov (RSFSR) (see Section 3.1) indicate that there is a large spatial variation in the external dose rate within the same locality [7]. The manner in which the average (or 90th percentile) external dose rate for a given settlement was determined by Soviet scientists was not made clear to the international experts.

The dose from external irradiation in the longer term, from 1988 onwards, has been estimated in Ref. [2] (Eq. 5) to depend on two half-time components. The first component is due to the migration in soil of radiocaesium and the decay of ^{134}Cs; the second component is due to the decay of ^{137}Cs. This formulation can be verified only with further monitoring of external exposure rates at individual locations.

3.2. Internal Dose

3.2.1. Caesium

The official methodology for calculation of internal doses from caesium radionuclides, with some modifications, has been used by scientists at the All-Union Scientific Centre for Radiation Medicine at Kiev, the Institute of Radiation Medicine at Minsk, and the Institutes of Radiation Hygiene at Leningrad and Novozybkov to calculate doses for residents of the UkrSSR, BSSR, and the RSFSR, respectively. Some of the more significant modifications or additions to the official methodology have been made at Kiev, where scientists have developed a more sophisticated Monte Carlo model, so that it is possible to compare doses calculated by the official methodology with the probability distribution calculated by a more realistic model [8]. Scientists in Leningrad have also made calculations with a more realistic model, as they believe that the projected decrease of ^{137}Cs content in food with time is too conservative [9].

The calculational methods given in 1986 [1] provide procedures for calculating doses during the first and second years. Estimates of doses for subsequent years are suggested as being derived from the second year estimates by assuming a half-time of ^{137}Cs in foodstuffs of 14 years. However, it was also stated that this was thought to be quite conservative, as other data indicate a more rapid decay of caesium in foodstuffs according to a half-time of 7.5 years. The emphasis in Ref. [1] is on a modelling approach for calculating the content of caesium in pasture, milk, total diet, and in the body.

The methodology given in 1988 [2] essentially supersedes that given in 1986 [1]. The 1988 methodology also has a rather different emphasis, in that it is more concerned with calculating the 70 year dose. This is important for comparisons with the 70 year dose limit of 35 rem. The 1988 methodology explicitly states that doses from the time period of 26 April 1986 to the end of 1989 should be based upon data on the actual content of caesium radionuclides in the bodies of inhabitants of specific settlements or according to measurements of the intake in the diet. The content of caesium in foodstuffs in 1988 is taken as the reference point upon which calculations for 1990 to 2056 are to be based.

3.2.2. Strontium-90

The dose calculation for ^{90}Sr is intended for long term prediction of internal exposure [3]. For the dose calculation, only intake via foods is considered. Inhalation is neglected because its contribution to the total ^{90}Sr dose was estimated to be only 1%. The dose equivalent is calculated to the red bone marrow, which appears to assume a dose conversion factor for the infant which is about five times higher than would apply to adults.

The method and parameters used for calculating the dose from the annual intake of ^{90}Sr seem, as far as can be seen, in accordance with international recommendations. The assumption that the concentration of ^{90}Sr in the diet is 0.01 of the concentration of caesium radionuclides may not be valid in the longer term. The database for this assumption seems to be small. In Gomel the ^{90}Sr to ^{137}Cs ratios in grain were reported to range from 1:11 to 1:420 in 1987 and 1:7 to 1:9 in 1989 [10]. The range, especially in 1987, might be due to different deposition patterns and different soil properties. In Novozybkov the results indicate that in a few plant products the activity of ^{90}Sr is about 3–6% of that of ^{137}Cs, and in milk 0–4%. These data are in agreement with expected uptake behaviour of caesium and strontium. The ratio may change with time, and ^{90}Sr can become relatively more important for the internal dose. Nevertheless, the dose from ^{90}Sr is expected to be small in comparison to the total dose because of the countermeasures that have been taken.

TABLE 2. Comparison of Thyroid Retention Coefficients for ^{131}I [4, 14]

USSR model		ICRP-56	
Age group (years)	Effective half-time (days)	Age group (years)	Effective half-time (days)
<1	6	0.25	5.6
1–3	6.2	1	5.7
3–7	6.4	5	6.4
7–9	6.6		
9–13	6.8	10	7.2
13–15	7.0		
15–18	7.2	15	7.3
Adult	7.5	Adult	7.4

3.2.3. Iodine-131

3.2.3.1. Measurement Procedures and Interpretation

A variety of instruments were used to measure the iodine content of the thyroid. Many measurements were made with the DP-5 Geiger counter and the SRP-68 scintillation detector [4, 11, 12]. A smaller number of measurements were made with hospital radiodiagnostic equipment [13]. Due to the urgency of the situation and the belief that the greatest problem was in the UkrSSR, many of the Soviet resources were moved there and 152 000 measurements were made under generally controlled conditions. These involved the use of collimators, frequent checks with standard sources, and the taking of background measurements over another part of the body [11]. The minimum detectable activity has been stated to be between 0.3 and 5 μCi, and the uncertainty is less than a factor of two.

In the BSSR, about 250 000 measurements of the thyroid were made. However, the conditions were not as well controlled, and the calculational process has been much more difficult. This process of converting measurements into doses is being conducted by personnel at the Institute of Biophysics in Moscow [12]. Eventually, 180 000 dose values are expected to be recovered, and the uncertainty is expected to be about a factor of two. Results that are available now for about 60 000 people indicate that, for a given region and age group, the data are log-normally distributed with a geometric standard deviation of between 2.8 and 3.7 [12].

In the RSFSR about 30 000 measurements were made. Of these, 3000 were of high quality and were made with hospital radiodiagnostic equipment. These 3000 high quality measurements have been used to reconstruct the doses for about 70 000 people [13].

In the Soviet dose estimation methodology [4], the values given for K, the instrument calibration factor, are of the same order of magnitude as those obtained from calibrating instruments used by the National Radiological Protection Board (NRPB) in the United Kingdom for an average adult thyroid, using the same counting geometry. The reductions of K by 1.5 for children between 3 and 10 years and by 2 for children under 3 years represent reasonable corrections for the probable differences in the average thickness of tissue overlying the thyroid in these age groups.

There is reasonable agreement between the values of r, the correction of the measured count rate for iodine isotopes other than ^{131}I, and of s, the correction to total dose for dose due to the inhalation of iodine isotopes other than ^{131}I, with the values calculated at the NRPB for evaluation of the consequences of a theoretical accidental release from a typical reactor in the United Kingdom.

The effective half-times of ^{131}I in the thyroid of different age groups used in the Soviet model are compared in Table 2 with the estimates given in ICRP Publication 56 [14], derived from the apparent biological half-time of iodine in the thyroid and the physical decay rate of ^{131}I. Note that ICRP Publication 56 was published after the Soviet model was formulated. If the values of the Soviet model are based on measurements of the local population, they may be more appropriate than the ICRP values.

The effective half-time of 4.6 days for ^{131}I in vegetation is given in the methodology document [4], corresponding to a stable iodine biological half-time of 11 days. Studies of the transfer of radionuclides from pasture to milk were conducted in the United Kingdom after the Chernobyl accident [15]. For pasture, a retention half-time of particles on vegetation of 14 days gives an effective half-time for ^{131}I of 5 days. These independent estimates of the effective half-time of ^{131}I in vegetation show reasonable agreement with the official value of 4.6 days.

TABLE 3. The Dose per Unit ^{131}I Activity Uptake to the Thyroid for Different Age Groups Relative to That for the Adult [4, 14]

USSR model		ICRP-56	
Age group (years)	Relative dose	Age group (years)	Relative dose
<1	7.5	0.25	8.4
1–3	5.3	1	8.2
3–7	3.2	5	4.8
7–9	2.2		
9–13	1.6	10	2.5
13–15	1.3		
15–18	1.2	15	1.6
Adult	1.0	Adult	1.0

The post-Chernobyl study carried out in the United Kingdom [15] reported that where cattle were grazing fresh pasture, concentrations of ^{131}I in milk reached a peak on day 4 after deposition and then decreased with a half-time of 5.6 days. This would cause doses from milk, calculated from the original Soviet deposition, to be estimated as 20% higher than the doses calculated using the official value of 4.6 days. However, from actual thyroid measurements, the Soviet dose calculation would give the higher dose estimates. Note that another report carried out in the United Kingdom [16] suggests a half-time of ^{131}I in milk of 4 days. Overall, these different values are in good agreement.

3.2.3.2. Comparison of Doses Calculated by Various Models

In order to assess the validity of the dose estimates resulting from the Soviet method, comparisons have been made using the models described in ICRP Publication 56 [14]: (a) a cyclic iodine metabolic model and (b) a single exponential function typical of the clearance rate of iodine from the thyroid between days 2 and 16 after intake.

The number of ^{131}I decays per mSv for an adult was calculated for the Soviet model and for the ICRP cyclic model using their tabulated values. For adults, the Soviet model gives 5.9×10^8 ^{131}I decays per mSv, and in the ICRP cyclic model 6.0×10^8 ^{131}I decays per mSv, a difference of 2%, probably due to using tabulated data. However, the agreement is not as good for the younger age groups (see Table 3). The largest discrepancies in dose per unit iodine uptake to the thyroid occur between the Soviet 1–3-year-old group and the ICRP Publication 56 1-year-old group, and between the Soviet 9–13-year-old group and the ICRP Publication 56 10-year-old group.

Doses were calculated using the Soviet model, the ICRP cyclic model, and the ICRP single exponential model, assuming, in all cases, that a count rate equivalent to 37 kBq (1 μCi) of ^{131}I had been measured in the thyroid (see Tables 4 and 5). For the ICRP single exponential dose model, the values of d were adjusted in accordance with the different decay coefficients used. The same Soviet correction factor, s, was used for all three models to correct for the dose from intakes of iodine isotopes other than ^{131}I.

All four cases (Tables 4 and 5) generally show reasonable agreement between the three models. The greatest differences are seen for acute inhalation by

TABLE 4. Dose to Thyroid from Single Acute Inhalation of ^{131}I Calculated by USSR and ICRP Models
Acute inhalation 2 days after release (measured activity: 37 kBq)

USSR model		ICRP cyclic model		ICRP single exponential model	
Age group (years)	Dose (mSv)	Age group (years)	Dose (mSv)	Age group (years)	Dose (mSv)
Case 1: Measurement 1 day after intake					
<1	630	0.25	900	0.25	590
1–3	440	1	860	1	410
3–7	270	5	480	5	270
7–9	190				
9–13	140	10	260	10	150
13–15	110				
15–18	100	15	160	15	110
Adult	80	Adult	100	Adult	80
Case 2: Measurement 6 days after intake					
<1	1 140	0.25	1 280	0.25	1 110
1–3	810	1	1 190	1	790
3–7	470	5	630	5	470
7–9	320				
9–13	220	10	310	10	240
13–15	180				
15–18	170	15	200	15	170
Adult	130	Adult	120	Adult	140
Case 3: Measurement 30 days after intake					
<1	18 000	0.25	34 000	0.25	27 000
1–3	12 000	1	22 000	1	14 000
3–7	6 400	5	8 600	5	6 500
7–9	3 900				
9–13	2 600	10	3 200	10	2 400
13–15	1 900				
15–18	1 700	15	1 900	15	1 700
Adult	1 200	Adult	1 100	Adult	1 300

TABLE 5. Dose to Thyroid from Chronic Ingestion of ^{131}I Calculated by USSR and ICRP Cyclic Models
Chronic ingestion, measured 10 days after deposition; intake ceased after measurement (measured activity: 37 kBq)

USSR model		ICRP-56	
Age group (years)	Dose (mSv)	Age group (years)	Dose (mSv)
< 1	850	0.25	1100
Adult	100	Adult	100

young children for measurements made in the first two days after intake and at long times after intake. These discrepancies arise from the differences in the values of dose per unit intake used in the models, and from the different coefficients for iodine clearance from the thyroid. In the first two days after intake these discrepancies are exacerbated by the Soviet single exponential model, which does not compensate for the time required for iodine uptake to the thyroid. Errors increase in dose estimates from measurements at long times after intake increase because of the different decay coefficients used in the different models to represent the shorter effective half-times of ^{131}I in children. Note also that the effective half-time of the recycling iodine model changes with time after intake. The important point is that dose estimates from measurements made at times greater than 2 or 3 effective half-times since intake must be regarded as very crude. This caution is given in the Soviet document [4] with respect to estimating dose to members of the population from ^{131}I activity concentrations in milk, but it should also be made concerning acute inhalation intakes.

In summary, the assumptions used in Ref. [4] and the doses calculated using the methods of that document show good agreement with the literature and with the doses calculated using models described in ICRP Publication 56 [14]. The largest discrepancies arise for young children monitored within two days of, or long after, an acute inhalation intake. The discrepancies of dose estimates from measurements made in the first two days after intake could be easily corrected by adjusting the values of the tabulated values of C (τ, t). It may also be advisable to alter the values of d (dose per unit activity) to give agreement with the more recent recommendations of ICRP Publication 56 for the different age groups. However, the current values should be kept, if they more accurately reflect iodine biokinetics in the population being monitored.

The method of estimating the thyroid dose equivalent from measurements of ^{131}I activity concentration in milk seems to be correct. However, such a method is invariably less certain than direct subject measurement, as there are more assumptions made, e.g. milk consumed per day.

The document describing the Soviet methodology [4] is not always clear and consistent in the definitions of the various parameters and coefficients used. Most notably, the factor f is not defined in the main text, but twice, and differently, in Annex 1 of the document [4].

If the purpose of the document [4] is to standardize the estimation of thyroid dose from iodine between different groups, then more information should be given on how to check the calibration of the instruments before use. For an external audience, more information on the instruments mentioned would be useful, and fewer tabulated data would be required.

The uncertainty of the dose estimates is not addressed in Ref. [4]. However, it has been stated that the uncertainty of the doses estimated for those persons measured in the UkrSSR is less than a factor of two [11]. For the BSSR, the uncertainty of doses for those persons measured has been stated to be about a factor of 2. Individuals of the same age group from the same area have log-normally distributed doses with geometric standard deviations varying from 2.8 to 3.7 [12].

4. Input Data and Reported Doses for Selected Settlements in the BSSR, the RSFSR and the UkrSSR

The international experts requested input data for selected settlements, namely Bragin, Korma and Veprin in the BSSR, Narodichi and Polesskoe in the UkrSSR, and Novozybkov and Zlynka in the RSFSR. These data were to form the basis for independent project dose evaluations.

4.1. Data Sources

The Institute of Biophysics in Moscow has collected data and has estimated doses in a calculational procedure called SDACHA for the populations of each settlement contaminated as a result of the Chernobyl accident according to the following breakdown:

- population, total and children, with date of evacuation of children, if applicable;
- gamma dose rate;
- ^{137}Cs deposition in the soil;
- ^{90}Sr deposition in the soil;
- ^{137}Cs concentration in milk;
- external, internal and projected doses;
- data on whole body monitoring;
- thyroid doses to children and adults;
- date of inclusion in the Strictly Controlled Zone (> 15 Ci/km^2).

Additional data and information were provided to the international experts by other institutes in the BSSR, the RSFSR, the UkrSSR and the USSR. The database acquired from the SDACHA listing and from the other sources is appended as Annex 2. The use of this database is hampered by a number of problems.

The radiation measurement results in this summary often consist of a single number without mention of the associated uncertainty or variability. When no indication is provided, this single number is assumed to be an average (arithmetic mean) value. Also, unexplained discrepancies sometimes occur between results reported for different years or by different laboratories; for example, the average ^{137}Cs deposition density in Bragin is reported as 1700, 1000, 270 and 1000 kBq/km^2 for the years 1986, 1987, 1988 and 1989, respectively. Other examples are that the average ^{137}Cs concentrations in milk in 1988 in Veprin are given as 1300, 1700 and 590 Bq/L by three separate organizations; the projected internal doses from radiocaesium in Narodichi for 1990–2060 were estimated as 173 mSv in 1988 and as 555 mSv in 1989. [*The international experts were informed in March 1991 that there was a mistake in the database for Narodichi.*]

Independent measurements of radiation in the environment and radiocaesium in humans were carried out during 1990 by the international expert teams as part of this assessment. More detailed information on the environmental measurements (external irradiation and concentrations in the air, soil, foodstuffs, etc.) is presented in Part D. In some cases the values for deposition density in Annex 2 are not exactly the same as presented in Part D. Due to the concurrent work schedules of the teams, the experts working on the review of the dose assessment used the official values provided by the USSR. In general the conclusions of the environmental corroboration task indicate that the data provided are adequate; therefore these values were used in the calculations presented in this Part.

The procedures and detailed results of whole body counting and personal dosimetry carried out by international teams are presented in Annexes 3 and 4. These independent measurements were also considered in the evaluations of dose estimates.

4.2. Discussion of Available Data

4.2.1. Deposition of Caesium-137 and Strontium-90

The deposition densities of ^{137}Cs and ^{90}Sr, for each of the settlements evaluated, are listed in Table 6 (reported by the State Committee on Hydrometeorology [17]). The deposition densities of ^{137}Cs in these settlements range from 600 to 1200 kBq/m^2 (16–33 Ci/km^2; 1 Ci/km^2 corresponds to 37 kBq/m^2). The deposition density of ^{90}Sr seems to be variable relative to that of ^{137}Cs (see Table 6 and Fig. 1). The settlements form three groups, with ^{90}Sr deposition corresponding to 8% of ^{137}Cs deposition in Bragin, 5% in the Ukrainian settlements (Narodichi and Polesskoe) and around 2% elsewhere. These groups also have geographical relevance, with Bragin to the north, Narodichi and Polesskoe to the west and the other settlements farthest from the reactor site to the northeast.

4.2.2. Caesium-137 in Diet

Limited data have been received on ^{137}Cs concentrations in food and on food consumption rates. While some estimates can, therefore, be made of ^{137}Cs intake, the relevance of this to dose estimates is uncertain. This

TABLE 6. Comparison of ^{90}Sr and ^{137}Cs Deposition Densities

Settlement	Deposition density (kBq/m²)		Ratio of ^{90}Sr to ^{137}Cs
	^{137}Cs	^{90}Sr	
Bragin	1000	78	0.078
Narodichi	630	34	0.054
Polesskoe	910	48	0.053
Zlynka	990	26	0.026
Veprin	1200	21	0.017
Novozybkov	600	9.3	0.016
Korma	670	7.4	0.011

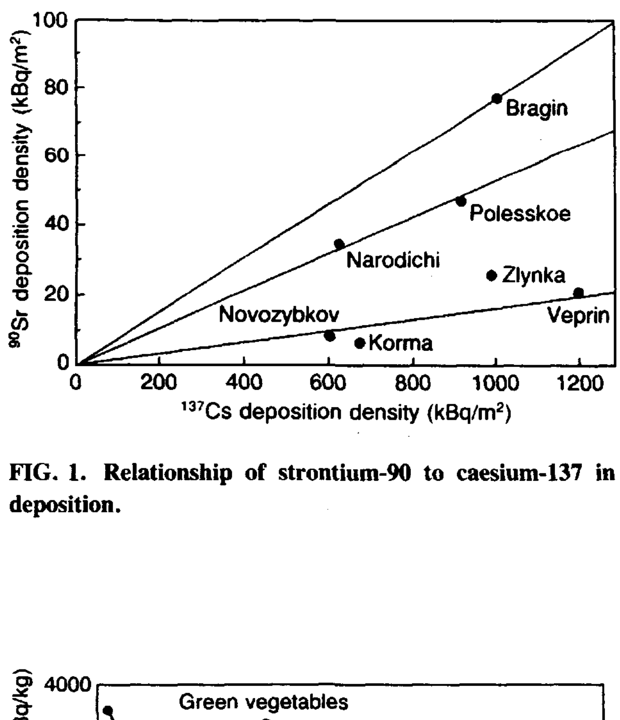


FIG. 1. Relationship of strontium-90 to caesium-137 in deposition.

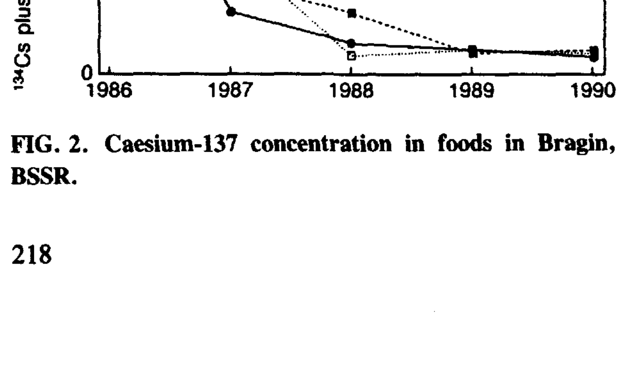


FIG. 2. Caesium-137 concentration in foods in Bragin, BSSR.

is because of the implementation of restrictive measures. In more contaminated areas, locally produced foods are not consumed (at least officially) and clean foods are imported. There are also more general problems in relating estimated to actual amounts of radionuclides in diet. Loss of activity in food processing and preparation and introduction of foods from other areas generally result in much lower actual intake amounts. It is, therefore, much more reliable to base dose estimates on whole body measurements of ^{137}Cs whenever this can be done.

A general indication of ^{137}Cs concentrations in foods is given in Fig. 2 for data reported from Bragin (Annex 2, Table 2-1). The highest concentrations in 1986 in green vegetables, 3700 Bq/kg (100 nCi/kg), milk and meat, 1670 Bq/kg (45 nCi/kg), declined to less than 370 Bq/kg (10 nCi/kg) by 1989. Some concentrations in mushrooms and berries are still of the order of 1100–1500 Bq/kg (30–40 nCi/kg). These are annual average values. Higher extreme values can, of course, be expected.

Based on consumption rates that apply to rural settlements in the BSSR and the approximate ^{137}Cs concentrations in foods (Bragin), alternative estimates of ^{137}Cs intake in diet are derived and listed in Table 7. For the data as reported, the intake rate is 550 Bq/d (alternative 1 in the Table). The concentration of ^{137}Cs in bread is unavailable in this listing, and, therefore, the data for bread from shops in Novozybkov have been used.

The concentrations of ^{137}Cs in milk and root vegetables are a factor of 2 less in other locations (e.g. Korma). Data from Novozybkov (10 farms in region) give 150 Bq/kg (4.1 nCi/kg) in locally produced milk in 1989 and 96 and 41 Bq/kg (2.6 and 1.1 nCi/kg) in potatoes in 1988 and 1989, respectively. Lower concentrations are also reported for foods from shops (e.g. Bryansk region), for example, 30 Bq/kg (0.8 nCi/kg) in milk and 110 to 150 Bq/kg (3 to 4 nCi/kg) in meat in 1989.

This information has been used to obtain the alternative estimates of ^{137}Cs intake listed in Table 7: alternative 2 with reduced concentrations in milk and potatoes and alternative 3 with further reduced concentration in milk and the lower value for ^{137}Cs in meat. The intake estimates range from 550 to 200 Bq/d (15 to 5.5 nCi/d).

4.2.3. Dose Estimates

The doses estimated by the Soviet scientists from external irradiation and internal exposures from radiocaesium, ^{90}Sr and ^{131}I along with the input data (deposition densities, concentrations in milk, etc.) are contained in Annex 2. In principle, the doses are estimated from the input data by means of the official methodology that was presented to the international experts. During the international review it was not possible to have demonstrations of actual applications of the

TABLE 7. Dietary Intake of ^{137}Cs in Bragin, BSSR, in the Years 1989-1990

Food item	Consumption rate (g/d)	Concentration (Bq/kg) Alternative 1	Concentration (Bq/kg) Alternative 2	Concentration (Bq/kg) Alternative 3	Intake (Bq/d) Alternative 1	Intake (Bq/d) Alternative 2	Intake (Bq/d) Alternative 3
Milk	735	260	150	30	190	110	22
Bread (wheat)	220	10	10	10	2	2	2
Bread (rye)	350	10	10	10	4	4	4
Potatoes	540	370	70	70	200	38	38
Vegetables	190	220	220	220	42	42	42
Fruit	160	330	330	330	53	53	53
Mushrooms	6	1100	1100	1100	7	7	7
Meat	150	300	300	150	45	45	23
Fish	46	220	220	220	10	10	10
Total (rounded)					550	310	200

TABLE 8. Summary of Input Data and Official Estimates of Doses for the Selected Settlements
Note: The dose from ^{90}Sr is the dose equivalent to red bone marrow, but it is the practice in the USSR to add this to the total whole body dose

Settlement	Input data: Deposition density (kBq/m^2)		Input data: ^{137}Cs concentration in milk (Bq/L)			Dose (mSv): 1986–1989 (0–4 years)			Dose (mSv): 1990–2056 (4–70 years)			Total
	^{137}Cs	^{90}Sr	Average	90%	Max.	Ext.	Int.	Total	Ext.	^{137}Cs	^{90}Sr	
Bragin	1000	78	210[a]		380	70	14	84	86	60	38	268
Korma	670	7.4	190[a]		740	29	9.0	38	58	48	5.0	148
Veprin	1200	21	1300[b]	1700[b]		53	16	69	104	176	19	369
Narodichi	630	34	3700[c]		9600			53	55	555[e]	18	681
Polesskoe	910	48	570[a]	810				77	79	223	24	403
Novozybkov	600	9.3	520[d]					34	52	57	6.3	149
Zlynka	990	26	440[b]	3000[b]				56	86	85	14	241

[a] 1989 values.
[b] 1988 values.
[c] In March 1991, Soviet scientists reported that this value was incorrectly reported in SDACHA; the value should have been 700 Bq/L.
[d] 1989 annual average concentrations for Novozybkov district.
[e] Invalid due to reported error.

dose assessment methodology. Because there are ambiguities in the official methodology, it was decided to attempt to reconstruct the doses for the selected settlements using the input data provided in Annex 2 and our understanding of the official methodology. Since the input data and the estimated doses presented in Annex 2 vary according to the reporting organization and the year in which they are reported, it was necessary to select a reporting organization and a particular year. The SDACHA listing, which was assumed to contain the best information, and the most recent year with reported measurements, 1989, were chosen for the purpose of dose reconstruction. Table 8 summarizes the selected information for the seven settlements under consideration. Updated information was received on the deposition densities after this work was completed, therefore the values in Table 8 vary slightly from the data presented for the same settlements in Part D.

4.2.3.1. External Doses

Reported values of doses from external irradiation for the period 1986–1989 seem to have been estimated as $K\sigma_{137}$, where K is a coefficient that varies from region to region [2] and σ_{137} is the deposition density of ^{137}Cs in the settlement considered. However, such dose estimates are provided in the SDACHA listing only for Bragin, Korma and Veprin. The projected external doses for the time period 1990–2060 have been calculated as $0.32\ \sigma_{137}$. This is a consistent result for all settlements.

4.2.3.2. Internal Doses

The projected doses from ^{90}Sr for the time period 1990–2060 seem to have been calculated as $0.2 + 1.7\ \sigma_{90}$, and not as $1.7\ \sigma_{90}$, as indicated in the methodology. An exception to this was Veprin, with a ^{90}Sr dose estimate of approximately $1.2 + 1.7\ \sigma_{90}$.

The projected doses from caesium for the 1990–2056 time period are believed to be related to the ^{137}Cs concentrations in milk in 1989, q_m expressed in nCi/L, according to the formula $2.1(0.017\ q_m + 0.1)$. However, the milk concentrations in the seven settlements considered were not reported in a consistent manner:

- 1989 average and maximum values are provided for Bragin, Korma, and Narodichi;
- 1989 average and 90th percentile are given for Polesskoe;
- 1989 average in the district is given for Novozybkov;
- 1988 average and 90th percentile are given for Veprin and Zlynka.

The dose estimates given in the SDACHA listing have been compared with the results obtained with the above equation, taking q_m to be either the 90th percentile (or the maximum concentration) or the average concentration. Most of the results provided by the equation differ from the dose estimates, sometimes by a factor of 3. The reasons for these discrepancies cannot be clarified.

The 1986–1989 doses from internal exposures due to caesium are based on measurements. These dose estimates are provided only for Bragin, Korma and Veprin in the SDACHA listing. Annual doses derived from body burden measurements are also given in the SDACHA listing for those three settlements for three age categories (children, teenagers and adults); in addition, information on the individual dose distribution is supplied for the years 1986 and 1987. From those data and using the assumption for the years with no reported measurements that the annual doses from internal radiocaesium were in the proportions 6:2:1.4:1 in 1986, 1987, 1988 and 1989, respectively, it seems that the 1986–1989 doses from internal exposures may have been calculated by adding the 90th percentile annual doses for adults. The 1986–1989 doses calculated in this way are within a factor of 2 of those reported in the SDACHA listing. The actual mode of calculation remains uncertain, as does whether the 1986–1989 doses include contributions from radiostrontium and other radionuclides or not.

4.2.3.3. Thyroid Doses

It is important to note that the summary listing of SDACHA does not include any input data on radioiodine that would allow verification to be made of the thyroid doses. The international experts were informed of some of the difficulties with the thyroid measurements and the intentions by the Soviet authorities to reconstruct estimates of thyroid doses. In the UkrSSR, as well as in the BSSR and in the RSFSR, the emphasis was placed on thyroid measurements. Those thyroid measurements, which involved several types of instruments, and teams that were often inexperienced, are being re-evaluated. The primary concern is to make sure that the instruments were used properly and that the appropriate detector efficiencies were applied. Secondary concerns include a more specific consideration of the influence of the short lived radioiodines in the body, the type of measurement method, and the morphology of the individual measured.

Usually, only one thyroid measurement is available for each individual. In order to estimate the thyroid dose on the basis of a single thyroid measurement, it is necessary to make use of the temporal variation of the radioiodine intake, which can be assessed from environmental measurements of radioiodine and from individual consumption data. The extent to which radioiodine concentrations were measured in ground-level air, soil, grass, milk, leafy vegetables, etc. in the settlements considered in this assessment could not be established. It is likely that environmental measurements of radioiodine were not carried out in most of the settlements or that those measurements have not yet been evaluated.

Information from the UkrSSR [11] is that the thyroid dose reconstruction for people with thyroid measurements will be carried out in three steps:

- in the first step, it is assumed that the ^{131}I intake was acute and occurred the first day of the accident (single intake hypothesis);
- in the second step, the residence history of the people measured is roughly analysed, resulting in most cases in the assumption that ingestion was the main contributor to the dose, and the dose estimates are made accordingly (prolonged intake hypothesis);
- in the third step, the results of a questionnaire requesting individual information on residence history, dietary habits, and use of potassium iodide tablets will be analysed to refine further the thyroid dose estimates. This effort may take between two and five years.

Thyroid dose reconstruction for people without thyroid measurements is only envisaged for the purposes of collective dose assessment and for the estimation of the thyroid doses of people who develop thyroid disease. This dose reconstruction will be based in the UkrSSR on the available concentrations of ^{131}I in milk or on the gamma dose rates in air in May 1986. The lack of input data for ^{131}I thyroid dose estimates is notable. Rather similar steps are being carried out for the estimates of thyroid dose in the BSSR [12] and the RSFSR [13].

4.3. Independent Data

During the course of the study by the international experts, 9058 people in 9 settlements were measured to determine the contents of ^{137}Cs in their bodies. This information serves as an important basis to check the validity of any calculated dose—whether calculated by the Soviet scientists or the international experts.

In addition, film badges were distributed by the IAEA to residents in the settlements. As almost all of these measurements resulted in 'non-detected' values, they have not been of great use, except for verifying that external exposure rates are less than 10 mR/month.

The results of the independent measurements of external and internal doses in the selected settlements are presented in Annex 3. An intercomparison programme for whole body counters was also carried out during the course of the international study. The results of this programme are described in Annex 4.

4.4. Collective Doses

The results of collective dose calculations have not been reviewed by the international study team. However, the collective dose may be easily calculated by multiplying the average doses in a region by the number of individuals in the region and then summing over all regions. Estimates of the numbers of individuals with various doses reported by Soviet authorities are illustrated in Fig. 3 for the period 1986–1990 and in Fig. 4 for the period 1986–2056 [18].

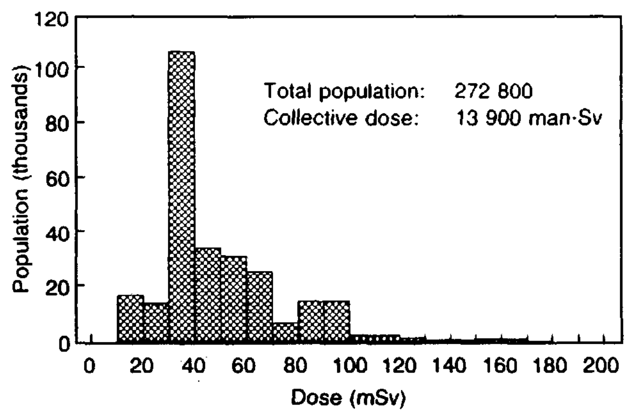


FIG. 3. Distribution of doses during 1986–1989 reported by Soviet authorities for individuals residing in permanently and strictly controlled zones (>550 kBq/m^2 of ^{137}Cs deposition) [18].

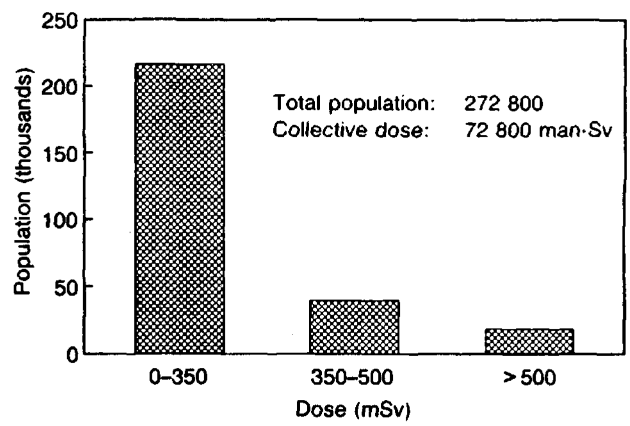


FIG. 4. Distribution of lifetime doses reported by Soviet authorities for individuals residing in permanently and strictly controlled zones (>550 kBq/m^2 of ^{137}Cs deposition) [18].

Part E

5. Project Dose Assessment

The project dose assessment was carried out on two parallel paths: (1) direct measurements of external and internal doses and (2) detailed dose calculations. The settlements selected for detailed dose calculations are from areas of relatively high contamination by ^{137}Cs, >550 kBq/m^2 (>15 Ci/km^2). The settlements are Bragin, Korma and Veprin in the BSSR, Narodichi and Polesskoe in the UkrSSR, and Novozybkov and Zlynka in the RSFSR. All of these settlements were visited by the project medical teams (Part F), and three settlements were visited by the environmental assessment teams (Part D). The external and internal measurements were made in the above settlements with the exception of Narodichi. Instead of Narodichi the settlement of Ovruch was included. In addition, internal dose measurements were made in the settlements of Daleta and Rakitnoe. For these two villages and for Ovruch, all in the UkrSSR, higher soil-plant transfer characteristics were known to prevail.

The independent measurements of external dose and of ^{137}Cs whole body contents are described in detail in Annex 3. The results, as appropriate, are considered in the dose calculations presented in this chapter. Reasonable amounts of input data were obtained for the settlements selected for dose evaluations. Nevertheless, the database is insufficient for detailed calculations of radiation doses to the residents. Continuous measurement records of the external exposure rates are unavailable. Data on radionuclide concentrations in foods are not extensive, particularly those reflecting actual intake rates. However, the internal doses from ^{137}Cs in the initial period may be estimated from available whole body measurements.

The dose evaluations have been performed in a manner such that comparisons could be made between the independent calculations and the results presented by Soviet scientists, namely for the periods 0–4 years (26 April 1986 to the end of 1989) and 4–70 years (1990–2056). From the dose assessment viewpoint, the major radionuclides of interest are ^{137}Cs, ^{90}Sr and ^{131}I. The database for ^{137}Cs is relatively good, as it contains information on deposition, concentrations in foodstuffs, and body contents. The data for ^{90}Sr allow only approximate estimates of potential doses based on deposition amounts. These cannot be verified with diet or body measurements. As previously indicated, no information was made available on the concentrations of ^{131}I in the environment or in people; the thyroid doses can only be estimated indirectly, using data on ^{137}Cs as a guide. No data are available for estimating doses from other radionuclides, including ^{239}Pu.

The independent dose calculations have been carried out using: (a) the methodology developed by UNSCEAR to estimate radiation exposures resulting from radionuclides released into the environment and (b) computer codes developed for the same purpose by the Centre d'étude de l'énergie nucléaire in Belgium (referred to as Mol in this report), by the Gesellschaft für Strahlen- und Umweltforschung in Germany (GSF), and the National Radiological Protection Board in the United Kingdom (NRPB). When appropriate, the dose estimates obtained with the four methodologies are presented in this report; however, preference is given to the UNSCEAR methodology, which serves as a reference against which the other methodologies are compared. This is because: (a) the UNSCEAR models have been reviewed by an international committee of experts and are familiar to many researchers, (b) they are relatively simple and easy to apply, and (c) the assumptions and equations used are presented in detail in reports [6, 19], which are available throughout the world.

For the dose estimates made by Mol, GSF and NRPB, there was no attempt to ensure uniformity of the input data to the models. Each organization made its own judgement about the values of the parameters. Variations arise due to:

— selection of deposition density from the available compilations;
— judgements about shielding and occupancy values, on the basis of data made available to the international study team;
— selection of transfer factors from soils to foods;
— judgements about the consumption rates of various foods, made on the basis of information made available to the study team;
— decisions on whether to include the effects of food restrictions.

It is therefore not surprising that the dose estimates vary. In this section, the dose estimates from those laboratories (Mol, GSF, NRPB) are compared with the UNSCEAR values by normalizing to the deposition density.

5.1. External Dose

Exposure rates in air decreased markedly in the first year after the accident, due to the decay of short lived radionuclides. Thereafter, the exposure rates are due primarily to ^{134}Cs and ^{137}Cs. Some degree of migration of caesium into the ground would further reduce exposure rates in time. A general assumption is that the initial surface contamination becomes distributed with depth in soil with a relaxation length of 1 cm during the first year and 3 cm thereafter [19].

Theoretical exposure rates in air 1 m above the ground for a surface distributed source are 0.3 μR/h per kBq/m^2 (11 μR/h per Ci/km^2) for ^{137}Cs and 0.80 μR/h per kBq/m^2 (29 μR/h per Ci/km^2) for ^{134}Cs [20]. The ratio ^{134}Cs to ^{137}Cs in deposition in 1990 was reported to be 0.15. Therefore, the expected exposure rate in air for a plane source distribution is 0.4 μR/h for each kBq/m^2 (15 μR/h for each Ci/km^2) of deposited ^{137}Cs.

The reduction in exposure rates with distributions of both ^{137}Cs and ^{134}Cs with depth in soil are as follows relative to a surface distribution: 1 cm relaxation length 0.6, 3 cm relaxation length 0.4 [20]. The reported exposure rates in the selected settlements are as listed in Table 9. The last column, comparing these values with those expected for a surface distribution, seems to verify that the 3 cm relaxation length is now appropriate.

Dose factors for estimating absorbed dose rates in air and effective dose equivalents for specific time periods can be derived from basic principles (see e.g. Refs [6, 16]). The values for the important radionuclides released in the Chernobyl accident are given in Table 10. In the UNSCEAR methodology the depth distributions have been taken to be 1 cm relaxation length in the first year and 3 cm thereafter. The values are derived for the periods 0–4 and 4–70 years.

These factors can be combined into a single transfer factor relative to ^{137}Cs deposition by using the commonly observed ratios to ^{137}Cs of radionuclides in

TABLE 9. Exposure Rates in the Selected Settlements in the Years 1989–1990 *[1 R = 258 μC/kg]*

Settlement	^{137}Cs deposition density (kBq/m^2)	Exposure rate (μR/h)	Normalized exposure rate ratio[a]
Bragin	1000	150[b]	0.38
Korma	670		
Veprin	1200	170[b]	0.35
Narodichi	630		
Polesskoe	910	150	0.41
Novozybkov	600	94	0.39
Zlynka	990	185[b]	0.47

[a] Normalized exposure rate (μR/h per kBq/m^2) relative to normalized exposure rate for a plane source (0.4 μR/h per kBq/m^2).
[b] Estimated from 1987 values.

TABLE 10. Derivation of Transfer Factors to Estimate Outdoor External Doses from All Radionuclides Based on ^{137}Cs Deposition

Radionuclide	Dose factor (μSv per kBq/m^2)		Initial deposition density relative to ^{137}Cs	Transfer factor relative to ^{137}Cs deposition (μSv per kBq/m^2)	
	0–4 years	4–70 years		0–4 years	4–70 years
Short lived				15[a]	
Ru-103	0.69		1.6	1.1	
Ru-106	3.7		0.5	1.9	
I-131	0.02		6.2	0.1	
Cs-134	43	13	0.5	22	6.6
Cs-137	23	190	1.0	26	190
Total (rounded)				66	200

[a] From Ref. [6].

TABLE 11. Estimates of Total External Dose Based on the Deposition Density of ^{137}Cs

Settlement	Deposition density of ^{137}Cs (kBq/m²)	External dose (mSv)		
		0–4 years	4–70 years	Total (rounded)
Bragin	1000	26	80	110
Korma	670	18	54	72
Veprin	1200	32	96	130
Narodichi	630	17	50	67
Polesskoe	910	24	73	97
Novozybkov	600	16	48	64
Zlynka	990	26	79	110

TABLE 12. Comparison of Estimates of External Doses per Unit Deposition Density of ^{137}Cs

Model	Occupancy shielding factor	Normalized effective dose (μSv per kBq/m²)		
		0–4 years	4–70 years	Total (rounded)
GSF	0.33	10	51	61
Mol	0.53	27	140	170
NRPB	0.51	21	59	80
UNSCEAR	0.4	26	80	110

deposition following the Chernobyl accident [6]. An additional contribution from short lived radionuclides (half-lives less than 30 days) is made in the initial period following deposition, and this has been added.

It is necessary to account for indoor occupancy and building shielding in the external dose calculations. These have been derived empirically in the USSR using thermoluminescent dosimeters (TLDs) with various population groups. The values range from 0.36 to 0.86, with the lowest values for children and the general population and the highest values for field and forest workers. Additional information seems to indicate that these factors are about the same as usually assumed in the UNSCEAR methodology [19], namely indoor occupancy of 80% and building shielding of 20%. These combine into an occupancy shielding factor as follows: outdoor 0.2×1.0, indoor 0.8×0.2, total 0.36. In the calculations below, a rounded value of 0.4 is taken for this factor.

Therefore, the transfer factors from ^{137}Cs deposition density to effective dose equivalent are:

0–4 years: 66 μSv per kBq/m² $\times$ 0.4
= 26 μSv per kBq/m² (0.1 rem per Ci/km²)
4–70 years: 200 μSv per kBq/m² $\times$ 0.4
= 80 μSv per kBq/m² (0.3 rem per Ci/km²).

The application of these transfer factors to the deposition densities of ^{137}Cs in the selected settlements gives the external dose estimates listed in Table 11.

The dose estimates per unit deposition density of ^{137}Cs that have been obtained using the computer codes developed at Mol, GSF, and NRPB are compared in Table 12 with the corresponding values derived from the UNSCEAR methodology. The results from the four methodologies are in fairly good agreement.

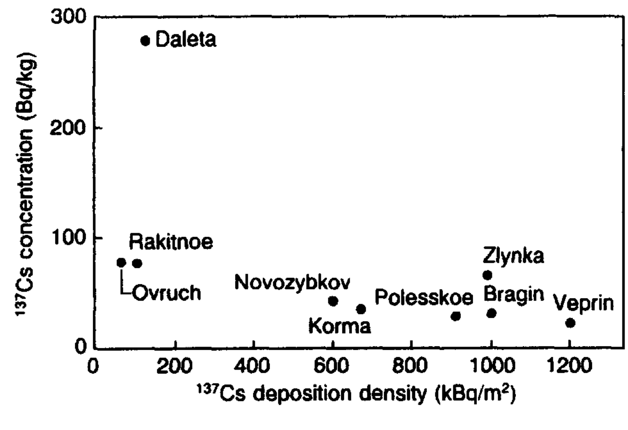


FIG. 5. Caesium-137 in the body, determined in measurements by the international team in 1990.

5.2. Internal Dose

5.2.1. Caesium-137

Primary reliance on whole body measurements is appropriate for the estimation of past internal doses. Estimates based on environmental transfer often lead to overestimation, especially if food substitutions have taken place and are likely to continue.

Results of body measurements of ^{137}Cs in 1990 are given in Table 3-4 of Annex 3. The median values are illustrated in Fig. 5. Measurements in earlier years were made only by Soviet scientists, who reported the ^{137}Cs levels in the body to be in the proportions 6:2:1.4:1 in 1986, 1987, 1988 and 1989. With the assumption that the 1989 and 1990 body levels are little different, the concentrations of ^{137}Cs in the body in the first 5 years after the accident have been estimated. These are listed in Table 13.

The effective dose equivalent per unit time integrated ^{137}Cs concentration in the body is 2.5 μSv per Bq·a/kg [6]. The dose factor for ^{134}Cs is higher by a factor of 1.4. It may be assumed that ^{134}Cs is maintained in the body at a ratio equal to that in environmental occurrence, which was 0.5 in 1986. From radioactive decay differences, the ratios in subsequent years are 0.37 in 1987, 0.27 in 1988, 0.19 in 1989, and 0.14 in 1990. Thus, the dose factors, accounting also for ^{134}Cs, for 1 Bq/kg of ^{137}Cs maintained in the body for the year are: 3.2 μSv in 1986 (May to December), 3.8 μSv in 1987, 3.4 μSv in 1988 and 3.2 μSv in 1989. For the subsequent period 1990–2056, the dose factor, based on the 1990 level of ^{137}Cs in the body and assuming levels in further years are reduced only by radioactive decay of ^{137}Cs and ^{134}Cs, is 86 μSv per Bq/kg. The resulting ^{137}Cs internal dose estimates are given in Table 14.

For comparison, the internal doses estimated from environmental transfer of ^{137}Cs may be derived. Dietary intake of ^{137}Cs in Bragin, BSSR, was estimated in Table 7 to be of the order 200–550 Bq/d (5 to 15 nCi/d) during 1989–1990. Continued intake at these same rates would lead to equilibrium body burdens of 26–78 kBq (0.7–2.1 μCi). This would appear to lead to an overestimate by a factor of 10 or more compared with the body measurements of 1990 (Table 13), which correspond to body burdens of 1.7–4.7 kBq in the 70 kg body. As is usually the case, estimated dietary intake based on concentrations in local foods will exceed and, in some cases, greatly exceed the actual intake.

Estimates of the internal dose over longer time periods may be made by applying dose coefficients to the deposition densities of ^{137}Cs. Such coefficients, or transfer factors from deposition to dose, were derived

TABLE 13. Concentrations of ^{137}Cs in the Body Based on Project Whole Body Measurements in 1990[a]

	^{137}Cs concentration in the body (Bq/kg)				
Settlement	1986	1987	1988	1989	1990
Bragin	190	64	45	32	32
Korma	220	73	51	36	36
Veprin	150	48	34	24	24
Polesskoe	180	60	42	30	30
Novozybkov	260	87	61	43	43
Zlynka	400	130	94	67	67

[a] Measurements were made in 1990 by the international team; the median results are listed. Values in earlier years were reconstructed based on the ratio 6:2:1.4:1:1 for 1986, 1987, 1988, 1989 and 1990, respectively.

TABLE 14. Estimates of Internal Dose Based on Project Body Measurements[a]

Settlement	Internal dose (mSv) 1986–1989	1990–2056	Total (rounded)
Bragin	1.1	2.8	3.9
Korma	1.3	3.1	4.4
Veprin	0.8	2.1	2.8
Polesskoe	1.0	2.6	3.6
Novozybkov	1.5	3.7	5.2
Zlynka	2.3	5.8	8.1

[a] Measurements made in 1990 by the international team were used to reconstruct doses for the years 1986–1989 and to project doses for the years 1990–2056. The dose estimates account for the presence in the body of both ^{134}Cs and ^{137}Cs.

TABLE 15. Estimates of Internal Dose from ^{134}Cs and ^{137}Cs Based on Environmental Transfer through the Food-Chain[a]

Settlement	^{137}Cs deposition density (kBq/m^2)	Internal dose (mSv) 0–4 years	4–70 years	Total	Overestimate[b]
Bragin	1000	54	22	76	20
Korma	670	36	15	51	10
Veprin	1200	65	26	91	30
Narodichi	630	34	14	48	
Polesskoe	910	49	20	69	20
Novozybkov	600	32	13	45	9
Zlynka	990	53	22	75	9

[a] The estimates are obtained from use of dose coefficients derived by UNSCEAR for assessment of doses to the population of the northern hemisphere.

[b] Relative to internal dose derived from body measurements.

in the UNSCEAR assessment of exposures from the Chernobyl accident for populations of the northern hemisphere [6]. These included contributions to dose from ^{134}Cs, ^{137}Cs and ^{131}I in the first year after the accident, and ^{134}Cs and ^{137}Cs subsequently. The projected behaviour of ^{137}Cs in the environment was based on global fallout measurement experience. The dose coefficients for the temperate region of the hemisphere are 44 μSv per kBq/m^2 (0.16 rem per Ci/km^2) in the first year and 32 μSv per kBq/m^2 (0.12 rem per Ci/km^2) in all subsequent years. The latter value is composed of contributions from ^{137}Cs and ^{134}Cs of 20 and 12 μSv per kBq/m^2, respectively. Based on radioactive decay considerations, it may be estimated that some 8% of ^{137}Cs transfer and 64% of ^{134}Cs transfer takes place during the second, third and fourth years following deposition. The actual transfers are probably somewhat greater during this period and somewhat less subsequently due to migration of caesium in soil and fixation. However, with this apportionment, the longer term transfer will not be underestimated. The required dose coefficients are, thus, 54 μSv per kBq/m^2 (0.2 rem per Ci/km^2) for the period 0–4 years and 22 μSv per kBq/m^2 (0.08 rem per Ci/km^2) in years 4–70.

The estimates of internal dose based on environmental transfer from use of these dose coefficients are listed in Table 15. These estimates of dose are 9 to 30 times

TABLE 16. Comparison of Estimates of Projected Internal Doses from Radiocaesium per Unit Deposition Density of ^{137}Cs

Model	Normalized effective dose for 4–70 years (μSv per kBq/m^2)
GSF	25
Mol	54
NRPB	4
UNSCEAR	22

higher than those derived from the whole body measurements. The differences reflect the effect of food restrictions.

In Table 16, the dose estimates per unit deposition density of ^{137}Cs that are obtained using the computer codes developed at Mol, GSF, and NRPB are compared with the values derived from the UNSCEAR methodology; the dose estimates correspond to the time period 1990–2056, and it is assumed in these calculations that there are no food restrictions. The range of estimated normalized future doses is from 4 to 54 μSv per kBq/m^2, the UNSCEAR value being close to the geometric mean of the four values.

Data on the transfer of caesium from specific soil types to various crops were provided by the Institute of Agricultural Radiology in Obninsk. These data showed large variability but were in the general range of values normally used in the GSF model. The usual parameters were thus used in the GSF calculations.

The projected doses in the NRPB calculations take account of fixation of caesium in soil as appropriate in European countries. It was not possible to adjust these calculations for more site specific factors. This largely accounts for the low NRPB estimate of the projected dose from ^{137}Cs in foods compared to the other calculations. If the NRPB estimate is omitted, the range of the independent estimates is small, from 22 to 54 μSv per kBq/m^2.

5.2.2. Strontium-90

No data are available to enable good estimation of internal doses from ^{90}Sr reflecting local conditions in the contaminated areas. It is, therefore, only possible to obtain approximate estimates of doses by applying generalized transfer factors as derived by UNSCEAR, to measured ^{90}Sr deposition. The transfer factors have been derived from measurements of global fallout [19]. Average values of the transfer factors are as follows:

Deposition to diet:	4 Bq·a/kg per kBq/m^2
Diet to bone:	38 Bq·a/kg per Bq·a/kg
Bone to dose:	
— bone marrow:	1.9 μGy per Bq·a/kg
— bone lining cells:	4.2 μGy per Bq·a/kg

The sequential product of these factors gives the transfer factors from deposition to absorbed dose and, applying the tissue weighing factors 0.12 for bone marrow and 0.03 for bone-lining cells, from deposition to effective dose equivalent:

Deposition to absorbed dose:	
— bone marrow:	290 μGy per kBq/m^2
— bone-lining cells:	640 μGy per kBq/m^2
Deposition to effective dose:	54 μSv per kBq/m^2

TABLE 17. Estimates of Internal Dose from ^{90}Sr Based on Environmental Transfer through the Food-Chain[a]

Settlement	^{90}Sr deposition density (kBq/m^2)	Internal dose		
		Bone marrow (mGy)	Bone lining cells (mGy)	Effective dose (mSv)
Bragin	78	23	50	4.2
Korma	7.4	2.1	4.7	0.4
Veprin	21	6.1	13	1.1
Narodichi	34	9.8	22	1.8
Polesskoe	48	14	31	2.6
Novozybkov	9.3	2.7	5.9	0.5
Zlynka	26	7.5	17	1.4

[a] The estimates are obtained from use of dose coefficients derived by UNSCEAR from measurements of global fallout.

TABLE 18. Comparison of Estimates of Internal Doses from ^{90}Sr per Unit Deposition Density of ^{90}Sr

	Normalized effective dose (μSv per kBq/m^2)		
	0–4 years	4–70 years	Total (rounded)
GSF[a]	95	100	190
GSF[b]	59	100	160
Mol	54	220	270
NRPB[c]	32	110	140
NRPB[d]	100	110	210
UNSCEAR	32	22	54

[a] Deposition: one third dry, two thirds wet.
[b] Deposition: 5% dry, 95% wet.
[c] With food ban.
[d] Without food ban.

TABLE 19. Estimates of ^{131}I Levels in Deposition and Outdoor Air Based on Reported Average $^{131}I/^{137}Cs$ Ratios in the UkrSSR, the BSSR and the RSFSR

Settlement	Ratio of ^{131}I to ^{137}Cs		Deposition density (kBq/m^2)		Integrated concentration in air (Bq d/m^3)	
	Deposition	In air	^{137}Cs	^{131}I	^{137}Cs	^{131}I
Bragin	15	9.1	1 000	15 000	1 500	14 000
Korma	15	9.1	670	10 000	1 000	9 100
Veprin	15	9.1	1 200	18 000	1 800	16 000
Narodichi	33	7.6	630	21 000	950	7 200
Polesskoe	33	7.6	910	30 000	1 400	10 000
Novozybkov	16	8.7	600	9 600	900	7 800
Zlynka	16	8.7	990	16 000	1 500	13 000

Application of these values of the transfer factors to the reported ^{90}Sr deposition densities in the selected settlements gives the estimates of internal dose from ^{90}Sr as shown in Table 17.

In Table 18, the dose estimates per unit deposition density of ^{90}Sr that are obtained using the computer codes developed at GSF, Mol and at NRPB are compared with the values derived from the UNSCEAR methodology. The range of estimated normalized future doses is from 54 to 270 μSv per kBq/m^2, the UNSCEAR value being the lowest. The estimate derived by UNSCEAR, based on extrapolation of available measurements of ^{90}Sr in global fallout, shows much less longer term transfer than the other models. There is no immediate way to suggest the uncertainty in the estimated doses from ^{90}Sr.

5.3. Thyroid Dose from Iodine-131

Data are unavailable to estimate doses to the thyroid from direct measurements of ^{131}I in thyroid gland or to derive doses from environmental measurements of ^{131}I. Therefore, some approximate estimates of dose can be made only from certain values of the ratios of ^{131}I to ^{137}Cs in deposition and in air. The median value of this ratio in deposition from measurements in all countries of Europe and elsewhere following the Chernobyl accident was 6.2 [6]; however, higher values were reported to apply to the BSSR, the RSFSR and the UkrSSR, namely 15, 16 and 33, respectively [6]. These latter values were applied to the ^{137}Cs deposition densities in the selected settlements to derive the estimates of the deposition densities of ^{131}I listed in Table 19.

TABLE 20. Estimates of ^{131}I in Milk and Leafy Vegetables Based on Reported Average Values of Transfer from Deposition to Milk and Leafy Vegetables in Central Europe

Settlement	^{131}I deposition density (kBq/m^2)	^{131}I integrated concentration (Bq·a/kg)[a]	
		Milk	Leafy vegetables
Bragin	15 000	1 500	6 000
Korma	10 000	1 000	4 000
Veprin	18 000	1 800	7 200
Narodichi	21 000	2 100	8 400
Polesskoe	30 000	3 000	1 200
Novozybkov	9 600	960	3 800
Zlynka	16 000	1 600	6 400

[a] Estimated using transfer factor values appropriate to central Europe at the time of the Chernobyl accident: 0.1 Bq·a/kg per kBq/m^2 for milk and 0.4 Bq·a/kg per kBq/m^2 for leafy vegetables.

TABLE 21. Transfer Factors to Estimate Thyroid Dose from ^{131}I Based on ^{137}Cs Deposition Density[a]

Region	Transfer factor (μGy per kBq/m^2)					
	Inhalation pathway			Ingestion pathway		
	Infants	Children	Adults	Infants	Children	Adults
BSSR	50	62	36	1200	950	270
RSFSR	48	60	34	1300	1000	290
UkrSSR	42	52	30	2600	2100	590

[a] Based on UNSCEAR methodology.

TABLE 22. Estimated Absorbed Dose to Thyroid from ^{131}I [a]

Settlement	Absorbed dose to thyroid (mGy)								
	Inhalation pathway			Ingestion pathway			Total (rounded)		
	Infants	Children	Adults	Infants	Children	Adults	Infants	Children	Adults
Bragin	50	60	40	1200	950	270	1200	1000	310
Korma	30	40	20	800	630	180	830	670	200
Veprin	60	70	40	1400	1100	320	1500	1200	360
Narodichi	30	30	20	1600	1300	370	1700	1300	390
Polesskoe	40	50	30	2400	1900	540	2400	1900	570
Novozybkov	30	40	20	760	600	170	790	640	190
Zlynka	50	60	30	1300	1000	290	1300	1100	320

[a] Based on UNSCEAR methodology, using the transfer factors given in Table 21.

The relationship between the integrated concentration of ^{137}Cs in outdoor air and the deposition density may be quite variable, depending mainly upon rainfall at the time of cloud passage. A representative value for the USSR of the quotient of integrated concentration of ^{137}Cs in outdoor air to the deposition density of ^{137}Cs has been reported to be 1.5 Bq·d/m^3 per kBq/m^2 [6]. The inferred integrated concentrations of ^{137}Cs in air in the selected settlements are listed in Table 19. The ratios of ^{131}I to ^{137}Cs concentrations in air have been reported for the BSSR, the RSFSR and the UkrSSR [6]. These ratios and the inferred values of integrated concentrations of ^{131}I in air are given in Table 19.

Average values of the relationship between ^{131}I deposition and the occurrence of ^{131}I in milk and leafy vegetables have been reported for larger regions of the USSR [6]. These values (0.03, 0.04, 0.06 Bq·a/kg in milk per kBq/m^2 and 0.01, 0.02, 0.09 Bq·a/kg in leafy vegetables per kBq/m^2 in the RSFSR, BSSR and UkrSSR, respectively) correspond to values where winter agricultural conditions prevailed with cows not yet on pasture, as experienced in northern Europe. More common values for countries of central Europe at the time of the Chernobyl accident were 0.1 Bq·a/kg in milk per kBq/m^2 and 0.4 Bq·a/kg in leafy vegetables per kBq/m^2 in deposition [6]. Assuming that these latter values would also have applied in the selected settlements, the estimates of integrated concentrations of ^{131}I in milk and leafy vegetables listed in Table 20 have been derived.

Estimates of thyroid doses have been made for infants (1 year old), children (5 years old) and adults in each of the selected settlements. Breathing rates have been assumed to be 3.8, 8 and 22 m^3/d; milk consumption 200, 260 and 260 L/a; and leafy vegetable consumption 5, 10, and 37 kg/a for infants, children and adults, respectively. The concentrations of ^{131}I in air indoors have been assumed to be less than outdoors by a factor of 0.3 [6]. The indoor occupancy factor of 0.8 has been used. The absorbed dose to the thyroid per unit intake of ^{131}I for infant, child and adult via inhalation has been taken to be 2.2, 1.3 and 0.27 μGy/Bq and via ingestion 3.6, 2.1 and 0.44 μGy/Bq respectively [9]. With these assumptions, transfer factors from ^{137}Cs deposition to thyroid dose from ^{131}I can be derived. These parameters are listed in Table 21. The differences in the transfer are due to differing reported ratios of ^{131}I to ^{137}Cs in air and deposition in the three regions.

The estimated thyroid doses in each of the selected settlements are listed in Table 22. The values are highest for infants and lower for children and adults. For these estimates of thyroid dose from ^{131}I, it is assumed that no protective measures were taken and that locally produced foods were consumed.

5.4. Total Dose

The total dose to residents of the selected settlements is summarized in Table 23. The projected doses from ^{137}Cs (4–70 years) are the estimates derived from environmental transfer. This would assume no further controls on foods and may overestimate doses. The projections pertain to general soil conditions rather than areas where high soil transfers may take place. This may compensate for the above possible overestimate, but substantial uncertainty remains.

TABLE 23. Summary of Estimated Total Doses from the Project Assessment for the Selected Settlements

Settlement	External dose (mSv)		Internal dose (mSv)[a]			Total (rounded) (mSv)
			^{137}Cs		^{90}Sr	
	0–4 years	4–70 years	0–4 years	4–70 years	0–70 years	
Bragin	26	79	1.1	22	4	130
Korma	18	53	1.3	15	0.4	88
Veprin	32	95	0.8	26	1	160
Narodichi	17	50	~1	14	2	84
Polesskoe	24	72	1.0	20	3	120
Novozybkov	16	47	1.5	13	0.5	78
Zlynka	26	78	2.3	22	1	130

[a] Internal doses from ^{137}Cs are estimated from body measurements (0–4 years) and environmental transfer (4–70 years); internal doses from ^{90}Sr are estimated from environmental transfer.

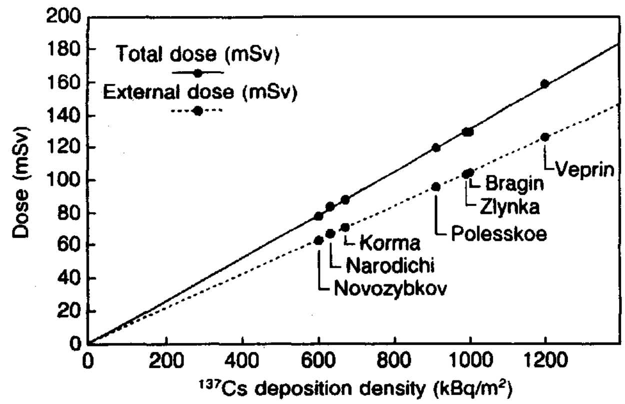


FIG. 6. Lifetime doses from all radionuclides to residents of selected settlements estimated by the international team.

An illustration of the 70-year dose estimates as a function of ^{137}Cs deposition density is given in Fig. 6. The 70-year dose estimates would not be expected to exceed 350 mSv (35 rem) for levels of ^{137}Cs contamination less than 2600 kBq/m^2 (70 Ci/km^2). It must be stressed, however, that these estimates do not take local soil conditions into account.

6. Comparisons of Dose Estimates

A final step in the corroboration of dose estimates is to compare the independently derived values with those reported from Soviet sources. In addition to the doses estimated above in Section 5, a few other values from independent assessments are introduced here.

6.1. External Dose

6.1.1. Calculated External Dose

Estimates of the effective dose equivalent from external irradiation per unit deposition density of ^{137}Cs have been derived in Section 5.1, namely 26 μSv per kBq/m^2 (0.1 rem per Ci/km^2) in the period 0–4 years after deposition and 79 μSv per kBq/m^2 (0.3 rem per Ci/km^2) in the period 4–70 years. The corresponding values from the Soviet official methodology are 43 to 70 μSv per kBq/m^2 (0.16 to 0.26 rem per Ci/km^2) in the period 0–4 years after deposition and 86 μSv per kBq/m^2 (0.32 rem per Ci/km^2) 4–70 years after deposition. These were obtained on a different basis (empirically in years 0–4 and based on a two component exponential decrease of the exposure rate due to ^{137}Cs in years 4–70), and yet the agreement with the independent estimates is very good. There may be some justification for the somewhat higher initial doses estimated by the Soviet scientists, if radionuclide composition was different from determinations made at much greater distances. Comparisons of the external dose estimates are presented in Table 24.

6.1.2. Measured External Dose

The external dose measurements conducted as part of the international review project were in nearly all cases below the detection limit of the film badges used. Thus, while the measurement results are consistent with the independent calculations and the Soviet results, no verification is possible.

TABLE 24. Comparison of External Dose Estimates from Project Assessment and Official Values

Settlement	External dose (mSv)						Ratio of official value to project assessment		
	0–4 years		4–70 years		Total (rounded)				
	Project assessment	Official value	Project assessment	Official value	Project assessment	Official value	0–4 years	4–70 years	Total
Bragin	26	70	80	86	110	156	2.7	1.1	1.4
Korma	18	29	54	58	72	87	1.6	1.1	1.2
Veprin	32	53	96	104	130	157	1.7	1.1	1.2
Narodichi	17	44[a]	50	55	67	99	2.6	1.1	1.5
Polesskoe	24	64[a]	73	79	97	143	2.7	1.1	1.5
Novozybkov	16	26[a]	48	52	64	78	1.6	1.1	1.2
Zlynka	26	43[a]	79	86	110	129	1.7	1.1	1.3

[a] Estimated according to the official methodology.

6.2. Internal Dose

6.2.1. Caesium-137 Dose from Environmental Transfer

Estimates of internal doses from ^{137}Cs can be made from available results of ^{137}Cs measurements in deposition, milk and diet. It is necessary, however, to account for variable transfers of ^{137}Cs to milk or diet in the various areas and to assess accurately the consumption rates and concentration in foods actually consumed. Because of these difficulties and the usual overestimation of doses, whole body measurements are used preferably to estimate past and present doses, and environmental transfer methods are used only to calculate projected doses. A short discussion on the variability of soil-plant transfer factors is presented in Annex 5.

6.2.1.1. Caesium-137 in Milk

The average activity concentrations of ^{137}Cs in milk produced in 1989, derived from measurements of ^{137}Cs and ^{134}Cs, are compared in Table 25 with ^{137}Cs concentrations predicted for the same year by the model ECOSYS [21] assuming that two-thirds of the deposition occurred with 5 mm rainfall and one-third via dry processes. The agreement between the two values is within a factor of two for four settlements (Veprin, Narodichi, Polesskoe and Novozybkov) and within a factor of 5 for three settlements (Bragin, Korma and Zlynka). The results obtained by the model are almost always higher than the measured values. This may be partly due to the effect of agricultural countermeasures. The wide range of measured ^{137}Cs concentrations in some of the settlements tends to indicate that milk is obtained from various sources, and may reflect a large variability in ^{137}Cs deposition and in agricultural practices.

It should be noted that, in controlled areas, the ^{137}Cs concentration in milk sold in shops is expected to be lower than that in the milk produced. For example, the average ^{137}Cs concentration in milk produced in ten farms of the Novozybkov region was 150 Bq/L in 1989, while the average concentration in the milk delivered to shops was only 60 Bq/L (see data listing of Annex 2).

6.2.1.2. Caesium-137 in Diet

Estimates of ^{137}Cs in diet for Bragin, BSSR are listed in Table 7. Assuming various alternative concentrations of ^{137}Cs in foods, the estimated dietary intakes were 550, 310 and 200 Bq/d (15, 8.4 and 5.5 nCi/d). The official methodology takes into account only the measured ^{137}Cs concentrations in milk (value in nCi/kg $\times$ 0.9 nCi/d per nCi/kg) plus a constant intake from other foods (5.4 nCi/d). This is Eq. (26) in Section 2.2.1.3. The results of this approximation for the intake of ^{137}Cs in food are 440, 330 and 220 Bq/d (12, 9 and 6 nCi/d) for alternatives 1, 2 and 3, respectively. These estimates are in good agreement with those derived in Table 7 from the more complete diet analysis.

6.2.1.3. Projected Dose

The comparisons of projected internal doses from caesium based on estimation of environmental transfer

TABLE 25. Comparison of Estimated ^{137}Cs Concentrations in Milk with Reported 1989 Official Values

Settlement	^{137}Cs deposition density (kBq/m^2)	^{137}Cs concentration in milk (Bq/L)		Ratio of official value to project assessment
		Project assessment[a]	Official value	
Bragin	1000	820	170 (140-310)	0.2
Korma	670	530	150 (70-590)	0.3
Veprin	1200	1200	1000 (470-1400)	0.8
Narodichi	630	500	790 (200-1400)[b]	1.5
Polesskoe	910	730	460 (30-2200)	0.6
Novozybkov	600	470	410 (<600-2200)	0.9
Zlynka	990	990	350 (180-2200)	0.4

[a] Based on the transfer model ECOSYS.

[b] These values were stated by Soviet scientists in March 1991 to be incorrect.

TABLE 26. Comparison of Estimates of Internal Doses from ^{137}Cs for the Period 1990–2056 Based on Environmental Transfer through the Food-Chain

Settlement	Internal dose (mSv)		Ratio of official value to project assessment
	Project assessment	Official value	
Bragin	22	60	3
Korma	15	48	3
Veprin	26	180	7
Narodichi	14	~220[a]	20
Polesskoe	20	220	10
Novozybkov	13	57	4
Zlynka	22	85	4

[a] The initial value (555 mSv) was stated by Soviet scientists in March 1991 to be incorrect. The correct value is approximately the same as for nearby Polesskoe.

TABLE 27. Comparison of Estimated ^{137}Cs Contents in the Body with Official Values

Settlement	^{137}Cs contents in the body (kBq)							
	1986		1987		1988		1989	
	Project assessment[a]	Official value	Project assessment[a]	Official value	Project assessment[a]	Official value	Project assessment[a]	Official value
Bragin	13	15	4.2	11	2.9	1.1	2.1	0.7
Korma	14		4.6		3.2		2.3	
Veprin	9		3.0		2.1		1.5	
Narodichi				7.4				26
Polesskoe	13		4.4	7.4	3.1	30	2.2	7.4
Novozybkov	18	74	6.0	15	4.2	15	3.0	7.4
Zlynka	24	81	8.0	41	5.6	26	4.0	

[a] Estimates based on measurements made in 1990. The median value (Annex 2) has been taken to apply also for 1989. The estimates in earlier years were reconstructed based on the ratio 6:2:1.4:1 for 1986, 1987, 1988 and 1989, respectively.

are given in Table 26. The overestimates of the doses reported by Soviet sources may reflect local conditions and thus be more accurate, especially in areas with known high soil–plant transfer characteristics. The estimates from the independent assessment do not take this into account in use of generalized transfer factors.

6.2.2. Caesium-137 Dose from Whole Body Measurements

The whole body measurements were made by the international review team only in the summer of 1990. From these results estimates of the average body contents in earlier years were derived from the relationship 6:2:1.4:1 reported by Soviet scientists for the years 1986 to 1989, respectively. The comparisons with results reported from Soviet sources are shown in Table 27. It would appear that the reconstructed record would provide reasonable estimates (within a factor of 2 or 3) to be used in dose estimation. Comparisons of the internal doses from ^{137}Cs and ^{134}Cs in the initial period (0–4 years) based on the whole body measurement results are made in Table 28. The doses are relatively low. The values reported from Soviet sources, based on

TABLE 28. Comparison of Estimates of Internal Doses from ^{137}Cs and ^{134}Cs for the Period 1986–1989 Based on Body Measurements

Settlement	Internal dose (mSv)		Ratio of official value to project assessment
	Project assessment	Official value	
Bragin	1.1	14	13
Korma	1.3	9	7
Veprin	0.8	16	20
Narodichi	~1.0	9	9
Polesskoe	1.0	13	13
Novozybkov	1.5	8	5
Zlynka	2.3	13	6

TABLE 29. Comparison of Estimates of Internal Doses from ^{90}Sr

Settlement	Dose to bone marrow (mGy)		Effective dose (mSv)		Ratio of official value to project assessment[a]
	Project assessment	Official value	Project assessment	Official value	
Bragin	23	38	4	—	2
Korma	2	5	0.4	—	3
Veprin	6	19	1	—	3
Narodichi	10	18	2	—	2
Polesskoe	14	24	3	—	2
Novozybkov	3	6	0.5	—	2
Zlynka	8	14	1	—	2

[a] For bone marrow doses only.

TABLE 30. Comparison of Estimates of Absorbed Doses to Thyroid from ^{131}I

Settlement	Absorbed dose (mGy)				Ratio of official value to project assessment	
	Children		Adults			
	Project assessment	Official value	Project assessment	Official value	Children	Adults
Bragin	1000	800	310	250	0.8	0.8
Korma	670	<200	200	<50	<0.3	<0.3
Veprin	1200	250	360	100	0.2	0.3
Narodichi	1300		390			
Polesskoe	1900	3200	570	700	1.7	1.2
Novozybkov	640	400	190	70	0.6	0.4
Zlynka	1100	400	320	70	0.4	0.2

measurements made during 1986–89, should be more valid than values of the independent assessment, which could be based only on measurements performed in 1990.

6.2.3. Strontium-90 Dose from Environmental Transfer

Comparisons of estimated internal doses from ^{90}Sr are given in Table 29. It is first of all noted that the estimates reported from Soviet sources appear to be absorbed doses to red bone marrow. These values are overestimated by about a factor of 2 compared with the independent results obtained by use of generalized transfer factors. The Soviet results may reflect more appropriately the conditions of transfer from local soils.

6.2.4. Thyroid Dose from Iodine-131

Comparisons of the absorbed doses to the thyroid from ^{131}I are given in Table 30. The highest dose from the independent assessment is for children from Polesskoe with an estimated thyroid dose of about 2 Gy. The corresponding estimate from Soviet sources is 3.2 Gy. In all other villages the estimates from Soviet sources are slightly less than the independent estimates. This comparison of thyroid doses is largely dependent on the ratios of ^{131}I to ^{137}Cs in deposition and air. The values used were those reported to be valid for the regions under consideration. Therefore, they should lead to comparable values of doses. It is not possible to verify these ratios, as the measurement results on which they are based are unavailable. The values of the ratios of ^{131}I in milk and leafy vegetables relative to ^{131}I deposition reported for larger regions of the USSR [6] correspond to values obtained elsewhere where pasturing of cows could be avoided or postponed (e.g. Sweden or the Netherlands) or where the growing season for leafy vegetables was not yet far advanced at the time of the accident (e.g. Sweden) [6]. The low transfer in these regions of the USSR may have been partly for these reasons and partly due to countermeasures implemented. It is not known whether measures were taken soon enough to reduce substantially the transfer of ^{131}I to milk and leafy vegetables. At any rate, because of the temperate location of the selected settlements, it seemed most reasonable to apply the transfer factors commonly applicable throughout central Europe. Because of substantial uncertainties in the transfer factors and the lack of any environmental data on ^{131}I in the affected regions, the estimates of the thyroid doses from ^{131}I estimated in the independent assessment are highly uncertain.

The information available on thyroid doses derived from thyroid measurements in the USSR is very limited. For most regions, only mean doses for two or three age categories were supplied to the international review team. For the Bragin region, however, the dose distribution has been reported both for the entire population of the villages of that region that were evacuated on 5 May 1986 and for the entire population of the villages that were not evacuated (Annex 2, Table 2-1). The differences between the thyroid dose distributions are small. For example, for the 0–7 year old children:

- the lowest class of doses is 0–0.3 Gy for evacuated and non-evacuated villages, with about 20% of the population in that category;
- the highest class of thyroid doses is 20–30 Gy for the evacuated villages and 30–40 Gy for the non-evacuated villages, with less than 1% of the population in those categories;
- the mean thyroid dose is 2.1 Gy for the population in the evacuated villages and 1.5 Gy for the population in the non-evacuated villages.

The dose distributions show that the thyroid doses, in the same age group and in the same region, are extremely variable, with a factor greater than 100 between the maximum and the minimum and a factor greater than 10 between the maximum and the mean. In the absence of quantitative information, it is speculative to indicate what the main causes of the variability in the thyroid doses are, but they are likely to be the spatial heterogeneity of ^{131}I deposition, the dietary habits of the population (especially, the origin of milk consumed and the milk consumption rate), and the use of stable iodine tablets.

While the mean doses obtained from thyroid measurements agree fairly well with the mean doses estimated using average values of transfer factors (Table 30), the maximum doses would agree better with alternative values of the transfer coefficients linking ^{131}I deposition to the time integrated concentrations of ^{131}I in milk generally selected in Europe and in the USA for use in environmental models. For example, for Bragin, with an ^{131}I deposition of 15 000 kBq/m^2 (Table 19), a mass interception coefficient of 2 m^2/kg (dry weight), a half-time of residence of ^{131}I on vegetation of 5 days, a consumption rate of pasture by cows of 10 kg/d (dry weight), a diet-to-milk transfer coefficient of 4×10^{-3} L/d, milk consumption rate by 1-year-old children of 0.7 L/d, and a thyroid dose factor of 3.5 μGy/Bq, the thyroid dose is estimated to be 21 Gy (to be compared with the maximum values in the range of 20 to 40 Gy for 0–7 year old children (Annex 2, Table 2-1), derived from thyroid measurements).

6.3. Total Dose

A comparison of total dose estimates from external and internal exposures is presented in Table 31. Except for the uncertainty in the reported dose for Narodichi,

TABLE 31. Summary Comparison of Total Doses

Settlement	Total dose (mSv)		Ratio of official value to project assessment
	Project assessment	Official value	
Bragin	130	270	2
Korma	88	150	2
Veprin	160	370	2
Narodichi	84	~350[a]	~4
Polesskoe	120	400	3
Novozybkov	78	150	2
Zlynka	130	240	2

[a] The initial value (680 mSv) was stated by Soviet scientists in March 1991 to be incorrect. This estimate has been revised with a corrected value for the projected internal dose from ^{137}Cs (Table 26).

TABLE 32. Summary Ranges of Doses to Residents of Selected Settlements Evaluated in the International Review Project

Dose component	Dose (mSv)		
	0–4 years	4–70 years	Total
	Project assessment		
External irradiation	16–32	47–95	63–130
Internal irradiation			
Caesium	0.8–2.3	13–26	15–27
Strontium[a]	0.2–2.4	0.2–1.6	0.4–4
Total	17–35	60–120	78–160
	Official value		
External irradiation	26–70	52–100	78–160
Internal irradiation			
Caesium	8–16	48–220	57–240
Strontium[b]	—	5–38	5–38
Total	34–84	110–330	150–400

[a] Effective dose.

[b] Dose equivalent to red bone marrow.

the total doses reported by Soviet sources and obtained in the independent assessment are in agreement within a factor of 2 to 3. Doses reported by Soviet sources are consistently higher. This corresponds to the stated intention not to underestimate doses, and a degree of conservatism of the order of a factor of 2 seems to be substantiated. It cannot be overemphasized, however, that there is substantial uncertainty in the independent dose estimates. There are also, no doubt, wide variations in individual doses about average values for residents in the evaluated settlements and in the wider affected region.

An overall summary of the results obtained is presented in Table 32. The general impression of the international experts is that the dose evaluations performed by Soviet scientists for individuals exposed to radiation as a result of the Chernobyl accident were made in a reasonable manner. The basic scientific judgements were sound, although many of the empirical approximations and selections of parameters were not well documented. The conservative nature of the dose estimates (i.e. the doses were not underestimated) was demonstrated.

References

[1] BARKHUDAROV, R.M., et al., Methodological Principles for Calculating Levels of External and Internal Exposure of the Populations Living in the Territories Contaminated by Radioactive Materials as a Result of the Chernobyl Accident, Moscow (1986).

[2] AVETISOV, G.M., et al., Methodological Basis for Predicting the Levels of Exposure of the Population Caused by Caesium Radioisotopes for Those Residing Permanently in Areas Contaminated as a Result of the Chernobyl Accident, Moscow (1988).

[3] AVETISOV, G.M., et al., Methodological Principles for Prediction of Levels of Population Exposure to Strontium Radionuclides during Permanent Residence in Areas Contaminated as a Consequence of the Chernobyl Accident, Moscow (1988).

[4] ILYIN, L.A. (Ed.), Guide to the Evaluation of Thyroid Exposure Doses due to Uptake of Radioactive Isotopes of Iodine in the Human Body, Moscow (1988).

[5] KONSTANTINOV, I.E., et al., A Model of the Vertical Migration of Caesium-137 in Soils and Prediction of the Exposure Dose, USSR State Committee on the Use of Atomic Energy, Rep. 79-10 (1979) (in Russian).

[6] UNITED NATIONS, Sources, Effects and Risks of Ionizing Radiation (Report to the General Assembly), Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), E.8IX.7, UN, New York (1988).

[7] MILLER, K.M., et al., Measurements of External Radiation and Radioactivity in Soil and Air in Novozybkov, USSR, Task 2, Mission 5, Team 2. Mission Report to the Task Leader (Oct. 1990).

[8] LIKHTAREV, I.A., KOVGAN, L.N., "Doses of irradiation to the Ukrainian population as a result of the Chernobyl accident", Comparative Assessment of the Environmental Impact of Radionuclides Released During Three Major Nuclear Accidents: Kyshtym, Windscale, Chernobyl (Proc. Conf. Luxembourg 1990), Commission of the European Communities, Luxembourg (1990).

[9] KONSTANTINOV, Yu.O., Institute of Radiation Hygiene, Leningrad, personal communication.

[10] FERSIKOVA, S., Institute of Agricultural Radiology, Gomel, personal communication.

[11] LIKHTAREV, I.A., All-Union Scientific Centre for Radiation Medicine, Kiev, personal communication.

[12] GAVRILIN, Yu.I., et al., Irradiation Levels on the Thyroid of Byelorussian Regions People after the Chernobyl Accident, Rep. Institute of Biophysics of the USSR, Ministry of Health, Moscow (1990).

[13] ZVONOVA, I., Institute of Radiation Hygiene, Leningrad, personal communication.

[14] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Age-dependent Doses to Members of the Public from Intakes of Radionuclides: Part I, ICRP Publication No. 56, Pergamon Press, Oxford and New York (1990).

[15] WILKINS, B.T., BRADLEY, B.J., FULKER, M.J., The influence of different agricultural practices on the transfer of radionuclides from pasture to milk after the Chernobyl accident, Sci. Total Environ. **68** (1988) 161–172.

[16] NATIONAL RADIOLOGICAL PROTECTION BOARD, The Derived Emergency Reference Levels for the Introduction of Countermeasures in Early to Intermediate Phase of Emergencies Involving the Release of Radionuclides to Atmosphere, Rep. NRPB-DL10, HMSO, London (1986).

[17] STATE COMMITTEE ON HYDROMETEOROLOGY, Data on Radioactive Contamination in Settlements of (a) the UkrSSR, (b) the BSSR, (c) the RSFSR by Caesium-137 and Strontium-90, Moscow (1989).

[18] ILYIN, L.A., et al., Radiocontamination patterns and possible health consequences of the accident at the Chernobyl nuclear power station, Radiol. Prot. Bull. **10** (1990) 3–29.

[19] UNITED NATIONS, Ionizing Radiation: Sources and Biological Effects (Report to the General Assembly), Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), E.82.IX.8, UN, New York (1982).

[20] BECK, H.L., Exposure Rate Conversion Factors for Radionuclides Deposited on the Ground, Rep. EML-378, US Department of Energy, New York, NY (1980).

[21] PRÖHL, G., Modellierung der Radionuklidausbreitung in Nahrungsketten nach Deposition von Strontium-90, Caesium-137 and Jod-131 auf landwirtschaftlich genutzte Flächen, GSF Rep. 29/90, Gesellschaft für Strahlen- und Umweltforschung, Munich (Sep. 1990).

Part E

Annex 1

Institutes Visited by the International Team for the Review of the Dose Assessment Methodology

Mission 1

16 July 1990	Ministry of Health of the UkrSSR, Kiev
16 July 1990	Ministry of Health of the USSR, Moscow
17 July 1990	Ministry of Health of the RSFSR, Moscow
17 July 1990	All-Union Scientific Centre for Radiation Medicine, Kiev
18 July 1990	Ukrainian Branch of the All-Union Research Institute of Agricultural Radiology, Kiev
18–19 July 1990	Institute of Biophysics, Moscow
20 July 1990	Institute of Medical Radiology, Obninsk
20 July 1990	All-Union Research Institute of Agricultural Radiology, Obninsk
20 July 1990	Academy of Sciences of the BSSR, Minsk
20 July 1990	Institute of Physics, Minsk
20 July 1990	Institute of Radiobiology, Minsk
21 July 1990	Institute of Radiation Medicine, Minsk
21 July 1990	Institute of Nuclear Power, Minsk
24 July 1990	Gomel Branch of the Institute of Radiation Medicine, Gomel
24 July 1990	Byelorussian Branch of the All-Union Research Institute of Agricultural Radiology, Gomel
17 August 1990	Settlement of Polesskoe
18 August 1990	Institute of Radiobiology, Minsk
21 August 1990	Byelorussian Branch of the All-Union Research Institute of Agricultural Radiology, Gomel
22 August 1990	Novozybkov Branch of the Leningrad Scientific Research Institute of Radiation Hygiene, Novozybkov
23 August 1990	Institute of Radiation Medicine, Gomel
25 July 1990	Novozybkov Branch of the Leningrad Scientific Research Institute of Radiation Hygiene, Novozybkov
25 July 1990	Collective farm, Svyatsk
25 July 1990	Settlement of Zlynka

Mission 2

13 August 1990	Institute of Biophysics, Moscow
14 August 1990	State Committee on Statistics, Moscow
15 August 1990	Institute of Experimental Meteorology, Obninsk
16 August 1990	State Committee on Hydrometeorology, Moscow
17 August 1990	All-Union Scientific Centre for Radiation Medicine, Kiev
17 August 1990	Institute of Radiation Medicine, Minsk

Annex 2

Database and Reported Doses for Selected Settlements

The database available to the international team of experts for the review of the dose estimates and for independent dose evaluations is for three settlements in the BSSR, two in the RSFSR and two in the UkrSSR. Data are given in

Table 2-1 for Bragin, BSSR
Table 2-2 for Korma, BSSR
Table 2-3 for Veprin, BSSR
Table 2-4 for Novozybkov, RSFSR
Table 2-5 for Zlynka, RSFSR
Table 2-6 for Narodichi, UkrSSR
Table 2-7 for Polesskoe, UkrSSR

These data are presented according to the following categories:

Population
Deposition density
Exposure rate
Concentration in foods
Consumption rate
External dose
Internal dose
Total dose
Projected dose
Thyroid dose

Note: 1 R = 258 μC/kg.

TABLE 2-1. Database for Bragin, BSSR

Population

Population group	1986	1987	1988	1989	1990	Ref.
Children	1667			2065		[1]
Total inhabitants	5600	4900		5888		

Deposition density (kBq/m²)

Radionuclide	1986	1987	1988	1989	1990	Ref.
Caesium-137	1700	1000	270 (5–1000) (n = 8)			[1]
				1000 (n = 18)		[2]
				830 (n = 50)		[3]
Strontium-90				78 (n = 9)		[2]

Exposure rate (μR/h)

	1986	1987	1988	1989	1990	Ref.
Measurement	8000 (10 May)	680 (10 May)				[1]

Concentration in foods (Bq/kg)

$^{134+137}Cs$	1986	1987	1988	1989	1990	Ref.
Milk						
Average			440	210		[1]
90th percentile			590			
Range				190–380		
			(n = 7)	(n = 14)		
Milk (Institute of Radiation Medicine, Minsk)						[1]
Average			590	360		
Data from Institute of Agricultural Radiology, Gomel (approximate median values)						[4]
Milk	1600	1500	220	300	260	
Root vegetables	740	630	330	370	370	
Green vegetables	3700	740	370	300	220	
Vegetables/fruit	1100	590	300	220	330	
Berries, mushrooms	2200	1100	1300	2600	1100	
Honey	1300	1900	1500	300	300	
Eggs	1300	190	190	190	300	
Meat	1700	1100	740	260	300	
Fish		1800	740	1500	220	

TABLE 2-1. (cont.)

Consumption rate (g/day)

Food item	Rural settlement	All BSSR	Ref.
Milk	735	690–710	[5]
Bread, white	220	240	
Bread, dark	350	350	
Potatoes	540	680	
Vegetables	190	240	
Fruit, berries	160	150	
Berries		1.5	
Mushrooms	6	7	
Meat	150	180	
Fish	46	60	

Internal dose (mSv)

$^{134+137}Cs$		1986	1987	1988	1989	1990	Ref.
Average	Children	2 (n = 292)	1 (n = 94)	0.2 (n = 203)	0.1 (n = 3)		
	Teenagers	5 (n = 87)	3 (n = 131)	0.2 (n = 731)	0.1 (n = 2)		
	Adults	4 (n = 683)	3 (n = 111)	0.3 (n = 641)	0.2 (n = 131)		
Maximum	Children	15	7				
	Teenagers	22	17				
	Adults	12	8				
90th percentile	Children	10	5				
	Teenagers	13	7				
	Adults	8	5				

Data for 1986, 1987: Institute of Biophysics, Moscow; data for 1988, 1989: Institute of Radiation Medicine, Minsk [1]

Projected dose (mSv)

Basis of estimate	1986–1989	1990–2060	Total lifetime	Ref.
1988 data	84	86 (external) 97 (internal Cs-137)	267	[1]
1989 data	84 (total) 70 (external)	86 (external) 60 (internal Cs-137) 38 (internal Sr-90)	268	[1]
Institute of Radiation Medicine, Minsk	84	163	246	[1]

Thyroid dose (mSv)

	1986	1987	1988	1989	1990	Ref.
Children, 0–7 years	800 (n = 207)					[6]
Children, 0–18 years	600 (n = 496)					
Adults	250 (n = 299)					

TABLE 2-1. (cont.)

Dose	Thyroid dose (mSv) (cont.)						Ref.
	Age group						
	0–7 years		0–18 years		Adults		
	Number	%	Number	%	Number	%	
	Settlements evacuated on 5 May 1986 (Bragin region)						
0–300	55	20	159	23	830	34	[6]
300–750	66	24	193	28	750	31	
750–2 000	78	28	186	27	667	27	
2 000–5 000	51	18	109	16	185	7.5	
5 000–10 000	15	5.4	26	3.8	16	0.7	
10 000–20 000	9	3.3	11	1.6	4	0.2	
20 000–30 000	2	0.7	2	0.3	0	0	
Total	276		680		2 452		
Mean dose	2 100		1 500		800		
	Settlements not evacuated (Bragin region)						
0–300	282	24	1 293	37	9 536	64	[6]
300–750	339	28	1 039	30	3 554	24	
750–2 000	331	28	779	22	1 547	10	
2 000–5 000	167	14	299	8.5	329	2.2	
5 000–10 000	55	4.6	66	1.9	30	0.2	
10 000–20 000	15	1.3	20	0.6	3	0.02	
20 000–30 000	3	0.3	3	0.09	0	0	
30 000–40 000	1	0.08	1	0.03	0	0	
Total	1 193		3 500		1 499		
Mean dose	1 500		950		400		

TABLE 2-2. Database for Korma, BSSR

Population

Population group	1986	1987	1988	1989	1990	Ref.
Children				2 980		[1]
Total inhabitants	6 400	6 200		7 201		

Deposition density (kBq/m²)

Radionuclide	1986	1987	1988	1989	1990	Ref.
Caesium-137		700	680 (310–1700) (n = 10)			[1]
				670 (n = 20)		[2]
				680 (2.9–67) (n = 40)		[3]
Strontium-90				7.4		[2]

Exposure rate (μR/h)

	1986	1987	1988	1989	1990	Ref.
Measurement	1000 (10 May)					[1]

Concentration in foods (Bq/kg)

$^{134+137}Cs$	1986	1987	1988	1989	1990	Ref.
Milk						
Average			320	190		[1]
90th percentile			430			
Range				85–740		
			(n = 74)	(n = 74)		
Milk (Institute of Radiation Medicine, Minsk)						
Average			410	250		[1]
Data from Institute of Agricultural Radiology, Gomel (approximate median values)						[4]
Milk	~37 000	1 100	740	300	220	
Root vegetables	1 300	370	300	220		
Green vegetables	~52 000	930		220		
Fruit	2 800	560	560			
Berries		5 900		3 700	740	
Mushrooms	7 400	5 600	740	560		
Meat	~3 700	1 500	1 900	3 000	3 000	
Fish	7 400	7 400	740	560		

TABLE 2–2. (cont.)

Internal dose (mSv)

$^{134+137}Cs$		1986	1987	1988	1989	1990	Ref.
Average	Children		0.5 (n = 63)		0.2 (n = 139)		[1]
	Teenagers		1 (n = 15)		0.2 (n = 847)		
	Adults		2 (n = 87)		0.3 (n = 1667)		
Maximum	Children		4				
	Teenagers		3				
	Adults		4				
90th percentile	Children		1				
	Teenagers		1.5				
	Adults		3				
Data for 1989: Institute of Radiation Medicine, Minsk							[1]

Projected dose (mSv)

Basis of estimate	1986–1989	1990–2060	Total lifetime	Ref.
1988 data	38	58 (external) 57 (internal Cs-137)	152	[1]
1989 data	38 (total) 29 (external)	58 (external) 48 (internal Cs-137) 5 (internal Sr-90)	148	[1]
Institute of Radiation Medicine, Minsk	38	118	156	[1]

Thyroid dose (mSv)

Population group	1986	1987	1988	1989	1990	Ref.
Children, 0–7 years	<200 (n = 22)					[1]
Children, 0–18 years	<100 (n = 50)					
Adults	<50 (n = 140)					

TABLE 2-3. Database for Veprin, BSSR

Population

Population group	1986	1987	1988	1989	1990	Ref.
Children		200				[1]
Total inhabitants	1048	948				

Deposition density (kBq/m²)

Radionuclide	1986	1987	1988	1989	1990	Ref.
Caesium-137	1670	1220	1200 (410–1440) (n = 11)			[1]
				1200 (n = 21)		[2]
				1270 (n = 48)		[3]
Strontium-90				21		[2]

Exposure rate (μR/h)

	1986	1987	1988	1989	1990	Ref.
Measurement	400 (10 May)	250 (10 May)				[1]

Concentration in foods (Bq/kg)

$^{134+137}Cs$	1986	1987	1988	1989	1990	Ref.
Milk						
Average			1300			[1]
90th percentile			1700			
Range			810–1800 (n = 4)			
Milk						
(Institute of Radiation Medicine, Minsk)			1700			[1]
Agroprom			590			

Consumption rate (g/day)

Type of food	Women		Children				Ref.
	Pregnant	Nursing	7–12 months	1–3 years	3–6 years	7–14 years	
Milk	42	345	800	192	331	230	[5]
Milk cheese	3	8	25	40	33	28	
Cream		35		5	4	14	
Eggs	0.1	0.5	0.5	0.2	0.5		
Bread, wheat	133	205	20	76	65	186	
Bread, rye	291	144		41	76	137	
Wheat flour		22		11	27	31	
Macaroni	49	132	60	55	66	76	

TABLE 2-3. (cont.)

Consumption rate (g/day) (cont.)

Type of food	Women		Children				Ref.
	Pregnant	Nursing	7-12 months	1-3 years	3-6 years	7-14 years	
Potatoes	422	462	140	170	225	166	[5]
Green vegetables	160	148	70	119	133	224	
Fruit, fresh	113	2.5	70	82	76	150	
Fruit, dry	3	13		6	7	17	
Sugar	59	92	15	52	50	63	
Meat	50	168	100	83	40	106	
Fish	13.3	38		53	6	57	

Internal dose (mSv)

$^{134+137}Cs$		1986	1987	1988	1989	1990	Ref.
Average	Children	3 (n = 26)	1 (n = 64)		0.2 (n = 5)		
	Teenagers	4 (n = 23)	1 (n = 38)		0.2 (n = 6)		
	Adults	3 (n = 98)	1 (n = 63)		0.3 (n = 32)		
Maximum	Children	47	11				
	Teenagers	122	23				
	Adults	131	15				
90th percentile	Children	15	4				
	Teenagers	25	6				
	Adults	12	5				

Data for 1986, 1987: Institute of Biophysics, Moscow. [1]
Data for 1989: Institute of Radiation Medicine, Minsk. [1]

Projected dose (mSv)

Basis of estimate	1986-1989	1990-2060	Total lifetime	Ref.
1988 data	69	106 (external) 176 (internal Cs-137)	351	[1]
1989 data	69 (total) 53 (external)	104 (external) 176 (internal Cs-137) 19 (internal Sr-90)	369	[1]
Institute of Radiation Medicine, Minsk	68	289	358	[1]

Thyroid dose (mSv)

Population group	1986	1987	1988	1989	1990	Ref.
Children, 0-18 years	250 (n = 200)					[1]
Adults	100 (n = 928)					

TABLE 2-4. Database for Novozybkov, RSFSR

Population

Population group	1986	1987	1988	1989	1990	Ref.
Children	14 600					[1]
Total inhabitants	46 200	46 800	46 400			

Deposition density (kBq/m^2)

Radionuclides	1986	1987	1988	1989	1990	Ref.
Caesium-137	890	630	530 (180–890) (n = 11)			[1]
				600 (n = 15)		[2]
Strontium-90				9.3 (n = 9)		[2]

Exposure rate (μR/h)

Location and exposure factor		1986	1987	1988	1989	1990	Ref.
Outdoors	Average from map				~100		[7]
	Monitoring record				120		
	In forests				300		
Outdoors (undisturbed locations)							
	In town and vicinity					94 ± 30	Task 2
	Within town					76	
	Outdoors, gardens					51 ± 15	
	Outdoors, hard surfaces					26 ± 13	
Indoors	Wood houses					18 ± 5 (n = 50)	Task 2
	Brick, concrete houses						
	Detached houses					14 ± 3	
	Apartment houses					10 ± 2	
	Public buildings					11 ± 6	
Activity ratio							
	Cs-134 to Cs-137					0.15	Task 2
Caesium exposure rate							Task 2
	Cs-137					70%	
	Cs-134					30%	
Background exposure rate							Task 2
	Indoors					7–9 μR/h	
	Outdoors					5–7 μR/h	
Occupancy							[7]
	Indoors 18 h/day						
	Outdoors 6 h/day						
Building shielding							[7]
	Wood houses (75% of residents):	0.5					
	Brick houses (25% of residents):	0.17–0.25					

TABLE 2–4. (cont.)

$^{134+137}Cs$	1986	1987	1988	1989	1990	Ref.
		Concentration in foods (Bq/kg)				
		Data from Novozybkov Laboratory				[8]
Milk from region						
January		1 500–5 600	<370–2 800	<740–1 100	<740–1 100	
February		740–4 800	<370–3 000	<740–2 000	<740–700	
March		370–3 700	<370–3 700	<740–2 800	<740–930	
April		370–7 400	<370–4 800	<740–1 100	<740–2 400	
May	2 200–96 000	740–6 300	<370–2 800	<740–1 200	<740–960	
June	1 100–44 000	590–5 200	<370–7 400	<740–2 200		
July	1 100–56 000	370–11 000	<370–8 500	<740–1 100		
August	2 200–9 600	740–4 100	<370–2 600	<740–1 300		
September	2 200–18 000	370–7 400	<740–1 500	<740–740		
October	370–9 300	370–2 600	<740–1 500	<740–1 900		
November	740–14 000	370–2 600	<740–1 100	<740–740		
December	2 200–5 200	370–5 600	<740–2 400	<740–1 900		
Milk imported		<70 in all periods				
Beef from region						
January		1 900–26 000	1 100–8 900	<70–1 900	<70–1 900	
February		1 100–24 000	1 100–8 900	<70–1 900	<70–1 900	
March		1 100–15 000	740–13 000	<70–1 900	<70–1 900	
April		1 100–13 000	1 100–9 300	<70–1 900	<70–1 900	
May	9 300–115 000	2 600–56 000	1 100–19 000	<70–1 900	<70–1 900	
June	2 200–330 000	2 300–30 000	<70–1 900	<70–1 900		
July	740–190 000	3 000–28 000	<70–1 900	<70–1 900		
August	370–3 000	740–19 000	<70–1 900	<70–1 900		
September	740–3 000	1 100–1 300	<70–1 900	<70–1 900		
October	1 900–44 000	1 900–15 000	<70–1 900	<70–1 900		
November	3 300–44 000	2 200–31 000	<70–1 900	<70–1 900		
December	2 700–31 000	1 500–15 000	<70–1 900	<70–1 900		
Pork from region						
January		370–5 200	<370–2 600	<70–1 100	<70–1 100	
February		370–6 300	370–3 300	<70–1 100	<70–1 100	
March		740–6 300	740–5 200	<70–1 100	<70–1 100	
April		370–8 900	370–4 400	<70–1 100	<70–1 100	
May	<3 700–17 000	1 100–16 000	<370–4 400	<70–1 100		
June	1 500–1 900	370–11 000	<70–1 100	<70–1 100		
July	<370–2 600	1 100–14 000	<70–1 100	<70–1 100		
August	370–2 600	1 500–3 700	<70–1 100	<70–1 100		
September	<370–2 200	1 100–9 300	<70–1 100	<70–1 100		
October	4 400–7 400	3 000–4 800	<70–1 100	<70–1 100		
November	2 200–12 000	370–3 700	<70–1 100	<70–1 100		
December	1 900–14 000	370–7 400	<70–1 100	<70–1 100		

TABLE 2-4. (cont.)

Concentration in foods (Bq/kg) (cont.)

$^{134+137}Cs$	1986	1987	1988	1989	1990	Ref.
Butter	<70-3 700	<70-370	<70-300	<70-190	<70-190	
Cheese	<70-7 400	<70-370	<70-370	<70-220	<70-220	
Potatoes	<70-7 400	<370-2 100	<70-370	<70	<70	
Tomatoes	<370-740	<370-740	<70	<70	<70	
Cucumbers	<70-12 000	370-740	<70-110	<70	<70	
Cabbage	<370-740	<370-1 200	<70-150	<70	<70	
Beets	1 500-7 400	<370-4 800	<40-190	<70	<70	
Greens	370-130 000	<370-3 700	<70-520	<70	<70	
Sorrel	<370-210 000	<370-150 000	190-3 000	<70-740	<70-370	
Berries, forest	2 600-30 000	<370-7 400	370-6 700	370-3 700	<370-3 700	
Berries, garden	1 100-85 000	370-2 200	70-300	<70-150	<70	
Mushrooms	22 000-250 000	370-300 000	370-66 000			
Fish, local	7 400-160 000	25-74 000	370-52 000	150-22 000	110-5 600	
Data from Institute of Agricultural Radiology, Obninsk						[9]
Milk from Novozybkov region						
January			1 500	740	260	
February			1 600	560	150	
March			1 500	560	190	
April			1 900	590	260	
May			440	300	190	
June			1 000	560		
July			890	560		
August			810	780		
September			740	480		
October			480	410		
November			520	410		
December			370	190		
Data from 10 farms in Novozybkov region						[10]
Milk, shops				63		
Milk, produced				150		
Wheat (animal feed)				370		
Cereals			140	89		
Potatoes			96	41		
Vegetables			33	30		
Apples				3.7		
Berries				7.4-37		
Fish				1 400		
Data from shops in Bryansk region						[11]
Milk		33	32	28		
Cheese		74	41	29		
Butter		1 200	78			
Meat, beef		530	200	120		
Meat, pork		270	160	160		
Bread, white		7.0	13	9.3		
Bread, dark		24	10	8.1		

TABLE 2–4. (cont.)

Consumption rate (g/day)

Food item	1986	1987	1988	1989	1990	Ref.
Milk	0.75					[7]
Bread, wheat	0.3					
Bread, rye	0.2					
Potatoes and vegetables	1.0					
Meat	0.1					
Water	2.0					

External dose (mSv)

Basis of estimate	1986	1987	1988	1989	1990	Ref.
Novozybkov Laboratory	7.7	4.5	3.6	3.4		[12]

Internal dose (mSv)

$^{134+137}Cs$	1986	1987	1988	1989	1990	Ref.
Institute of Radiation Hygiene, Leningrad						[1]
Body content (kBq)	74	15	15	7.4		
Annual dose (mSv)	2.6	0.7	0.7	0.7		

Total dose (mSv)

Basis of estimate	1986	1987	1988	1989	1990	Ref.
Novozybkov Laboratory	12	6	3–4	3–4		[1]
Institute of Radiation Hygiene, Leningrad	10.3	5.2	4.3	4.1		

Projected dose (mSv)

Basis of estimate	1986–1989	1990–2060	Total lifetime	Ref.
1988 data	37	54 (external) 35 (internal Cs-137)	126	[1]
1989 data	34	52 (external) 57 (internal Cs-137) 6.3 (internal Sr-90)	149	[1]

Thyroid dose (mSv)

Population group	1986	1987	1988	1989	1990	Ref.
Children, 0–7 years	400					[12]
Children, 7–14 years	200					
Adults	70					

TABLE 2-5. Database for Zlynka, RSFSR

Population

Population group	1986	1987	1988	1989	1990	Ref.
Children	2100	1407				[1]
Total inhabitants	5936	5800	5600			

Deposition density (kBq/m²)

Radionuclide	1986	1987	1988	1989	1990	Ref.
Caesium-137	1010	1070	990 (640–1400) (n = 11)			[1]
				990 (n = 16)		[2]
Strontium-90				26 (n = 5)		[2]

Exposure rate (μR/h)

	1986	1987	1988	1989	1990	Ref.
Measurement		270 (10 May)				[1]

Concentration in foods (Bq/kg)

$^{134+137}Cs$	1986	1987	1988	1989	1990	Ref.
Milk						
Average			440			[1]
90th percentile			3000			
Data from Institute of Agricultural Radiology, Obninsk						[9]
January			1700	410	190	
February			2700	480	150	
March			1600	590	260	
April			1900	440	110	
May			440	330	150	
June			1100	550		
July			740	630		
August			960	550		
September			550	410		
October			440	410		
November			440	370		
December			220	190		

External dose (mSv)

Basis of estimate	1986	1987	1988	1989	1990	Ref.
Institute of Radiation Hygiene, Leningrad	16.2	9.4	7.5	5.5		[12]

TABLE 2-5. (cont.)

Internal dose (mSv)

$^{134+137}Cs$	1986	1987	1988	1989	1990	Ref.
Data from Institute of Radiation Hygiene, Leningrad						
Body content (kBq)	81	41	26	30		[1]
Annual dose (mSv)	3.1	1.3	1.2	1.0		

Total dose (mSv)

Basis of estimate	1986	1987	1988	1989	1990	Ref.
Institute of Radiation Hygiene, Leningrad	19.3	10.7	8.7	6.5		[1]

Projected dose (mSv)

Basis of estimate	1986–1989	1990–2060	Total lifetime	Ref.
1988 data	64	93 (external) 56 (internal Cs-137)	213	[1]
1989 data	56	86 (external) 85 (internal Cs-137) 14 (internal Sr-90)	241	[1]

Thyroid dose (mSv)

Population group	1986	1987	1988	1989	1990	Ref.
Children, 0–7 years	400					[12]
Children, 7–14 years	200					
Adults	70					

TABLE 2–6. Database for Narodichi, UkrSSR

Population

Population group	1986	1987	1988	1989	1990	Ref.
Children				1443		[1]
Total inhabitants				6334		

Deposition density (kBq/m²)

Radionuclides	1986	1987	1988	1989	1990	Ref.
Caesium-137	700	630	620 (410–870) (n = 6)			[1]
				630 (n = 26)		[2]
Strontium-90				34 (n = 6)		[2]

Exposure rate (μR/h)

Measurement	1986	1987	1988	1989	1990	Ref.
Measurement	600 (10 May)					[1]

Concentration in foods (Bq/kg)

Radionuclide	1986	1987	1988	1989	1990	Ref.
Caesium 134+137						
Milk average		1035 ± 684 (n = 120)	1133 ± 962 (n = 120)	988 ± 742 (n = 125)		[13]
Milk (average)					3696 (273–9620) (n = 7)	[1]
Vegetables (average)		115 ± 82 (n = 86)	129 ± 111 (n = 90)			[13]
Strontium-90						
Milk (average)		2.0 (n = 22)	9.5 (n = 12)			[13]
Vegetables (average)		1.7 (n = 18)	3.8 (n = 2)			

External dose (mSv)

Basis of estimate	1986	1987	1988	1989	1990	Ref.
TLD measurements		2.5 (n = 25)	1.5 (n = 18)	1.3 (n = 50)	1.6 (n = 42)	[14]

TABLE 2-6. (cont.)

Internal dose (mSv)

$^{134+137}Cs$	1986	1987	1988	1989	1990	Ref.
Body content (kBq)						[13]
Children		8.1 (n = 905)		4.1 (n = 350)		
Adults		8.5 (n = 65)		25 (n = 242)		
All		8.1 (n = 970)		13 (n = 592)		
Annual dose (mSv)						
Children		0.58		0.43		[13]
Adults		0.34		0.95		
All		0.56		0.64		
All	3.8	0.6	0.3	0.6		[1]
Dose distribution (%)						
0–1 mSv		87.6		88.5		
1–2 mSv		9.5		7.1		
2–3 mSv		1.3		2.4		
3–4 mSv		0.4		0.7		
4–5 mSv		0.3		0.3		
5–6 mSv		0.3		0.3		
7–8 mSv		0.1		0.2		
8–9 mSv		0.1		0.3		
> 10 mSv		0.3 (n = 970)		0.2 (n = 592)		

Total dose (mSv)

Basis of estimate	1986	1987	1988	1989	1990	Ref.
All-Union Scientific Centre for Radiation Medicine, Kiev	11.4	7.0	6.8	3.4		[1]

Projected dose (mSv)

Basis of estimate	1986–1989	1990–2060	Total lifetime	Ref.
1988 data	53	54 (external) 173 (internal Cs-137)	280	[1]
1989 data	53	55 (external) 555 (internal Cs-137) 18 (internal Sr-90)	681	[1]
All-Union Scientific Centre for Radiation Medicine, Kiev	29	198	226	[1]

TABLE 2-7. Database for Polesskoe, UkrSSR

Population						
Population group	1986	1987	1988	1989	1990	Ref.
Children	4 719			3 022		[1]
Total inhabitants	12 890			11 800		

Deposition density (kBq/m^2)						
Radionuclide	1986	1987	1988	1989	1990	Ref.
Caesium-137	1 080 (n = 83)	930 (n = 226)	770 (n = 49)	1 290 (n = 306)		[1]
				910 (n = 84)		[2]
Strontium-90				48 (n = 11)		[2]

Exposure rate ($\mu R/h$)						
Measurement or factor	1986	1987	1988	1989	1990	Ref.
Measurement	2 600 (10 May)			150 ± 20 (<60–300)		[1, 15]
Occupancy/shielding factor						[16]
Children	0.36					
Farm machinists	0.67					
Field workers	0.51					
Forest workers	0.86					
Other population	0.37					
Shielding reduction						[16]
Wood houses	2.0–2.5					
Wood with brick	3.0–4.5					
Brick houses	5.0–10					

Concentration in foods (Bq/kg)						
Radionuclide and food	1986	1987	1988	1989	1990	Ref.
Caesium-134+137						
Milk 22 February				390		[13]
22 February				560		
6 March				320		
21 March				280		
21 March				2 800		
28 March				41		
4 April				150		
7 April				37		
17 April				1 920		
17 April				1 140		
24 April				37		
3 May				440		
13 May				700		

TABLE 2-7. (cont.)

Concentration in foods (cont.)

Radionuclide and food	1986	1987	1988	1989	1990	Ref.
Caesium-134+137						
Milk 13 May				810		[13]
30 June				130		
20 July				740		
20 July				570		
Average				570 (n = 7)		[1]
Minimum				130		
Maximum				810		
Strontium-90						[13]
Milk (average)		2.6 (n = 9)	3.9 (n = 7)	2.8 (n = 11)		
Vegetables (average)			6.9 (n = 3)			

Consumption rate (g/day)

Type of food	Workers	Farmers	Ref.
Milk	105–112	243–256	[17]
Milk products	364–441	342–439	
Sweet cheese	6	5–7	
Potatoes	94–141	215–258	
Vegetables	68–103	105–113	
Meat	58–62	68–69	
Fish	14–16	15	
Bread products	97–105	139–161	
Fruit	31–41	32–33	
Mushrooms, fresh	0.3–0.6	0.1–0.3	
Mushrooms, dry	0.02–0.1	0.01–0.02	

External dose (mSv)

Basis of estimate	1986	1987	1988	1989	1986–1989	Ref.
Average						
Children	12	3.2	2.4	1.6	19	[15]
Adults	22	5.5	4.0	2.5	34	
All	19	5.0	3.2	2.3	30	
90th percentile						
Children	20	5	4	3	32	[15]
Adults	28	7	6	5	46	

	1987	1988	1989	1990	Ref.
TLD measurements	3.9 (n = 194)	4.7 (n = 10)	2.1 (n = 93)	2.8 (n = 150)	[14]

TABLE 2-7. (cont.)

Internal dose (mSv)

$^{134+137}Cs$	1986	1987	1988	1989	1990	Ref.
Body content (kBq)						[13]
Children		5.6 (n = 1360)	3.0 (n = 28)	3.3 (n = 919)		
Adults		6.7 (n = 122)	31 (n = 109)	8.1 (n = 1440)		
All		5.9 (n = 1482)	25 (n = 137)	5.9 (n = 2359)		
Annual dose (mSv)						
Children		0.44	0.36	0.35		[13]
Adults		0.26	1.17	0.29		
All	5.2	0.43	1.01	0.31		
Dose distribution (%)						
0–1 mSv		95.8	65.7	95.1		[13]
1–2 mSv		4.0	19.0	3.9		
2–3 mSv		0.1	5.8	0.3		
3–4 mSv		0.1	5.8	0.4		
4–5 mSv			2.9	0.1		
5–6 mSv			0.7			
7–8 mSv				0.1		
>10 mSv				0.1		
		(n = 1482)	(n = 137)	(n = 2359)		

Total dose (mSv)

Basis of estimate	1986	1987	1988	1989	1990	Ref.
All-Union Scientific Centre for Radiation Medicine, Kiev	24	5.4	3.3	2.6		[1]

Projected dose (mSv)

Basis of estimate	1986–1989	1990–2060	Total lifetime	Ref.
1988 data	84	86 (external) 264 (internal Cs-137)	434	[1]
1989 data	77	79 (external) 223 (internal Cs-137) 24 (internal Sr-90)	403	[1]
All-Union Scientific Centre for Radiation Medicine, Kiev	36	303	339	[1]

Thyroid dose (mSv)

Population group	1986	1987	1988	1989	1990	Ref.
Children, 0–7 years	3180 (n = 465)					[1]
Children, 7–14 years	1020 (n = 1033)					
Adults	670 (n = 460)					

Part E

References for Annex 2

[1] Radiation data for settlements from the information system SDACHA. Institute of Biophysics, Ministry of Health, Moscow, 1990.

[2] Data on radioactive contamination in settlements of (a) the UkrSSR, (b) the BSSR, (c) the RSFSR by caesium-137 and strontium-90. State Committee on Hydrometeorology, Moscow, 1989.

[3] Caesium deposition density measurement results for Veprin, Korma, Bragin, Chadiony and Kirovsk. Data from Institute of Radiobiology, Minsk, 1990.

[4] Caesium in foods in Bragin and Korma during 1986–1990. Transfer factors for milk, meat, grass, grain and vegetables for various soil pH in UkrSSR regions. Concentration of caesium and Sr-90 in grass and grain in 1989 in an area with 30 Ci/km^2 of Cs-137 and 1.2 Ci/km^2 of Sr-90. Transfer factors for grain during 1987, 1988 and 1989; caesium and Sr-90 in grain in 1987. Annual dose per unit deposition density for children, pensioners and 21 occupational groups. Data from Institute of Agricultural Radiology, Gomel, 1990.

[5] Consumption data for the regions of Brest and Mogilev and for the entire BSSR. Data from Institute of Biophysics, Moscow, 1990.

[6] Tabulated dose distributions for the populations of the rajons of Khojniki and of Bragin in the BSSR. Data from Institute of Biophysics, Moscow, 1990.

[7] Data from Institute of Radiation Hygiene, Novozybkov, 1990.

[8] Concentration of caesium in foods for Novozybkov region. Data from Laboratory of Radiation Hygiene, Novozybkov, 1990.

[9] Variation with time (1988 to 1990) of the concentration of Cs-137 in milk in each rajon of Bryansk. Data from Institute of Agricultural Radiology, Obninsk, 1990.

[10] Data from collective farm of Svyatsk, Bryansk region, RSFSR, 1990.

[11] Average ^{137}Cs concentrations in food products from 1987 to 1989 in the Bryansk region. Data from Institute of Radiation Hygiene, Novozybkov, 1990.

[12] Dosimetric information for Bryansk region. Data from Institute of Radiation Hygiene, Novozybkov, 1990.

[13] Caesium in milk in Polesskoe during February–July 1989. Caesium in milk and vegetables in Zhitomir and Rovno regions in 1987–1990. Strontium-90 in milk and vegetables in Narodichi, Ovruch and Polesskoe in 1987–1989. Results of measurements of internal doses from caesium in Polesskoe, Ovruch, Daleta, Narodichi in 1987–1989. Data from All-Union Scientific Centre for Radiation Medicine, Kiev, 1990.

[14] Tables and figures of external gamma TLD measurements. Data from All-Union Scientific Centre for Radiation Medicine, Kiev, 1990.

[15] Special report on the radiation situation in Polesskoe in January 1990. Institute of Biophysics, Moscow, 1990.

[16] Occupancy/shielding factors. Data from All-Union Scientific Centre for Radiation Medicine, Kiev, 1990.

[17] Food consumption estimates for workers and farmers of Kiev, Zhitomir, Chernigov and Rovno regions in 1988 and 1989. Data from All-Union Scientific Centre for Radiation Medicine, Kiev.

Annex 3

Independent Measurements of External and Internal Doses in Selected Settlements

As part of the international assessment programme, two projects were implemented by the IAEA to provide independent measurements of the external and internal doses currently received by individuals in selected settlements. Some 12 000 personal dosimeters were used to evaluate the external dose to the population, and approximately 9000 whole body measurements were made.

External Dosimetry

Film badge dosimeters provided by the Service Central de Protection Contre les Rayonnements Ionisants (SCPRI) in France were used in the independent assessment of external doses. Three sets of dosimeters were distributed in the BSSR, the RSFSR and the UkrSSR. The first set of 4000 dosimeters was distributed in seven settlements in May 1990 and collected in July 1990. At the time of collection an additional 4000 dosimeters were distributed. These were collected in October 1990. The third set was distributed in December 1990 and collected in February 1991.

Methodology

The dosimeters were brought to each settlement by members of the International Project, who explained the external dosimetry project to the population. The dosimeters were distributed to individuals selected by the local authorities in each settlement on the basis of predetermined criteria. In addition to the original seven settlements that were included in the first set, dosimeters were distributed in six settlements that were chosen as low radiation control areas in which independent project medical examinations were performed (Part F). The first two sets of results were presented to the population in February 1991.

The most important criteria in measuring the dose to a representative sample of the population for each location surveyed were sex, age and occupation. The personal dosimeters were distributed to an approximately equal proportion of men and women. It was intended that individuals of all ages would be provided with dosimeters; however, at the first and second distribution periods most of the children were not present in the settlements because they had been sent to summer camps outside the affected areas. Occupation was an important factor because of different times spent working indoors or outdoors.

The participants were instructed to carry the dosimeters in a pocket in their clothing on the upper half of the body, and to place it by the bedside while they slept. This procedure was to be continued until the dosimeters were collected.

The film type used in the dosimeters was KODAK US Type 3. This film has two emulsions on one film. Filters of copper (0.2 mm) and lead (1 mm) were used. The energy response is $\pm 10\%$ from 500 to 1000 keV. The detection limit of this method is 0.2 mSv, and the accuracy accords (-33% to $+50\%$) with recommendations of the International Commission on Radiation Units and Measurements (ICRU) and the International Commission on Radiological Protection (ICRP). The films were processed by conventional manual methods at SCPRI and the results were reported to the IAEA laboratory for evaluation.

Results

Altogether, 11 773 dosimeters were distributed to individuals or the local authorities. A set of dosimeters was used for background dose mea-surements or testing. In some cases, insufficient information on the individual was provided to allow inclusion of the datum.

Table 3-1 presents the summary results for 8611 personal dosimeters exposed for approximately two months in the selected settlements, divided into four ranges of dose.

The higher measurements, in most cases, could be attributed to the individual living in a slightly more contaminated area, or were due to their profession (i.e. forest worker). In five cases it was found that the dosimeters had been exposed to X rays, probably intentionally. A few outliers of higher exposures were measured. These could not be explained by the dose rate measured in the areas. It is suspected that these were from 'hot spots' in the environment or that the individuals wearing them spent long periods of time outdoors.

Internal Dosimetry

During the period from 5 July to 7 September 1990 a whole body counting campaign was conducted in the BSSR, the RSFSR and the UkrSSR. Over 9000 measurements were made, using a mobile whole body counting van provided to the project by SCPRI, France. The

TABLE 3-1. Summary Results of External Dose Measurements in a Monitoring Period of Two Months

Settlement	Number of measurements	Group I <0.2 mSv	Group II 0.2-1 mSv	Group III 1-4.5 mSv	Group IV >4.5 mSv
			BSSR		
Bragin	395	383 (97.0%)	8 (2.0%)	4 (1.0%)	—
Veprin	716	635 (88.7%)	66 (9.2%)	15 (2.1%)	—
Korma	843	774 (91.8%)	64 (7.6%)	5 (0.6%)	—
Khodosy[a]	328	274 (83.5%)	54 (16.5%)	—	—
Total	2282	2066 (90.5%)	192 (8.4%)	24 (1.0%)	—
			RSFSR		
Novozybkov	1882	1211 (64.3%)	564 (30.0%)	97 (5.15%)	10 (0.55%)
Zlynka	780	664 (85.1%)	112 (14.3%)	4 (0.5%)	—
Unecha[a]	453	329 (72.6%)	124 (27.4%)	—	—
Total	3115	2204 (70.7%)	800 (25.7%)	101 (3.2%)	10 (0.3%)
			UkrSSR		
Polesskoe	987	954 (98.6%)	31 (3.1%)	1 (0.1%)	1 (0.1%)
Ovruch	814	801 (98.2%)	7 (0.85%)	6 (0.7%)	—
Kalinovka[a]	534	407 (76.2%)	125 (23.4%)	2 (0.4%)	—
Brovany[a]	34	29 (85.3%)	5 (14.7%)	—	—
Trokovichi[a]	305	272 (89.1%)	33 (10.9%)	—	—
Korosteny	540	529 (98.0%)	11 (2.0%)	—	—
Total	3214	2992 (93.1%)	212 (6.6%)	9 (0.3%)	1

[a] Settlement outside the contaminated areas.

measurements included (a) reference measurements of a calibration phantom, as well as of van staff, for quality control, and (b) replicate measurements. Some of the measurement results were found to be in error. Therefore, the results for 9058 people are reported here. The counting locations, dates and number of people counted are summarized in Table 3-2.

Counting Procedure

The mobile van is equipped with four chair counters. Each counter has a 7.62 × 7.62 cm cylindrical NaI crystal housed in a collimated lead shield (Fig. 3-1). The person is positioned for counting so that the shield is centred on the chest, over the region of the lungs, and in contact with the body. The counting period was 5 minutes. The background counting rates of the counters were determined by inserting a conical plastic plug into the collimator.

During counting, the person being measured provided some self-shielding, thus reducing the counter background. Unfortunately, the degree of self-shielding was variable, depending on the mass of the person. This is particularly a problem in evaluating results for small children. The counting procedure as established by SCPRI did not make provision for corrections based on body mass.

The data were processed with a Canberra S35 multichannel analyser connected to an Amstrad portable computer using software developed at SCPRI. Results were recorded on diskette and displayed on computer printout. The SCPRI data unfolding process is intended to accommodate up to three radionuclides. However, the counting statistics were often poor, so only results for ^{137}Cs are presented in this report. From information provided by whole body counting specialists in Kiev and Minsk, based on their counting results, the ratio of ^{137}Cs to ^{134}Cs was approximately 6.5. Results of this ratio for an environmental sample, dried green peas

TABLE 3-2. Location, Date and Number of Persons Counted During the Internal Dosimetry Campaign

Settlement	Date of measurements	Number of persons counted
	BSSR	
Korma	10-14 July 1990	719
Veprin	15-21 July 1990	1064
Bragin	5-11 August 1990	1154
	RSFSR	
Zlynka	22-28 July 1990	998
Novozybkov	29 July-4 August 1990	1453
	UkrSSR	
Ovruch	12-18 August 1990	1153
Polesskoe	19-25 August 1990	1003
Rakitnoe	26 August-1 September 1990	1320
Daleta	2-7 September 1990	194
Total		9058

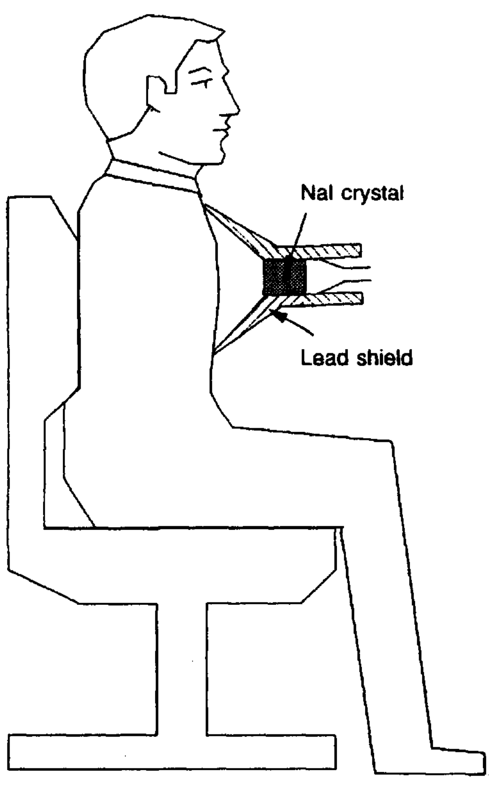


FIG. 3-1. Schematic diagram of counting geometry in mobile van.

grown in the Chernobyl region and assayed in December 1990, ranged from 7.9 to 8.8. This would be equivalent to 7.2 in August 1990, the mid-point of the whole body counting project.

The limit of detection (LOD) as defined by the data processing software of the mobile van is three times the background count standard deviation. Because of the high variability in background from one town to another, the LOD is variable. In addition, the efficiency depends significantly on the size of the person being counted. Therefore, a single value cannot be quoted. However, a typical LOD for an adult is about 0.74 kBq (0.02 μCi), while for a small child the value drops to about 0.19 kBq (0.005 μCi).

Counter Calibration

Since the mobile van was designed for operational emergency response applications, the calibration is based on a 70 kg reference man, 170 cm tall. The activity, A (in Bq), is determined using the following calibration:

$$A = \frac{\text{Count rate}}{0.0003 \times \text{CF}} \qquad (3\text{-}1)$$

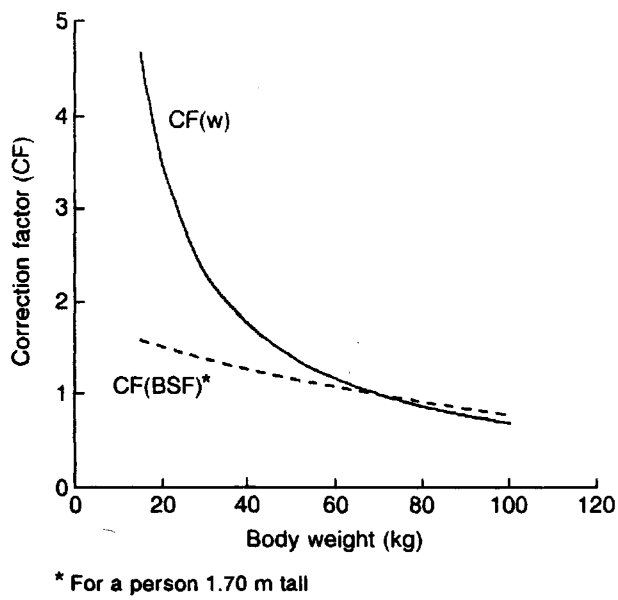


FIG. 3-2. Correction factors for detectors in mobile van. The value based on the body size factor (BSF) was intended to be used only for adults. The modified correction factor based on weight, CF(w), is more appropriate also for children and has been applied to measurements of the International Project.

TABLE 3-3. Results of Whole Body Counting in the Mobile Van for Purposes of Quality Assurance

Subject	Counter	Reference activity[a] (kBq)	Measured activity (kBq)	Standard deviation		Number of measurements
				(kBq)	(%)	
Phantom	1	131	139	2.55	1.8	16
	2		134	4.62	3.4	19
	3		134	5.62	4.2	23
	4		136	7.36	5.4	25
	Average		136	5.92	4.4	83
Person 1	1	3.26[b]	3.00	0.59	19.3	9
	2	2.66[c]	2.29	0.52	21.9	10
	3		2.81	0.78	27.5	7
	4		3.00	0.44	15.0	12
	Average		2.78	0.63	22.9	38
Person 2	1	3.37[b]	4.77	0.37	7.4	8
	2	3.22[c]	4.29	0.56	12.5	4
	3		3.92	0.52	13.0	8
	4		3.88	0.30	7.4	8
	Average		4.22	0.56	13.5	28
Person 3	1		1.44	1.00	69.7	4
	2		2.59	0.81	31.7	5
	3		2.96	0.92	31.7	10
	4		2.96	1.04	35.3	12
	Average		2.70	1.11	40.5	31
Person 4	1		3.37	0.92	27.2	12
	2		3.18	1.00	31.2	9
	3		3.63	0.96	26.8	13
	4		4.11	0.37	9.4	8
	Average		3.55	0.92	26.3	42
Person 5	Average	1.26[c]	2.26	1.59	71.4	5

[a] Reference value for the phantom was provided by SCPRI. Reference values for members of the van staff are based on counting in the IAEA whole body counter at Seibersdorf.
[b] Measured immediately before mission to USSR.
[c] Measured at regular intervals following mission to USSR.

where CF is the correction factor for body size, primarily chest thickness (CF = 1 for reference man):

$$CF = 2.088 - (1.695 \times BSF) \quad (3\text{-}2)$$

where BSF is the body size factor: $[\text{Weight/Height}]^{1/2}$ (weight in kg force and height in cm).

The design of the counters in the counting van is such that only activity in the torso is detected. For adults this means that the mass of tissue seen by the counter is roughly constant. Following a review of the counting procedure, it was concluded that the calibration was reasonably accurate in the weight range 50 to 90 kg. However, for individuals outside that range the results could be significantly in error. For a child weighing 20 kg with a height of 100 cm, for example, the original calibration would overestimate the caesium burden by a

TABLE 3–4. Summary Results of the IAEA Whole Body Counting Project in the USSR

Settlement	Statistical quantity	Weight (kg)	Age (years)	^{137}Cs total body burden (kBq)	^{137}Cs specific body burden (Bq/kg)	Annual dose based on specific body burden (mSv)
			BSSR			
Bragin	Average	71.5	40.1	3.10	44.4	0.11
Population	Median	73	39	2.10	32.1	0.08
sample:	Geometric mean	67.9	34.8	2.20	31.9	0.08
1154	Standard deviation	19.5	17.6	5.70	90.5	0.23
	Minimum	12	2	0.280	6.6	0.02
	Maximum	135	89	130	2110	5.3
	Lower quartile	61	28	1.30	20.2	0.05
	Upper quartile	84	54	3.50	48.2	0.12
Veprin	Average	64.6	36.5	3.20	46.7	0.12
Population	Median	69	38	1.50	24.2	0.06
sample:	Geometric mean	58.9	28.7	1.60	27.4	0.07
1064	Standard deviation	22.7	20.0	6.10	78.1	0.20
	Minimum	10	2	0.090	2.16	0.0054
	Maximum	125	86	107	1370	3.4
	Lower quartile	55	18	0.650	12.9	0.03
	Upper quartile	80	53	3.50	51.4	0.13
Korma	Average	67.6	38.5	3.40	50.6	0.13
Population	Median	70	38	2.30	36.4	0.09
sample:	Geometric mean	62.0	31.1	2.00	32.7	0.08
719	Standard deviation	22.3	19.2	5.10	66.5	0.17
	Minimum	10	1	0.100	2.83	0.0071
	Maximum	118	85	67.0	932.9	2.3
	Lower quartile	60	26	0.800	18.2	0.05
	Upper quartile	81	54	4.00	57.5	0.14
			RSFSR			
Novozybkov	Average	69.3	40.4	5.60	78.0	0.20
Population	Median	72	42	3.00	43.4	0.11
sample:	Geometric mean	65.1	34.4	3.00	45.3	0.11
1455	Standard deviation	20.1	17.7	11.0	131	0.33
	Minimum	11	2	0.160	6.5	0.02
	Maximum	130	85	180	2200	5.50
	Lower quartile	60	29	1.40	23.0	0.06
	Upper quartile	83	54	6.10	85.3	0.21
Zlynka	Average	66.7	38.7	7.80	116	0.29
Population	Median	70	39	4.00	67	0.17
sample:	Geometric mean	62.0	31.6	4.10	65.4	0.16
998	Standard deviation	21	19.3	12.0	172	0.43
	Minimum	10	2	0.160	7.3	0.02
	Maximum	120	96	170	1990	5.0
	Lower quartile	59	25	1.70	31.9	0.08
	Upper quartile	80	53	8.70	132	0.33

TABLE 3-4. (cont.)

Settlement	Statistical quantity	Weight (kg)	Age (years)	^{137}Cs total body burden (kBq)	^{137}Cs specific body burden (Bq/kg)	Annual dose based on specific body burden (mSv)
			UkrSSR			
Daleta	Average	55.84	22.0	23.0	396	0.99
Population	Median	55	16	15.0	279	0.70
sample:	Geometric mean	49.1	16.2	12.0	249	0.62
194	Standard deviation	25.2	16.4	30.0	425	1.1
	Minimum	13	2	0.280	13.3	0.03
	Maximum	115	67	320	3750	9.4
	Lower quartile	35	10	5.60	135	0.34
	Upper quartile	78	31	31.0	524	1.3
Ovruch	Average	69.3	38.6	13.0	185	0.46
Population	Median	72	42	5.00	77.9	0.20
sample:	Geometric mean	64.5	32.7	5.70	88.1	0.22
1153	Standard deviation	20.9	16.9	25.0	353	0.89
	Minimum	11	3	0.300	8.2	0.02
	Maximum	130	80	280	4060	10
	Lower quartile	62	28	2.30	37.6	0.09
	Upper quartile	83	52	13.0	182	0.46
Polesskoe	Average	73.9	36.8	5.70	76.2	0.19
Population	Median	75	36	2.20	29.9	0.08
sample:	Geometric mean	70.1	32.2	2.50	35.0	0.09
1003	Standard deviation	19.8	15.8	12.0	158	0.40
	Minimum	14	3	0.170	5.3	0.01
	Maximum	140	76	170	1960	4.9
	Lower quartile	65	26	0.820	13.4	0.03
	Upper quartile	85	50	5.33	70.6	0.18
Rakitnoe	Average	67.1	33.9	10.0	143.9	0.36
Population	Median	70	35	5.30	77.4	0.19
sample:	Geometric mean	63	29.0	5.30	83.6	0.21
1320	Standard deviation	20.1	15.6	15.0	203	0.51
	Minimum	13	2	0.170	9.0	0.02
	Maximum	120	76	180	2524	6.30
	Lower quartile	59	24	2.30	42.3	0.11
	Upper quartile	80	45	12.0	163	0.41

factor of 2.6. Therefore, it was recommended that a modified correction factor based only on weight be used:

$$CF = \frac{70}{\text{Weight (kg)}} \qquad (3\text{-}3)$$

The original and modified correction factors are displayed graphically in Fig. 3-2. All data presented in this report have been derived using the revised calibration factors.

Quality Assurance

During the measurement programme, a plastic cylindrical phantom provided by SCPRI was used to check the counting efficiency on a daily basis. In addition, a few members of the van staff had measurable levels of ^{137}Cs. They were also counted at regular intervals. These results are presented in Table 3-3. Three of the people who were routinely counted had been checked by

Text cont. on p. 269.

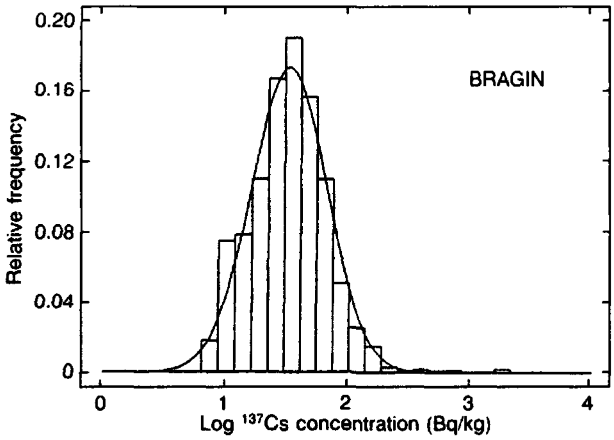


FIG. 3-3a. Frequency distribution of the logarithm of the concentration of ^{137}Cs in the body. Measurement results of the International Project in selected settlements. Bragin.

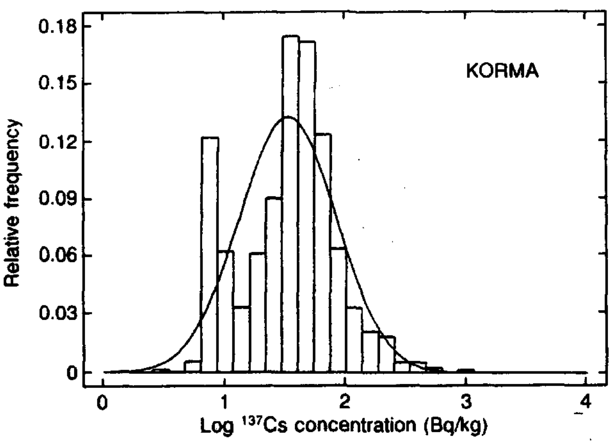


FIG. 3-3b. Frequency distribution of the logarithm of the concentration of ^{137}Cs in the body. Measurement results of the International Project in selected settlements. Korma.

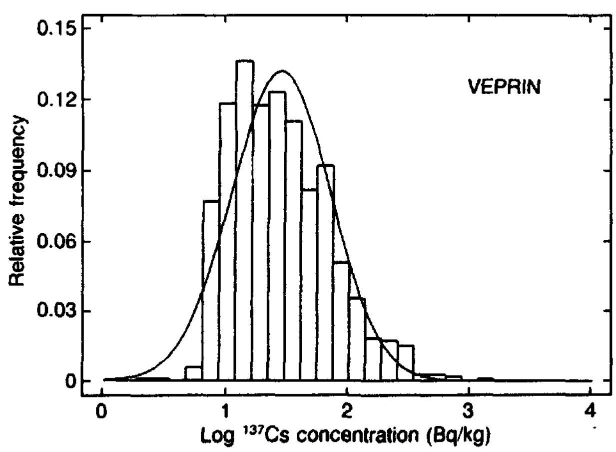


FIG. 3-3c. Frequency distribution of the logarithm of the concentration of ^{137}Cs in the body. Measurement results of the International Project in selected settlements. Veprin.

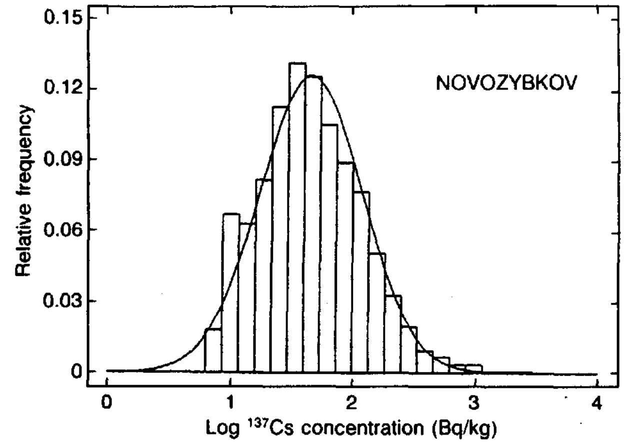


FIG. 3-3d. Frequency distribution of the logarithm of the concentration of ^{137}Cs in the body. Measurement results of the International Project in selected settlements. Novozybkov.

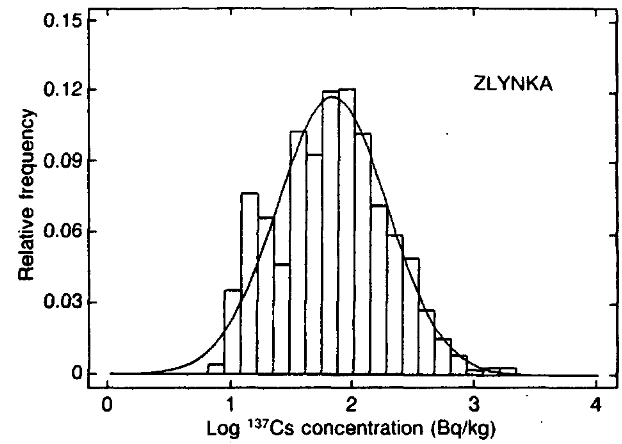


FIG. 3-3e. Frequency distribution of the logarithm of the concentration of ^{137}Cs in the body. Measurement results of the International Project in selected settlements. Zlynka.

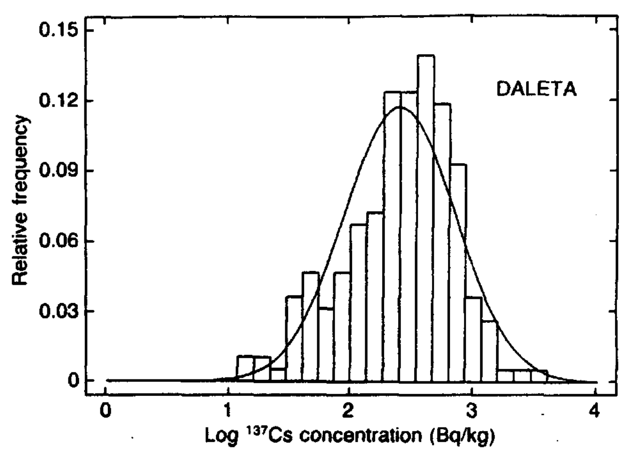


FIG. 3-3f. Frequency distribution of the logarithm of the concentration of ^{137}Cs in the body. Measurement results of the International Project in selected settlements. Daleta.

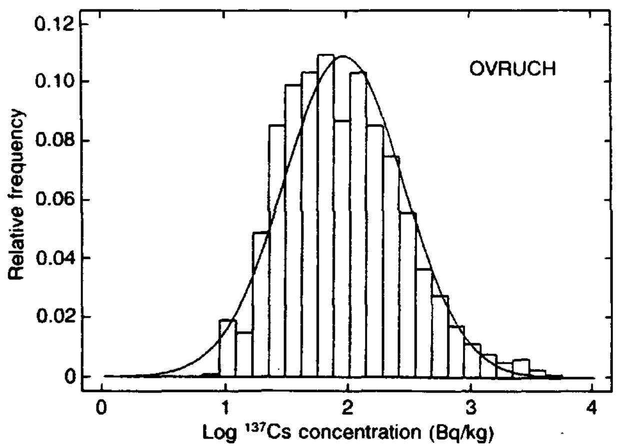


FIG. 3-3g. Frequency distribution of the logarithm of the concentration of ^{137}Cs in the body. Measurement results of the International Project in selected settlements. Ovruch.

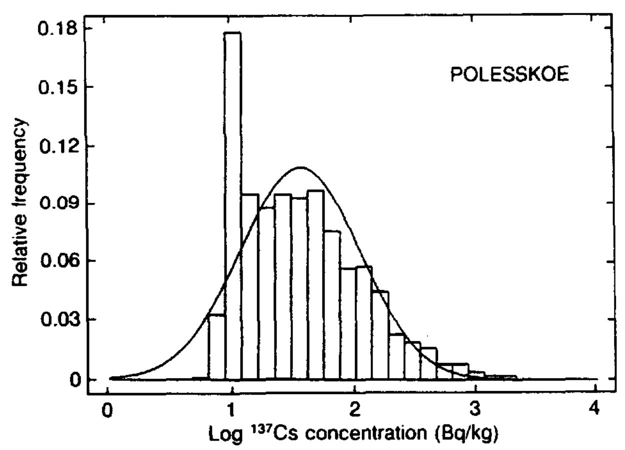


FIG. 3-3h. Frequency distribution of the logarithm of the concentration of ^{137}Cs in the body. Measurement results of the International Project in selected settlements. Polesskoe.

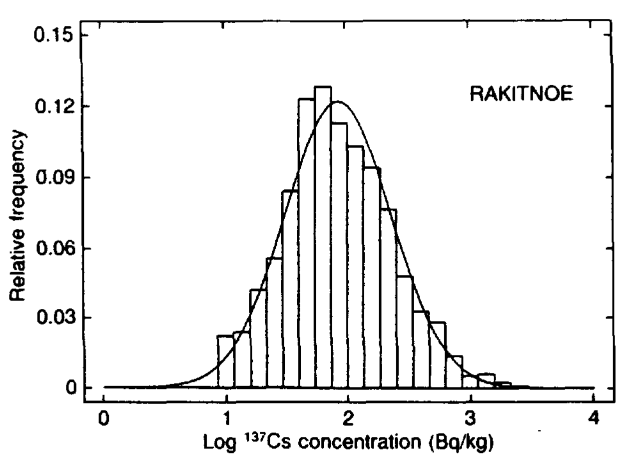


FIG. 3-3i. Frequency distribution of the logarithm of the concentration of ^{137}Cs in the body. Measurement results of the International Project in selected settlements. Rakitnoe.

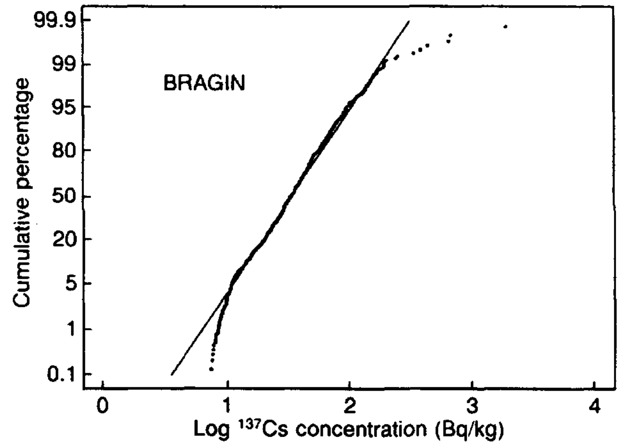


FIG. 3-4a. Log-normal probability distribution of concentration of ^{137}Cs in the body in 1990. Measurement results of the International Project in selected settlements. Bragin.

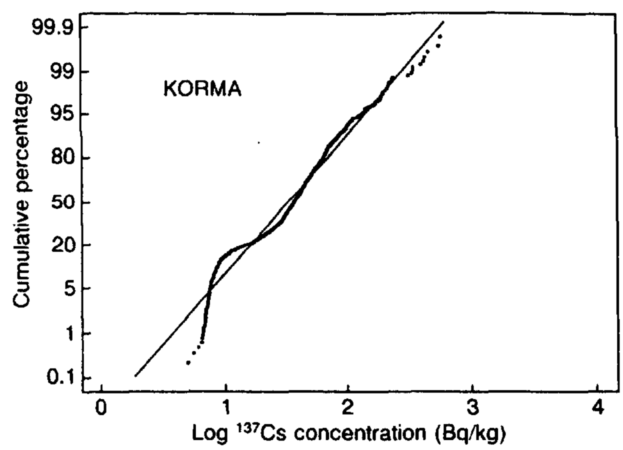


FIG. 3-4b. Log-normal probability distribution of concentration of ^{137}Cs in the body in 1990. Measurement results of the International Project in selected settlements. Korma.

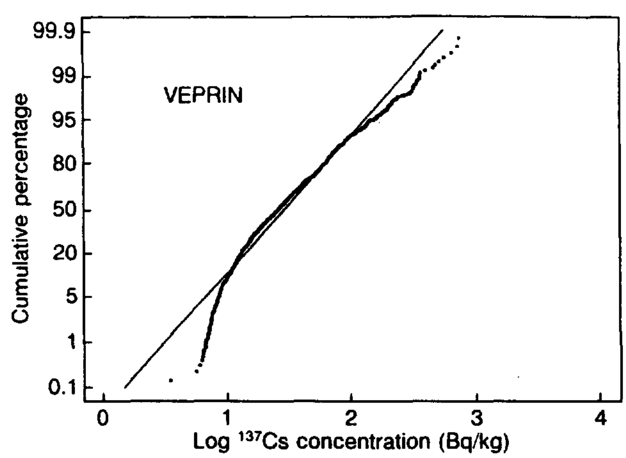


FIG. 3-4c. Log-normal probability distribution of concentration of ^{137}Cs in the body in 1990. Measurement results of the International Project in selected settlements. Veprin.

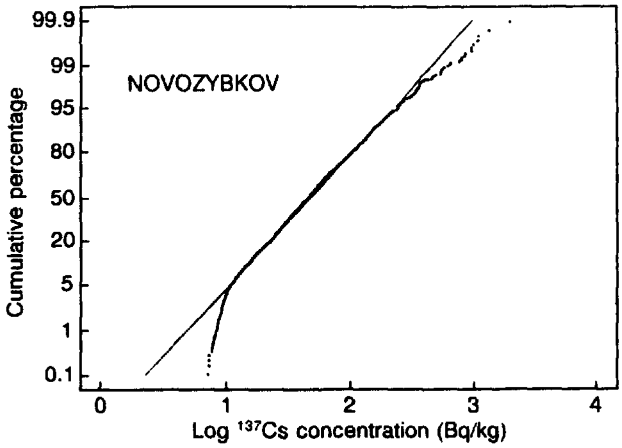


FIG. 3-4d. Log-normal probability distribution of concentration of ^{137}Cs in the body in 1990. Measurement results of the International Project in selected settlements. Novozybkov.

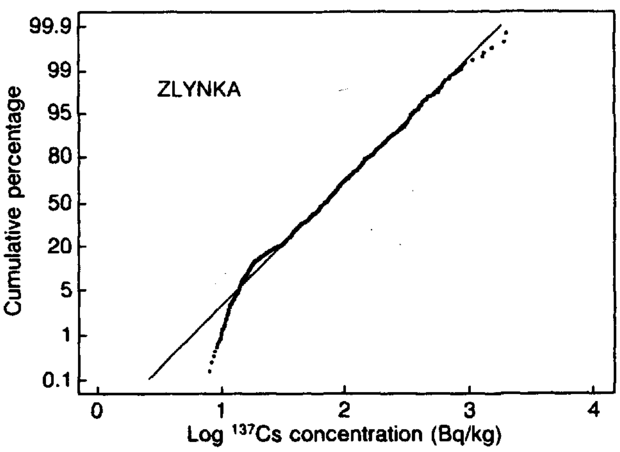


FIG. 3-4e. Log-normal probability distribution of concentration of ^{137}Cs in the body in 1990. Measurement results of the International Project in selected settlements. Zlynka.

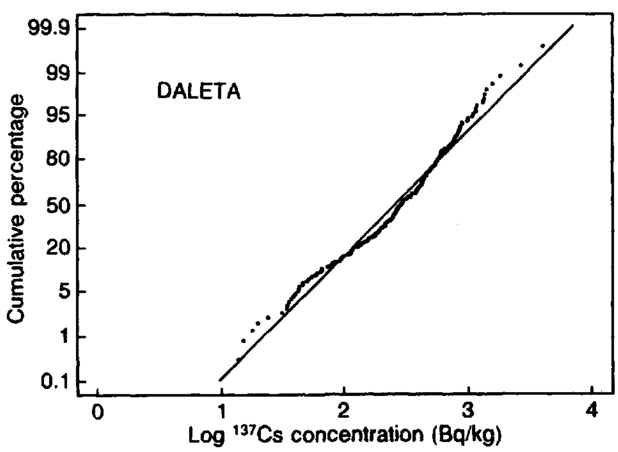


FIG. 3-4f. Log-normal probability distribution of concentration of ^{137}Cs in the body in 1990. Measurement results of the International Project in selected settlements. Daleta.

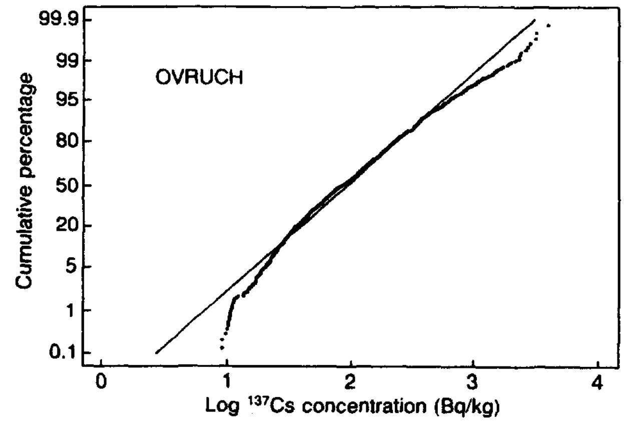


FIG. 3-4g. Log-normal probability distribution of concentration of ^{137}Cs in the body in 1990. Measurement results of the International Project in selected settlements. Ovruch.

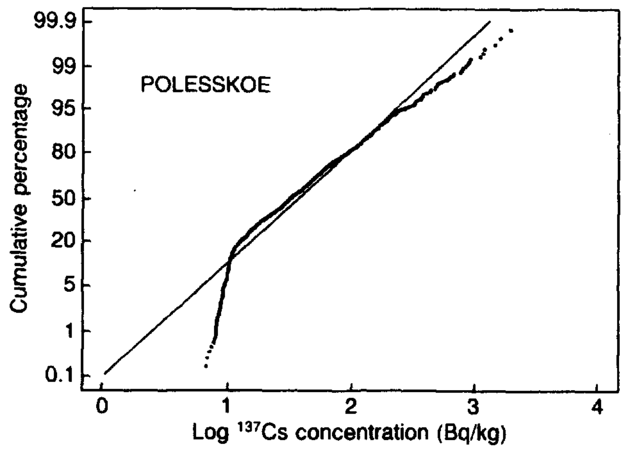


FIG. 3-4h. Log-normal probability distribution of concentration of ^{137}Cs in the body in 1990. Measurement results of the International Project in selected settlements. Polesskoe.

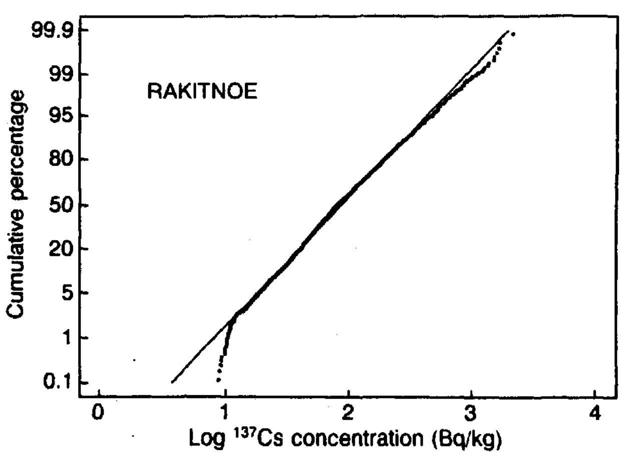


FIG. 3-4i. Log-normal probability distribution of concentration of ^{137}Cs in the body in 1990. Measurement results of the International Project in selected settlements. Rakitnoe.

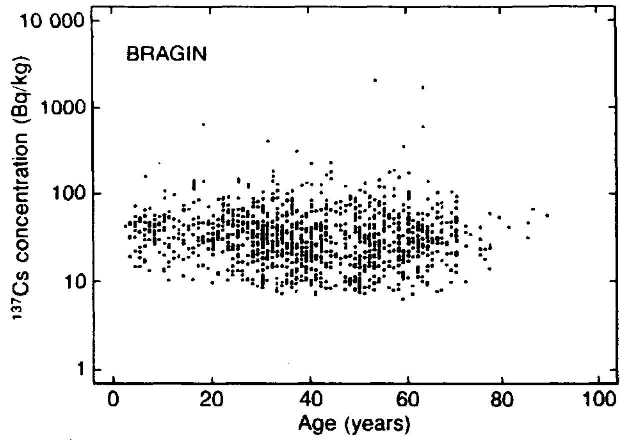


FIG. 3-5a. Scatter diagram of concentration of ^{137}Cs in the body as a function of age. Measurement results of the International Project in selected settlements. Bragin.

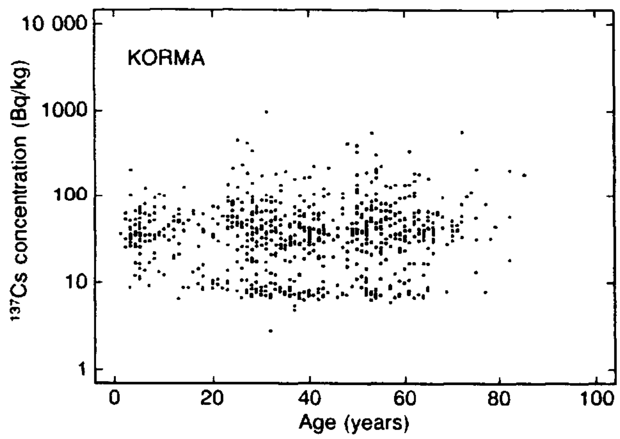


FIG. 3-5b. Scatter diagram of concentration of ^{137}Cs in the body as a function of age. Measurement results of the International Project in selected settlements. Korma.

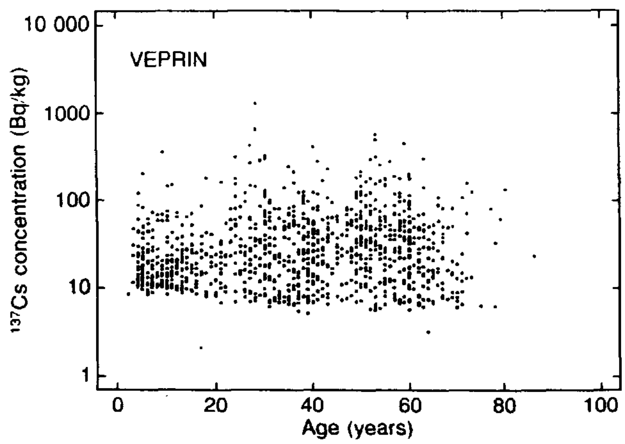


FIG. 3-5c. Scatter diagram of concentration of ^{137}Cs in the body as a function of age. Measurement results of the International Project in selected settlements. Veprin.

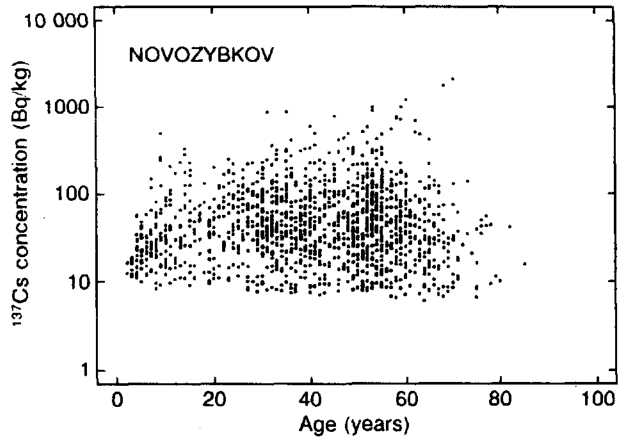


FIG. 3-5d. Scatter diagram of concentration of ^{137}Cs in the body as a function of age. Measurement results of the International Project in selected settlements. Novozybkov.

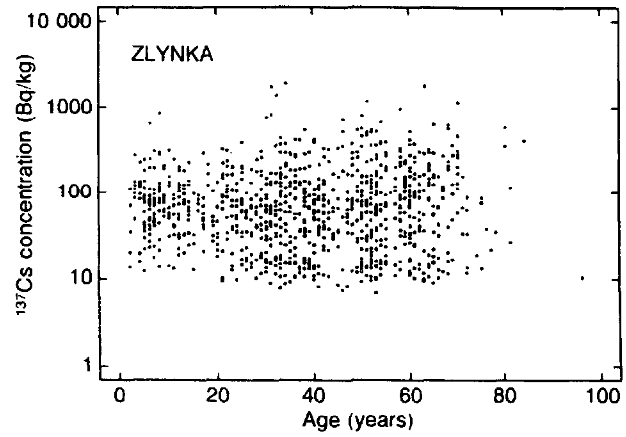


FIG. 3-5e. Scatter diagram of concentration of ^{137}Cs in the body as a function of age. Measurement results of the International Project in selected settlements. Zlynka.

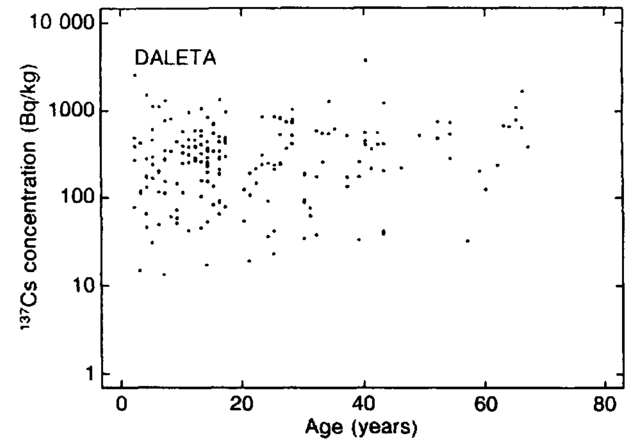


FIG. 3-5f. Scatter diagram of concentration of ^{137}Cs in the body as a function of age. Measurement results of the International Project in selected settlements. Daleta.

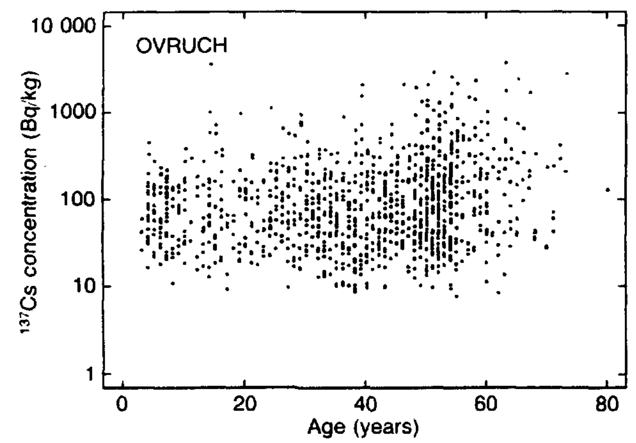


FIG. 3-5g. Scatter diagram of concentration of ^{137}Cs in the body as a function of age. Measurement results of the International Project in selected settlements. Ovruch.

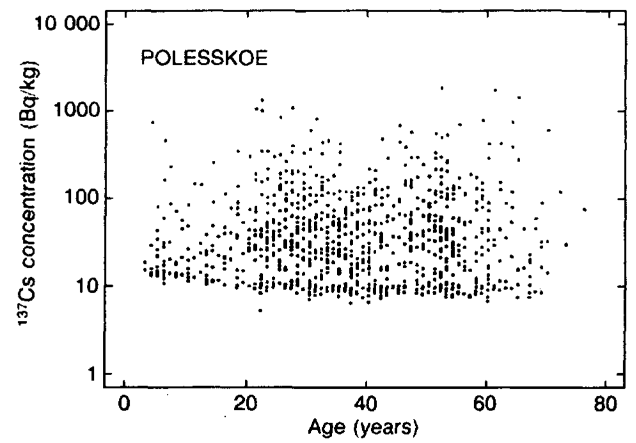


FIG. 3-5h. Scatter diagram of concentration of ^{137}Cs in the body as a function of age. Measurement results of the International Project in selected settlements. Polesskoe.

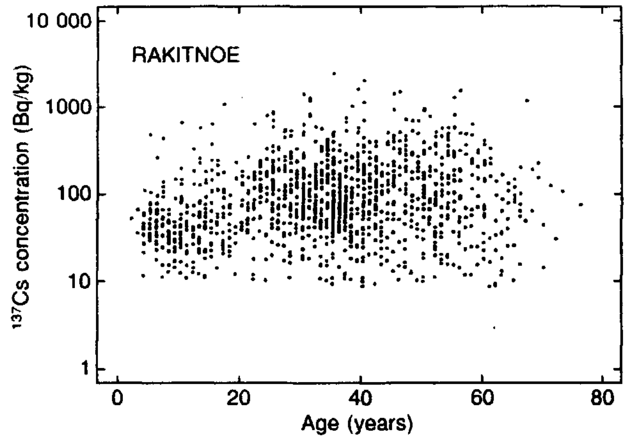


FIG. 3-5i. Scatter diagram of concentration of ^{137}Cs in the body as a function of age. Measurement results of the International Project in selected settlements. Rakitnoe.

the IAEA whole body counter in Seibersdorf, and these results have been taken to be the reference values.

At the end of the counting programme, the van returned to Seibersdorf. At that time, the calibration of each counter was checked with (a) a standard bottle phantom obtained from the Battelle Pacific Northwest Laboratory in the USA and (b) two liquid filled manikins from Salzburg University simulating an adult female and a child. The bottle phantom contained 11.2 kBq ^{137}Cs in a solid polyurethane tissue substitute. The Salzburg phantoms had very low levels of activity. These additional results are not presented here.

Results

Summary statistics and internal dosimetry results for the nine settlements in the BSSR, the RSFSR and the UkrSSR are presented in Table 3-4. These include the number of persons counted, weight, age, total body burden, specific body burden (body burden/weight), and estimated annual dose based on specific body burden. Since the measurements were made at only one time, it is impossible to determine time dependent changes in the internal body levels. Therefore, a constant intake was assumed. A conversion factor for specific body burden to dose rate of 2.5 μSv/a per Bq/kg was used to calculate annual dose. The annual dose in future years will be reduced in proportion to the reduction in environmental caesium levels.

It can be expected that the results for a given population will have a log-normal distribution, i.e., the log of the variable x is normally distributed. In this case, the variable is the specific body burden. Comparison of the distribution of specific body burden for each village with an estimate of the best fit for a log-normal distribution is presented in Fig. 3-3. It is clear that the quality of agreement varies from village to village, and that, in some cases, non-statistical factors influence the results. One such influence is the assignment of the value of the detection limit to those measurements at or below that limit. The practice obviously biases the low activity results upwards.

This effect can be seen more clearly in the cumulative normal probability plots of the log of the specific body burden shown in Fig. 3-4. The overlying straight lines represent the distribution that would be expected for a population having a log-normal distribution without additional influences. These plots also demonstrate deviation from the expected distribution at higher values of the specific body burden. The reason for this deviation has not been definitely identified. A possible explanation is that it is the result of a small subset of the population that does not observe the dietary restrictions imposed by local authorities, or that dietary habits (such as eating large quantities of forest mushrooms) predispose members of the population to higher body burdens.

The distributions of annual doses are derived from the specific body burden multiplied by the constant dose factor. There is, thus, no need to illustrate these results separately, since they vary exactly as do the specific body burdens.

Age dependent distribution is an important issue; however, the scatter plots shown in Fig. 3–5 do not indicate a strong age dependence.

Annex 4

Intercomparison of Whole Body Counters

During a mission to the USSR in August 1990 it was concluded that an intercomparison of USSR, IAEA and of the Austrian whole body counters used for in vivo measurement of ^{137}Cs would be valuable in corroborating large scale measurements of the Soviet population.

The IAEA arranged to obtain use of a standard, adult phantom from the Battelle Pacific Northwest Laboratories in the USA. The phantom is a 'Bush' or 'Bottle' type, filled with solid, polyurethane tissue substitute and labelled uniformly with ^{137}Cs (Fig. 4–1). The total quantity at the time of the intercomparison was 11 170 Bq (0.3 μCi). A solid matrix was necessary to avoid the practical problems of handling radioactive liquids during transport. Although accurate measurement of the caesium level in children is a major concern, it was not possible to locate a standard child phantom with a solid matrix.

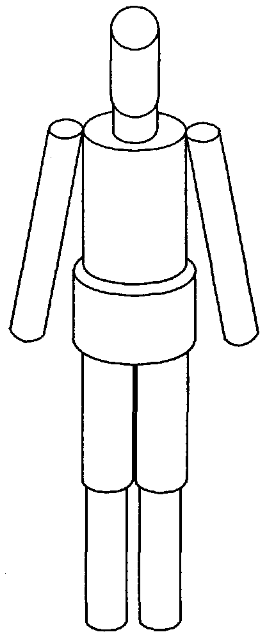


FIG. 4–1. Bottle calibration phantom.

Intercomparison Sequence

Counting was performed in the SCPRI counting van, with the IAEA chair counter and with a whole body counter of the Austrian Research Centre during the week starting 17 September 1990. The phantom was then taken to the USSR and used there in various institutes. The intercomparison programme was completed in December 1990 with a final counting of two Soviet phantom systems at Seibersdorf. The Soviet institutes that participated in the intercomparison programme and the counter characteristics are listed in Table 4–1.

TABLE 4–1. Participants in the IAEA Whole Body Counting Intercomparison Programme and Counter Characteristics

Institute	Location	Counter type	Detector	^{137}Cs background rate (counts/s)
Institute of Biophysics	Moscow	Stool, CIB-2	Ge, 100 cm^3	
		Chair, CIB-1	NaI, 350 cm^3	1.2
Ministry of Health	Minsk	Stool, QBM-1	NE 110, 5100 cm^3	
		Chair, CIB-1	NaI, 1770 cm^3	24.8
	Cherikov	Chair, CIB-1	NaI, 200 cm^3	4.9
	Krasnopolje	Stool	NaI, 1310 cm^3	3.2
Institute of Sea Transport Health Studies	Leningrad	Chair	NaI, 200 cm^3	1.8
Institute of Radiation Hygiene	Novozybkov	Chair, CIB-1	NaI, 200 cm^3	1.7
All-Union Centre for Radiation Medicine	Kiev	Stool	NaI, 2060 cm^3	8.6
Ministry of Health	Kiev	Chair	NaI, 200 cm^3	5.1

TABLE 4-2. Intercomparison Results for Phantoms Counted at Institutes in the USSR, in Austria and in the Mobile Van

Reporting institute and/or type of counter	Measured activity (Bq/kg)						
	Bottle phantom	Infant phantom	Child phantom	Adult phantom	Bag phantom of dried peas		
	74 kg	10.8 kg	24.3 kg	63 kg	15.5 kg	27.7 kg	58.4 kg
USSR 1[a]	148						
USSR 2	138						
USSR 3	190						
USSR 4	132	3420	3500	3120			
USSR 5	165	3390	3390	3330			
USSR 6	120	3900	3910	2840			
USSR 7	160	4210	4350	3900			
USSR 8	165						
USSR 9	90	4110	3340	3520			
USSR 10		4800		2640			
USSR 11		4450		2520			
USSR 12	172	3090	3060	3380			
USSR 13	109	3220	3340	2960			
Van 1[b]	160						
Van 2	148						
Van 3	152						
Van 4	136						
IAEA[c]	120	2150	2360	2190	477	507	485
ARC[d]	130	3850	3810	3220	684	610	673
Reference value	151	3190[e]	3190[e]	3190[e]		570[e] 587[f] 574[g]	

[a] Institutes in the USSR are designed only by number.
[b] Counter number in mobile van.
[c] Chair counter at IAEA Laboratory, Seibersdorf.
[d] Chair counter at Austrian Research Centre, Seibersdorf.
[e] USSR value.
[f] IAEA value.
[g] Austrian Research Centre value.

Soviet Phantom Counting, Seibersdorf

At the invitation of the IAEA, two Soviet phantoms were brought for counting to Seibersdorf in December 1990, namely a block phantom from the Leningrad Institute of Sea Transport Health Studies and a phantom in the form of a bag of dried peas from the All-Union Scientific Centre for Radiation Medicine. Equivalent configurations from both phantom systems were counted, representing (a) a small child, (b) a child of about age 10, and (c) a small adult. In addition, samples of the dried peas used in the Kiev phantom were assayed. Counting was done in both the IAEA chair counter and the counter of the Austrian Research Centre. It must be noted that the IAEA counter is intended only for adults, and is not specifically calibrated for children. The Austrian Research Centre also normally only counts adults. The results of the measurements made using the child phantoms should be viewed accordingly.

Results

The results of the phantom intercomparison measurements are presented in Table 4-2. Under the conditions of the intercomparison, it was agreed that the results from the Soviet counters would not be specifically identified. Therefore, the participating Soviet institutes are indicated only by numbers in Table 4-2. However, each Soviet facility has been provided with a tabulation of the intercomparison results together with specific identification of its own data.

Conclusions

The IAEA does not have specific criteria for the acceptability of the performance of whole body counters. However, the quality of the intercomparison results can be compared with guidance provided in IAEA Safety Series No.84, Basic Principles for Occupational Radiation Monitoring, paragraph 4.1.5, where it is stated that: "In the case of routine individual monitoring for external radiation relative uncertainties of -50% and +100% at the 95% confidence level are acceptable for annual dose equivalents in the range of one fifth of the derived limit. If, however, values are of the order of the annual limits, the relative uncertainties should not exceed −33% and +50% at the 95% confidence level."...
"Similar requirements should, in principle, also apply in the case of routine individual monitoring for internal contamination, but in practice uncertainties as small as 50% are rarely possible."

In 5 of 36 measurements reported from institutes in the USSR (Table 4-2), the results were outside a range of ±30% compared with the reference values. One result was slightly more than 50% above the reference value. In the latter case, the measurement was made with an unshielded probe used with the phantom doubled over in the 'Marinelli' position.

On the basis of the distribution of the intercomparison results, it can reasonably be concluded that the participating institutes are capable of performing internal caesium measurements with an accuracy that is acceptable and adequate for radiation protection purposes.

It should also be noted that four of the five instances of results outside the range of ±30% from the reference value occurred with phantoms representing children. Although the differences are not excessive, they do suggest the need for additional attention to the calibration of counters for measurements of children.

Annex 5

Variability in Soil–Plant Transfer Factors

The deposition of radionuclides on the ground (soil and agricultural plants) is the first and, in many cases, the only link in the food-chain by which the environmental contamination is transferred to human beings (excluding processing losses). In the short term (up to a few weeks following the accident), the activity deposited on agricultural plants is available for consumption by human beings and by animals. Later on, the activity deposited on the soil, as well as the activity that is removed from the plant by environmental processes, migrates in the soil. A fraction of the activity present in the soil is then taken up by the roots of the plant and transferred to its aerial parts. This long term process is not important for short lived radionuclides such as ^{131}I, which essentially decay before they can be taken up by the plant roots; it is also, in general, less important than deposition on the plant surfaces for long lived radionuclides. However, it is the predominant pathway by which agricultural plants are contaminated during the years following the accident for radiocaesium and radiostrontium (the other pathway being the contamination of the aerial parts of the plant through rainsplash or resuspension by atmospheric turbulence of the activity deposited on the soil). Because of the relative importance of milk and meat as internal exposure pathways, the transfer of radiocaesium from soil to pasture and/or fodder is of particular importance. The magnitude of transfer depends on various factors: the physical–chemical characteristics of the radioactive particles contaminating the soil; the 'age' of the radioactive contamination; the chemical characteristics of the radionuclide compounds; the agrochemical and physical characteristics of the soil; the plant species concerned; and meteorological and climatic conditions [1].

Due to the large number of confounding factors, it is difficult to predict with confidence the transfer coefficient from soil to plant. The transfer coefficient is defined as the ratio of the specific activity of the nuclide in dry vegetable matter (Bq/kg) to the activity density of the radionuclide in the soil (Bq/m^2); the units of the coefficient are therefore m^2/kg.

The measurement of this coefficient for a wide variety of conditions is an important component of current Soviet research programmes, in order to determine the relationship between the various confounding factors and the transfer. While it is still difficult to predict accurately concentrations in the plant, research to date seems to indicate tentative exponential relationships with soil pH and organic content. It is also clear, however, that clay mineral content, water content and other factors can also be important. An indication of the significance of soil pH can be obtained by a consideration of the data presented in Table 5–1. For the crops listed and for the animal products associated with cattle grazing on pasture of a particular soil, there is generally a much higher uptake of caesium to plants from acid soils (as much as a factor of ten between soils of pH in the range 4.5 to 5.5 compared to those in the range 6.6 to 7.5).

Although some understanding has been gained of the relationships between the various factors and the uptake of caesium from soil to plants, combinations of certain

TABLE 5–1. Dependence of Caesium Transfer on Soil Activity [2]

Product	Transfer coefficient (10^{-3} m^2/kg)		
	pH value of soil 4.5–5.5	pH value of soil 5.6–6.5	pH value of soil 6.6–7.5
Milk	0.4–3.2	0.2–0.5	0.2
Meat	1.2–1.8	0.6	0.3–0.6
Hay	15–20	5–7	2
Clover	0.8–2.9	0.3	0.1
Winter wheat	0.5	0.2	0.05

TABLE 5-2. Indication of Caesium Transfer from Soil to Meadow Grass [2]

Soil type	Transfer coefficient (10^{-3} m^2/kg)
Podzol, sandy	4–21
Podzol, clay	1.3
Light grey podzol, sandy	2.6
Meadow, sandy	2–10
Peaty	30–80
Peaty, bog	190

conditions can lead to unexpectedly high transfers. The reasons for this and indeed the mechanisms of soil-plant uptake themselves are not yet fully understood. An example of a high transfer from soil to meadow grass is presented in Table 5-2 along with other data. The transfer to pasture grass for peaty bogs is typically two orders of magnitude higher than that to clay podzols. Within areas in the USSR affected by the Chernobyl accident there are considerable areas of land with peaty soils used for the grazing of privately owned cattle, and for which the transfer to animal products can be relatively high.

Because of the geographic variability in soil type, pH, organic content, etc., the transfer of radiocaesium into crops varies from region to region. For example, Table 5-3 shows the uptake of ^{137}Cs in two areas of the UkrSSR with different soil and climatic conditions for 1988. Even within geographical regions, there are local variations due to the aforementioned factors that make the prediction of transfer difficult.

The transfer of caesium from soil to plants can be additionally altered by the application of lime, zeolites and fertilizers, which can lead to an order of magnitude reduction in transfer, again depending on the soil type, acidity and other factors in a way that is not fully understood. The transfer of strontium from soil to plants is not as variable as that of caesium, but much fewer data exist on this.

TABLE 5-3. Transfer Coefficient K_d for Caesium Uptake by Various Crops in the UkrSSR [3]

Type of crop	Product	Transfer coefficient (10^{-3} m^2/kg)	
		Polessye woodlands	Forest, steppe
Winter wheat, rye	Grain	0.15	0.02
	Straw	0.24	0.13
Barley, oats	Grain	0.10	0.02
	Straw	0.14	0.08
Maize	Grain	0.11	0.03
	Green matter	0.43	0.54
Fodder plants	Clover	1.0	0.53
	Lucerne	0.26	0.51
Potatoes (cleaned)		0.23	0.15

References for Annex 5

[1] VETROV, V.A., et al., "Radiation and migration characteristics of the Chernobyl radionuclides causing environmental contamination in various provinces in the European Sector of the USSR", Environmental Contamination following a Major Nuclear Accident (Proc. Symp. Vienna, 1989), Vol. 1, IAEA, Vienna (1990) 179–192.

[2] PRISTER, B.S., Oral presentation at IAEA Radioecology Seminars, Kiev, January 1991.

[3] KIRCHMANN, R., Agricultural Countermeasures Taken in the Chernobyl Region and Evaluation of the Results. Report by the International Union of Radioecologists, Commission of the European Communities, Luxembourg (1990).

Part F
Health Impact

Contents

1. Introduction

1.1. Aims

The main aims of the International Chernobyl Project Task 4 (Health Effects) Group were:

(a) To determine the current health status of the population still living in contaminated settlements;
(b) To determine which health problems, if any, are due to the Chernobyl accident but not to radiation exposure;
(c) To determine which health effects, if any, are due directly to radiation exposure;
(d) To determine what health effects may be expected from radiation in the future.

Task 4 was directed solely at those individuals who are currently living outside the 30 km zone and who are in contaminated settlements at this time. The request of the Government of the USSR was directed toward evaluation of this population specifically. It did not include the health of those who had already been evacuated or relocated, of the plant workers or of the decontamination workers.

There are three control zones now based on the level of caesium deposition on the soil (<5–15 Ci/km^2 (185–555 kBq/m^2); 15–40 Ci/km^2 (555 kBq/m^2–1.48 MBq/m^2); >40 Ci/km^2 (>1.48 MBq/m^2)). The areas of contamination are not contiguous and there are areas of hot spots within settlements. In general, the highest areas show approximately 100 Ci/km^2 (3.7 MBq/m^2) of ^{137}Cs. However, since the accident people have been living essentially continuously in settlements where the contamination levels exceed 40 Ci/km^2 (1.48 MBq/m^2) of ^{137}Cs.

Caesium body burdens in some areas of low contamination are higher than in highly contaminated areas. Some of this has to do with the soil quality and transfer factors in the soil and transfer to animals from place to place as well as with some people eating contaminated food in spite of published restrictions.

Most of the area affected is undeveloped and represents a large number of rural and farming settlements. The total number of settlements in the USSR in the strict control zone is approximately 800. Many or most of the streets in the towns are unpaved. The areas that are contaminated are somewhat unusual not only because they are undeveloped, but because they have special social structures that have existed for centuries and because their living and social structure is based on local agriculture. If the local agriculture does not continue, it is difficult to see how the small settlements will continue to exist.

There is a large problem with the population who is now perceiving most health disorders as being due to radiation exposure. It should be noted that prior to the Project two international groups (World Health Organization and the League of Red Cross and Red Crescent Societies) had conducted observational visits to areas affected by the Chernobyl accident (see Part A). Their conclusion was that there were psychological consequences but no direct effects of radiation upon health. Neither group had conducted an actual health study nor an exhaustive review of Soviet data.

1.2. Scope of Health Effects Study

The Task 4 Project was directed at an assessment of the health of the population still living in areas contaminated by the Chernobyl accident. In addition, potential health effects from the radiation exposure or otherwise attributable to the accident were to be assessed. The Task Group did not examine the health of the decontamination workers who took part in remedial measures related to the accident, nor did it examine the health of those persons who had already been relocated to other areas. The rationale for this was that the radiation exposure of those two groups had essentially ceased. The population who had lived in contaminated areas since the accident and was still living there was continuing to be exposed to radiation.

The purpose of the early missions was to locate and review as many official data as was possible in several months. No attempt was made to visit each scientist and physician in every city, but rather a general picture relative to the data in each of the three Republics was to be obtained.

Field trips (missions) were designed to corroborate official data, if possible, and potentially to examine some issues that were felt to be important which had not been comprehensively examined by Soviet scientists. The field trips were limited by the time, staff and equipment that were available. Thus the missions concentrated on the basic and most pertinent issues that could be assessed under existing field conditions in a two day trip to each settlement.

The first missions located and assessed official data relative to the following areas of concern:

— Dosimetry
— Anaemia
— Immune function
— Thyroid function
— Thyroid goitre
— Birth data
— Foetal and genetic effects
— Radiation cataracts
— General health statistics
— Lead poisoning
— Nutrition

— Iodine prophylaxis
— Health registers
— Cancer statistics
— Psychological aspects.

They were also used to design and evaluate a questionnaire for field trips as well as to design the field trips logistically. Field trips concentrated upon:

— Attitudes
— Stress effects
— Nutrition
— Iodine prophylaxis
— Haematological status
— Lead poisoning
— Growth parameters
— Thyroid function
— Thyroid structure
— Past medical history
— General physical examination
— Limited cytogenetics.

1.3. Plan of Task Group 4

Task Group 4 had the following general plan:

(a) To talk to persons in contaminated settlements and to local physicians to determine their current concerns (Mission 1);
(b) To prepare and present a proposal to address the purpose of the mission and concerns of the population and government (Mission 2);
(c) To locate and talk to Soviet physicians and scientists about their data which have been collected over the last 4.5 years (Mission 3);
(d) To conduct an educational effort for health care workers (Mission 4);
(e) To evaluate the current nutritional status (Mission 5);
(f) To have experts travel to the USSR and review selected data with the scientists and physicians who generated them (Mission 6). The main purpose was to make sure that the team's experts were interpreting official data correctly;
(g) To set up and calibrate equipment and conduct training for field trips (Mission 7);
(h) To design and conduct an epidemiologically sound method of studying the population living in contaminated areas in order to determine the current health status of the population as well as that of populations in nearby areas of negligible contamination (Missions 8, 9 and 10).

The structure of Part F of the Technical Report differs from that of the other parts in that, because of the many different technical issues addressed, each of them will be discussed separately. Each section addresses a single topic and is divided into the following subsections:

— Rationale
— Review of official data
— Results of field trips
— Summary.

Conclusions and Recommendations are presented in Part H of the Technical Report.

A listing of the data which were submitted by Soviet investigators and authorities is given at the end, as are the References.

2. Field Trip Design

2.1. General Comments

The field missions (8–10) were designed to address concerns and perceived health effects as outlined by the Soviet scientists, physicians and public as well as to look for radiation effects that had been documented in non-Chernobyl epidemiological studies. The topics (roughly divided) and some of the preliminary available comments are given in the following:

1. Dosimetry

— Cytogenetics
Essentially no official data available. Samples were to be taken to place an upper limit on whole body dose estimates.

2. Haematological

— Anaemia
Reported in Soviet studies.
Thought by some Soviet scientists to be related to dietary restrictions imposed as a result of the accident.
— Lead poisoning
Mentioned in most settlements.
Possible from lead dumped on reactor. Reported as positive in some children in the BSSR.
Could cause anaemia if severe.
— Immune function
Mentioned as a concern of Soviet physicians and population. Also mentioned as a cause of an increase in all diseases. Lymphocytes known to be radiation sensitive.
Lymphocytosis reported by some Soviet physicians.

3. Thyroid

— Goitre
Entire area stated to be an endemic goitre region. Soviet physicians indicated thyroid enlargement in up to 70% of the population in some areas.
— Nodules
Known to be caused by radiation exposure.
Latent period usually in excess of ten years.
Plan to establish baseline prevalence for later studies.
— Function
Reports of hypothyroidism.
— Ultrasound appearance
Soviet physicians reported abnormal ultrasound appearance.

4. Cataracts

Reported as a concern of Soviet physicians and population in settlements.

5. Epidemiology and Cancer

— Leukaemia
— Thyroid cancer
Both reported to have increased by some Soviet investigators.
— Other cancers
News media reported increases in incidence of all cancers.
Some Soviet scientists report increases in all types of cancers.

6. Cardiovascular

Reports of increases in all forms of cardiovascular diseases in contaminated areas by local physicians.

7. Foetal and Genetic

An area of concern expressed both by the population and local physicians.
The foetus is known to be more radiosensitive than the adult.

8. General Diseases

Some Soviet scientists and news media report increases in almost all diseases.

9. Psychological

Many reports of 'radiophobia', of stress associated diseases such as ulcers, headaches and hypertension.

10. Nutrition

Poor nutrition felt by Soviet population to be resulting in many diseases.
Scattered comments about trace element deficiencies.

Each medical field team had specialists in radiation effects, paediatrics, haematology, thyroid diseases, thyroid ultrasound and internal medicine. On one trip there was an expert in psychological/psychiatric aspects. There were three to four administrative persons assisting with the logistics. There were representatives of the World Health Organization on both expert review and field teams.

Missions 8–10 of Task 4 were for evaluation purposes only. Any persons found to need further evaluation or treatment were referred to the local health authorities, where possible the findings of the teams were entered immediately into the person's local clinic medical record.

2.2. Selection of Study Population

Since the field teams could examine only a relatively small fraction of the hundreds of thousands of persons possibly affected by the accident, it was important to choose the study population carefully. This was done on the basis of anticipated clinical problems and by using well established cross-sectional sampling techniques. The groups were chosen as follows:

Group 1: **2 year olds.** Born in 1988 (after the accident).
Chosen to look for: anaemia, lead poisoning, possibly rickets, nutritional problems.

Group 2: **5 year olds.** Born in 1986 (infants at the time of the accident).
Chosen to look for: thyroid function related to radioiodine ingestion, nutritional aspects.

Group 3: **10 year olds.** Born in 1980.
Chosen to look for: aspects related to endemic goitre and general health status.

Group 4: **40 year olds.** Born in 1950.

Group 5: **60 year olds.** Born in 1930.
Chosen to look for: aspects related to general health, cytogenetic studies of outdoor workers.

Groups 1–5 comprised the study groups and were identified on the basis of birth dates.

In small settlements persons were selected by the year of birth. In many small settlements the birth rate was about 40–50 per year. A sample size of 20 was used to obtain a sample size of at least 40%. In larger settle-

TABLE 1. Number of Persons Examined by the Medical Team

Republic	Settlement	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Total
		Year of birth: 1988	Year of birth: 1985	Year of birth: 1980	Year of birth: 1950	Year of birth: 1930	Other	
BSSR	Bragin[a]	25	31	25	25	17	45	168
	Kirovsk	22	23	19	21	19	35	139
	Khodosy	23	20	26	25	18	38	150
	Veprin[a]	14	23	25	8	14	29	113
	Korma[a]	18	23	22	20	19	27	129
RSFSR	Unecha	26	21	26	22	22	3	120
	Surazh	20	20	20	22	20	0	102
	Novozybkov[a]	21	22	21	23	21	1	109
	Zlynka[a]	24	27	26	19	20	2	118
UkrSSR	Trokovichi	17	22	23	9	18	68	157
	Narodichi[a]	23	19	22	19	19	5	107
	Polesskoe[a]	22	21	20	22	19	5	109
	Krasilovka, Chemer	19	21	21	21	20	33	135
Total		274	293	296	256	246	291	1656
BSSR	Surveyed contaminated	57	77	72	53	50	101	410
	Surveyed control	45	43	45	46	37	73	289
RSFSR	Surveyed contaminated	45	49	47	42	41	3	227
	Surveyed control	46	41	46	44	42	3	222
UkrSSR	Surveyed contaminated	45	40	42	41	38	10	216
	Surveyed control	36	43	44	30	38	101	292
Total	Surveyed contaminated	147	166	161	136	129	114	853
	Surveyed control	127	127	135	120	117	177	803

[a] Settlement in a contaminated area.

ments the birth dates were restricted to a number of months in the given year. In all settlements studied the sample sizes ranged from a low of 10% to a high of 80%. All birth dates were verified by examination of the patients' medical records. This was possible in 11 of 13 settlements.

Group 6 consisted of persons who were identified by the local health authorities and who wanted to be seen or who had a particular problem.

The number of persons in each group seen in each settlement was initially chosen to be 20. It varied slightly from a low of 17 to a high of 24, depending upon the availability of the persons and the team's attempt to make the sample size as large as possible within the constraints of supplies available to perform complete examinations.

In each settlement, a total of about 250 persons were seen. They received full examinations with the exception of Group 6, in which not all patients were fully examined since they were self-selected, often had a known problem for which they were seeking consultation and since the team's supplies would have been exhausted before the end of the missions. The data from this Group 6 (self-selected persons) were not used for final analysis except as an indication of how inclusion of such persons might bias results.

Since there might have been some movement of persons between settlements since the accident, all persons were specifically questioned as to their location at the time of the accident, in the month after the accident, and up to the time of the examination. These data were analysed by computer as a possible confounding factor.

Ministry of Health personnel from each Republic contacted the local physician in each settlement to allow notification of the persons of interest for this study. In addition, local authorities visited the field teams on site in a settlement that was being studied. This allowed an appropriate working place to be set up ahead of time as well as allowing the local officials and physicians to see what the teams were planning to do in their area.

Table 1 gives a numerical breakdown of the study population in Groups 1 to 6 in the surveyed contaminated settlements (Bragin, Veprin and Korma in the BSSR, Novozybkov and Zlynka in the RSFSR and Narodichi and Polesskoe in the UkrSSR) as well as in the surveyed control settlements. It shows that altogether 1656 persons underwent examination, 853 who live in surveyed contaminated settlements and 803 who live in control settlements.

2.3. Selection of Study Settlements

All settlements studied were chosen by the team leader of Task 4. Soviet authorities complied with all requests regarding the settlements selected by the teams. They were chosen to have a population of about 2000–50 000. This size was chosen so that the settlements were small enough to ensure that the persons studied represented a relatively large cross-sectional percentage of the population present. The settlements were also small enough to enable the group to contact easily the persons of interest and to have a relatively uniform food supply and contamination density. On the other hand, the settlements had to be large enough to have a polyclinic nearby, as well as a local physician. Visits were made to at least two settlements in each Republic that had contamination levels in excess of 15 Ci/km^2 (555 kBq/m^2) of ^{137}Cs. In one of the contaminated settlements, a portion of the population had been relocated. In all, seven contaminated settlements were visited.

The selected control settlements surrounded the contaminated regions. They were all at least 20 km beyond areas known to have contamination levels of 1 Ci/km^2 (37 kBq/m^2) of ^{137}Cs. Six such settlements were studied. These settlements were also selected for their radial distribution about the contaminated regions and to have populations of 50 000 persons or less. Control settlements were examined by the Project Environmental Group (Task 2) to confirm the fact that levels of contamination were only very low. Most control settlements had an external mean dose rate of less than 0.15 μSv/h. Samples of bread, milk, vegetables and meat were also examined from these control settlements. Analysis

TABLE 2. Population Number and Birth Rates in Selected Settlements

Republic	Settlement	Total population	Year	Birth rate per year
BSSR	Bragin	5 888	1989	55
	Kirovsk[a]	10 000	1990	150
	Khodosy[a]	2 400	1990	35
	Veprin	1 048	1986	7
	Korma	7 201	1989	100
RSFSR	Unecha[a]	14 000	1990	200
	Surazh[a]	5 000	1990	60
	Novozybkov	49 400	1988	600
	Zlynka	5 600	1988	75
UkrSSR	Trokovichi[a]	4 500	1990	45
	Narodichi	6 334	1989	60
	Polesskoe	11 800	1989	160
	Krasilovka, Chemer[a]	2 500	1990	40

[a] Estimate.

revealed low levels of contamination, as expected. Detailed results of these measurements are presented in Part D.

Population statistics of the various settlements were obtained from Ministry of Health data in some instances for 1986 to 1989. They are shown in Table 2. In a few instances the population number and birth rate in a settlement were estimated by local authorities and the chief physician.

2.4. Quality Control Methodology

The selection process of persons examined and the use of specific age groups were designed to eliminate the potential bias of either self-selection or local physician selection on the basis of disease.

In order to minimize learning effects of the field teams on the examination process, each field team visited both contaminated and control settlements. The settlements were visited in a random order for each of the three field trips (Missions 8–10). The order was as follows:

Mission 8:	Trokovichi	(control settlement)
	Narodichi	(contaminated settlement)
	Polesskoe	(contaminated settlement)
	Krasilovka, Chemer	(control settlement)
Mission 9:	Unecha	(control settlement)
	Surazh	(control settlement)
	Novozybkov	(contaminated settlement)
	Zlynka	(contaminated settlement)
Mission 10:	Bragin	(contaminated settlement)
	Kirovsk	(control settlement)
	Khodosy	(control settlement)
	Veprin	(contaminated settlement)
	Korma	(contaminated settlement)

All physician examinations were identified by a physician code to allow later analysis for examiner biases.

To eliminate differences in results of examinations or tests caused by use of different equipment, the same pieces of equipment were used for all three field trips for a given examination. To eliminate technical differences between the operators, standards were utilized daily or the equipment settings were standardized at the beginning of the field trips and maintained throughout all the trips. To minimize operator dependent changes, either the same operator was used throughout the field trips (as in the case of the haematological analysis on the Coulter T 660) or the number of operators was minimized. These operators were trained and worked together for the first two weeks to standardize protocol (as in the case of thyroid ultrasound).

The four interpreters received instructions from the team leader at the beginning of the field trips as to the exact meaning and interpretation of each question on the questionnaire. The same four interpreters were present for all six weeks of the field trips to help local persons fill out the forms correctly. In order to avoid biases on a local basis, local medical staff in the settlements were not used for patient interaction during the filling out of the questionnaire.

In order to eliminate differences in results due to materials, identical lot numbers of radioimmunoassay kits, slides, reagents, test tubes, etc. were used for all field trips. These are specified in the protocols provided.

All tests that were not performed on site were analysed by the same laboratory. Split samples and controls were provided for all such tests. Specifics are provided in each written protocol.

All samples were identified only by number. For each study person, there was a computer generated set of labels for the questionnaire. There were six such labels for each person entered. The set of labels was stapled to the questionnaire and the labels were used as needed. Use of the computer labels minimized hand-writing of patient numbers. Each label was backed with water resistant glue so that the labels would not come off the samples if they were refrigerated or frozen. Each number was unique and contained a terminal check digit. This check digit was based upon a mathematical algorithm of the patient's number. The check digit allowed any number that was handwritten to be checked for accuracy and/or digit transposition. Until all samples and Project analyses were completed the correlation of the identifying numbers to the patient name or settlement was only known to Drs Mettler and Royal.

To eliminate bias of results, interpretation and analysis were not done by the persons who collected the data. The data from the questionnaires were entered onto computer tape by experienced keypunchers of the New Mexico Tumor Registry who had no knowledge of which settlements were contaminated and by persons who had no other connection to this project. One third of the results were double entered to examine the data for keypunch error. Less than one error per 2000 entries was found. Information was placed on magnetic tape at 1600 BPI (bytes per inch) in both ASCII and EBCDIC formats. The data tapes were analysed independently in the United Kingdom and in Japan. As an initial step in analysis, outlying values were identified and referred to the Task Leader for rechecking of the original data forms. This was done to eliminate residual keypunching errors. Less than one error was identified per 10 000 entries.

Prior to operation of field equipment by Soviet personnel, there was appropriate training (Mission 8). Prior to use of the Coulter T 660 for haematological analysis, a technologist was sent from the University of New Mexico Hospital to the All-Union Scientific Centre for

Radiological Medicine (AUSCRM) in Kiev for a week to train the Soviet personnel. In addition, a technologist came from Coultronics (Paris) to calibrate the machine and provide additional training. Before the field trips, several team members were also provided with training sessions in operation, maintenance and simple repair of this equipment.

Written protocols were provided for all examinations and procedures. These included how all measurements were made, including the patient's height, weight and blood pressure. Protocols also were provided for all laboratory tests as well as for the medical examinations. Each field team had a one day's orientation and training session immediately before work on a field trip started. All sessions were conducted by Dr. Mettler.

Quality control items related to the nutritional field trip are presented in the nutrition section of this report.

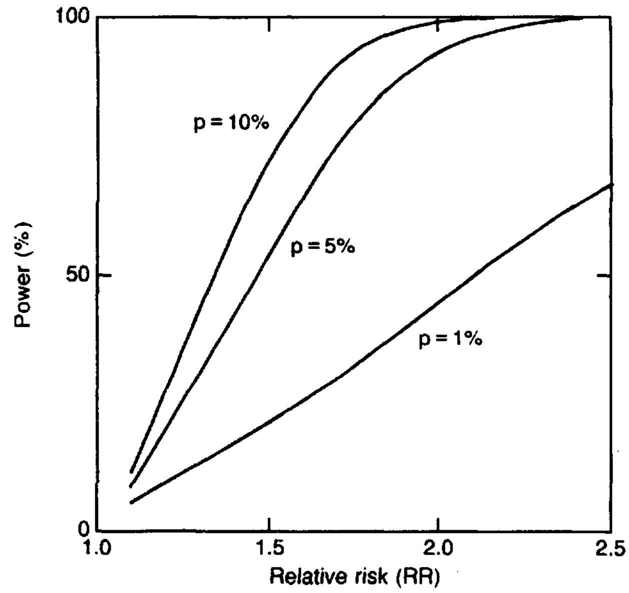


FIG. 1. Probability (power) of detecting a difference between exposed and non-exposed populations based on samples of 700 persons from each when the statistical test is carried out at the conventional 5% level.

2.5. Limitations of the Field Studies

In spite of the use of appropriate randomization and sampling methods, use of standardization, independent analysis of results, etc. there are some limitations of the study that should be understood.

The medical study sample comprised about 1700 persons from the 13 surveyed contaminated and control settlements. Samples of these persons were statistically compared in order to investigate the relationship between contaminated and control groups. The study was not a complete census of health effects on people in contaminated and comparable uncontaminated areas. Indeed, given the resources available, such a census would be impossible. Rather, the results described in this report are based upon a sample of the population of interest. If it can be assumed that the examination participants are a representative sample of the population of interest, then standard statistical methods can be used to estimate prevalence and to test hypotheses about differences in the prevalence of health effects in the study regions. In addition, statistical methods allow us to determine the precision of estimates of the population prevalence and differences between the study and control areas. Although the statistical power of this study to detect differences in prevalence for relatively rare conditions, e.g. less than 10%, is limited because of the small sample size, the information obtained here can be used to design future studies.

Figure 1 shows the probability (power) of detecting a difference between exposed and non-exposed populations based on samples of 700 persons from each when the statistical test is carried out at the conventional 5% level. This figure indicates that if the health effect of interest is present in 5% of the non-exposed population (prevalence = 5%) and the exposure resulted in a doubling of the risk (relative risk (RR) = 2.0), then the probability of detecting this difference is over 90%. If the RR is 1.5, the probability of detecting the difference is slightly over 50%. If the prevalence of the health effect in the non-exposed population is 10%, the study has a power of almost 100% to detect the RR of 2.0 and about 70% to detect the RR of 1.5.

The time of the year that the study was conducted would be expected to affect the findings in terms of radionuclide burden (for example, many of the children were away at camp during the summer). Also, the nutritional status might have been affected by the choice of the season; this could, in turn, affect the severity of anaemia and other findings, to some extent. It is probable that the population, especially the children, are healthiest at the end of the summer and harvest season. We believe, however, that it would be most unlikely that severe health abnormalities would completely disappear as a result of this factor and clearly some health disorders such as cardiac disease and cancer should have remained unaffected.

The study concentrated on specific rural settlements of small to moderate size. The reason for this was because the highest levels of contamination were located in such settlements and if radiation effects were to be detected the probability would be highest in these locations. Whether the results of the study can be extrapolated to cities is to some extent unknown. Certainly, in terms of pollutants and availability and type of food, there may be differences between rural areas and cities (such as Gomel). Almost certainly, there is both better access to medical care and better medical care in the larger settlements and cities. This might lead to higher detection rates of disease at earlier stages in the cities.

For some of the major areas of health concern, however, such as hypertension, there do not seem to be major differences between the settlements the Project teams visited and the prevalence rates reported in Moscow and Leningrad (see, for example, the later section on hypertension).

If longitudinal studies are to be carried out in the future and are to be compared with the work of Task 4, the same methodology and settlements should be utilized to obtain valid and comparable data.

Since the teams of Task 4 examined specific age groups, the prevalence of various diseases and the findings apply only to that specific age group and not to the population as a whole. One needs to remember that the purpose of this study was to look for differences in health that were the result of the accident, not to determine exact rates of diseases. Since the examination methodology was the same in control and contaminated settlements, if there are biases in this regard they are systematic in nature.

There was not an exhaustive medical workup of each person. For example, pelvic and rectal examinations were not performed. In this regard, the results may be incomplete with regard to the total amount of disease that may be present in the population. They are considered adequate to indicate the amount of disease that would be defined in a well conducted screening examination of a population.

The results and data obtained by the medical teams represent the state of health at a given point in time (September and October of 1990). It is possible that the rates of diseases have changed in the four years since the accident. Therefore, the results may not exactly compare with results obtained by Soviet physicians in the same settlements at other points in time.

The results presented in this report were obtained by using the very best technology available. Such technology often was not available in the past to Soviet physicians and scientists. Therefore, the results obtained are not exactly comparable. For some parameters, however, the results obtained by the medical teams turned out to have reasonably good correlation to previous Soviet work.

2.6. Protocols and Methodology for Missions 8–10

2.6.1. Questionnaire

2.6.1.1. General

The bilingual, single sheet folded questionnaire was used as a source of data for patient identification and data recording. The questionnaire was developed with the Institute of Biophysics (Moscow), the AUSCRM in Kiev and the Republican Ministries of Health. The form was tested on a trial basis on Soviet hospital patients and reviewed by four epidemiologists (from Japan, the UK and the USA) prior to printing. The single folded sheet of paper was used to minimize loss of portions of the data. Each form was filled out by the patients upon initial arrival at the study site with the aid of four interpreters. The interpreters were instructed about the exact meaning and interpretation of each question. All forms were collected and reviewed for completeness before the study population left the study site.

The field trip protocol provided specific instructions regarding each entry on the questionnaire.

Entries 1–2

Settlement
The actual name of the settlement was recorded by the study group persons or their accompanying parents. In addition, a study settlement code number was placed on each form by the administrative support staff.

Patient identification
This was accomplished by use of the computer generated labels. The first label was removed from the label sheet and affixed to the top of the questionnaire. Other labels were removed as needed for the samples.

Entries 3–43

These were questions related to patient demographics, diet attitudes, etc. This portion was filled out by the study persons themselves (for Groups 4 and 5) or by the parents or relatives of the children (for Groups 1–3).

Entries 44–72

Past medical history
This was filled out by the same persons as replied to questions 3–43. For the children (Groups 1–3), the accompanying adults filled out information relating only to the children.

Entries 73–91

Medical examination
This portion was filled out by the field team physicians. (See later portion of protocol for specific methodology.)

Entry 92

Physician codes
The physician(s) examining the patient entered their codes.

2.6.1.2. Laboratory Results

Entries 93–108

There were three copies of the results of the Coulter counter haematological analyses. The top copy of the results was detached on the day of examination and given to the polyclinic physician for entry into the polyclinic records. The second copy was detached and sent to the Radiation Effects Research Foundation (RERF) in Hiroshima, Japan. The third copy of the Coulter counter printer results was stapled to the questionnaire. All haematological results were examined by the medical team leader at the end of each day and those with abnormal findings were brought to the attention of the local medical authorities before the team left that settlement or town. The results on the third copy were entered into the computer. Thyroid function, lead analysis and microscopic analysis results were also directly entered into the computer as they became available.

2.6.1.3. Thyroid Ultrasound

Entries 109–113

These entries were made by the field team physician performing or present during the procedure and were based upon real time ultrasound examination. If a positive finding was identified, a thermal printer image was obtained of the abnormality and stapled to the questionnaire. In addition, a longitudinal image of the right lobe of the thyroid was obtained for all patients. This included the dimensions of the right lobe and the calculated volume. It was also stapled to the form.

A thyroid nodule was defined for purposes of this study as "an abnormality in echogenicity that was 5 mm or more in diameter". Abnormalities as well as thyroid dimensions were recorded in the patient's local clinic medical record when it was available.

2.6.1.4. Final Check

This was performed by Project administrative staff prior to the study person leaving the study site.

2.6.2. Height

The patient's height was measured in centimetres after shoes had been removed. The result was entered immediately on the form.

2.6.3. Weight

The weight, without shoes or overgarments, was recorded in kilograms. Patients were allowed to wear shirts, pants, skirts, socks. They were asked to remove obviously heavy items from their pockets.

2.6.4. Blood Pressure and Pulse

Blood pressure was taken by a physician prior to haematological and physical examination. The room that was used was chosen to be as far from the venopuncture room as practical and it was chosen to be as quiet as possible. A paediatric sphygmomanometer (cuff) was used on all children under the age of ten.

The brachial pulse was used with the patient seated upright. The sleeve was rolled up above the cuff unless the sleeve was too tight, in which case the shirt was removed. The arm was placed at the level of the heart and the cuff was snug prior to inflation. The deflation rate of the cuff was at 2–3 mmHg/s.

A person with a diastolic pressure ≥ 90 mmHg or a systolic pressure ≥ 140 mmHg had another measurement made by a different physician who was performing the general medical examination about 30 min later. This second measurement (if different) was also recorded on the data sheet.

2.6.5. Physical Examination

The physical examination was performed by a physician with an interpreter present. A female interpreter was present at the examination of every female.

The examination included review of the patient's past medical history, current medications and current symptoms. There was an examination of the ears, eyes, nose and throat. No visual acuity examination was performed. There was an auscultatory examination of the heart and lungs, palpatory and auscultatory examination of the abdomen, examination of the skin, back and extremities. A general neurological examination with reflex testing was also performed. No breast, pelvic or rectal examination was performed.

An abnormality was listed when the examining physician felt that there was an abnormality so severe that the person should currently be under the care of a physician or should be seen by a physician for follow-up treatment. All questionnaires were reviewed for uniformity.

2.6.6. Haematology

All personnel drawing or handling blood were requested to wear latex gloves. Sterile preparation of lancet or venopuncture sites was performed with alcohol preparation pads. Venopuncture was used on all persons over the age of two. Venopuncture was attempted on the two year olds but if unsuccessful a finger stick was made using a disposable lancet. All samples submitted for thyroid function or blood lead studies were collected by venopuncture. Disposable needles and syringes or disposable vacutainers were used for blood collection.

On-site haematology testing was performed using one of the two Coulter T 660 systems. The same machine was used throughout and the second system was kept for backup but was not needed. All samples were handled by a single operator for all field trips. The operator had received training in both machine operation and repair for a period of one week prior to the beginning of the field trips. All reagents used were supplied in Uni-T-Paks and were premixed (lot No. 12905).

The Coulter T 660 model performed red blood cell count (RBC), white blood cell count (WBC), haemoglobin (Hb), haematocrit (Hct), mean corpuscular erythrocyte volume (MCV), platelet count (Plt), lymphocyte number and lymphocyte %. These parameters were performed on a 0.1 mL sample of blood in EDTA anticoagulant.

The EDTA vacutainers were manufactured by Becton Dickinson and an identical lot number (OS008) was utilized for all analyses. The EDTA microtainers used for small children were also manufactured by Becton Dickinson (lot No. QE587). A triplicate analysis was done and averaged. The analysis time was one minute per sample. To avoid data loss all results were directly printed in triplicate. One copy was stapled to the questionnaire, one was sent to RERF in Japan and the third was given to the local physician for inclusion in the person's medical record.

Prior to operation each day, standards were run to include each of the above parameters in high, low and normal ranges. The machine was not operated unless all the 24 tests were within manufacturer defined standard deviations. In addition, a blood sample from the team leader was taken each day of the mission and used as a biological control. This sample was rerun each hour of the day to detect possible drift in calibration. Weekly preventive maintenance was carried out according to manufacturer's specifications. The machine was always operated with an electrical power conditioner and surge suppressor. All haematological samples were analysed within 15 minutes of venopuncture. During the interval they were constantly mixed by an electrical mixer.

Blood smears were made on the site with microscope slides brought from the USA. All glass slides were new and were manufactured by the Clay Adams Division of Becton Dickinson. An identical lot (No. 2450) was used for all smears made.

Two slides were made for each person. Both were air dried and stained on the site in Copeland jars using a three step fixation and stain technique. The stain and fixative were from an identical lot for all slides in the study. Each slide was labelled in pencil with the unique subject number.

One stained slide for each subject was forwarded to the AUSCRM in Kiev. The second slide was sent to the RINMB (Research Institute for Nuclear Medicine and Biology) at Hiroshima University, Japan, for differential and microscopic analysis. Some of the slides were restained prior to microscopic analysis.

2.6.7. Thyroid Function

2.6.7.1. Radioimmunoassay

The thyroid function tests consisted of radioimmunoassay of thyroid stimulating hormone (TSH) and free tetraiodothyronine (T4). Blood for thyroid function was drawn from all persons in Groups 2–5. Some samples were drawn from Group 1 (children age 2) patients if venopuncture was done. Efforts were made to draw only as much blood as necessary from the children, and microtainers (rather than standard vacutainers) were available and used when appropriate.

All persons in Groups 2–5 had blood collected in a 3 mL brown stoppered gel serum separation tube. These were serum separation tubes (SST) manufactured by Becton Dickinson and all had an identical lot number (0B911). Samples were allowed to clot for 30 min and then centrifuged at 4000 rev/min for 3–4 min to separate cells and serum. These samples were labelled with the computer generated label containing the patient identification number.

Samples were examined after centrifugation. Only those samples which contained at least 1 mL of serum were sent for analysis. As many samples as possible were sent from Group 2 (age 5) subjects. At least five and, preferably, ten samples were sent from each of Groups 3–5. These were chosen as the samples that contained the most serum for analysis.

Samples were refrigerated within an hour of drawing and were then transported in a refrigerated cooler by car to AUSCRM for analysis. All samples were sent for analysis within 72 hours. Each set of samples also contained a biological standard which was marked with a computer generated label with a number known only by the team leader and not known by the analysing laboratory.

The radioimmunoassay kits were manufactured by Becton Dickinson. Both the TSH and the free T4 were ^{125}I labelled solid phase component systems.

The normal range for the TSH test was 0.60–4.96 μIU per mL with the hyperthyroid range being 0.0–0.2 μIU/mL and the hypothyroid range being greater than 13.2 μIU/mL (μIU refers to micro International Units per mL of blood assuming a haematocrit of 55%).

The normal range for the free T4 was 0.7–1.7 ng/dL. For hyperthyroidism the range is 1.7–11.4 ng/dL and for hypothyroidism it is 0.1–0.7 ng/dL. The actual machine used for counting was a Gamma Trac 1191 TM analytic spectrometer.

During the first field trip, the Project team visited the radioimmunoassay laboratory at AUSCRM in Kiev to review the methodology of the thyroid radioimmunoassay. During this visit, laboratory handling of the specimens, calibration of the instruments and the binding curves were examined. Over 90% of all samples were run in duplicate.

A second backup method used to test thyroid function (TSH) involved the use of special pure cotton linter paper with no wet-strength additives. The Type 903 specimen collection papers used were all of an identical lot number (W891) and were manufactured by Schleicher and Schuell, Inc. A patient identification number label was applied to the paper. Blood was applied to the paper in an amount sufficient to fill a designated printed circle and to soak through the paper. These blood spot samples were collected from all persons in Groups 1–5 (including the 2 year old children).

These filter papers were air dried, collected and placed in a large brown envelope. They were kept cool (not refrigerated) and in the dark. They were hand carried to the USA for subsequent analysis.

Samples were analysed at the New Mexico State Chemistry Laboratory in Albuquerque, New Mexico, USA. The method used was a double antibody ^{125}I radioimmunoassay. All kits were obtained from Diagnostic Products Corporation. All samples were analysed in duplicate and calibration was done using a standard curve constructed from supplied blood spot disk calibrators. With this method normal values are TSH of 25 μIU/mL or less, possibly abnormal are values of 26–80 μIU/mL and definite abnormality prevails when the TSH level exceeds 80 μIU/mL.

2.6.7.2. Thyroid Physical Examination

Thyroid palpation was performed on all subjects by the thyroid endocrinologist of the team. This was done with the examined person standing as well as sitting. Both visual and palpatory examination was performed. Water was available so that patients could swallow when necessary. Assessment was made of thyroid size (0 = normal, 1 = enlarged) and of nodularity (0 = normal, 1 = nodular). Additional comments were also made as needed by the individual examiner. The physician also specifically inquired about previous personal and family history of thyroid disease as well as the use of thyroid medication or stable iodine preparations.

2.6.7.3. Thyroid Ultrasound

Thyroid ultrasound was done on all persons in Groups 2–5 (that is, not on the 2 year old children). Thyroid ultrasound was done using a single machine (Hitachi Medical Corporation, Tokyo, model EUB-310) with a 7.5 MHz linear array transducer for all patients. The machine was equipped with an electrical surge suppressor and power conditioner supplied by Coultronics. All examinations were carried out by one of three operators who all worked together for the first two weeks to assure uniformity of methodology. Interoperator and intraoperator variabilities were tested regarding the measurement of thyroid volume, and the variability was within 20% for both.

The examination was done with the person supine and the neck extended when possible. In older hypertensive subjects the examination was performed with the person sitting and the neck extended.

The same technical settings were used for each patient including power, contrast and gain. Contact gel (manufactured by Parker Laboratories) was used on all patients. The length, thickness and width of the right lobe were measured in the maximal dimension. The formula used to calculate the volume of the lobe was:

$$\text{Vol} = (3.1416/6) \times D1 \times D2 \times D3$$

where D refers to the dimension of the lobe in maximal length, width and thickness. This formula was built into the software of the machine. The volume of the right lobe was multiplied by 2 to obtain total gland size. This methodology was compared for 30 persons with measurements made of each lobe individually and then summed. The difference between the two methods was less than 15% in total volume in over 90% of the subjects.

A thermal paper printer (Mitsubishi Video) was used to obtain a single longitudinal image of the right lobe. This was done on thermal paper manufactured by Mitsubishi. All images were stapled to the questionnaire.

The homogeneity of the gland was determined by the thyroid ultrasound expert on the team utilizing real time examination of the gland. Areas of non-uniformity >5 mm constituted the diagnosis of a non-uniform or nodular gland. Any gland diagnosed as abnormal had an additional image printed of the abnormality, which was stapled to the questionnaire. When possible this was also included in the person's clinic record.

2.6.8. Lead Samples

Hair and fingernail samples were not used for lead analysis since the results were felt to be less reliable than is analysis of blood obtained by venopuncture. Blood samples were taken in each settlement from persons in Groups 1 and 2. The samples chosen were based upon the amount of blood left in the EDTA vacutainer tube after Coulter haematological analysis. Those samples containing the most blood (and a minimum of 2 cm^3) were refrigerated and sent by air to the USA for analysis.

They were analysed by ESA Laboratories in Bedford, Massachusetts. The laboratory had only the computer generated labels and did not know which samples came from which settlement. The analytical method was flameless atomic absorption. The normal value for the laboratory was less than 29 mg/dL.

Biological controls were also sent for analysis, as were some empty tubes of the same lot number for analysis of lead that could have been leached from the glass in the tubes. No significant leaching was identified.

2.6.9. Cytogenetics

Blood samples were obtained for cytogenetic analysis (chromosome aberrations and somatic cell mutation) in settlements that were visited during the last week of each team's visit mainly from persons who were suspected of having the highest exposure and internal burdens. These were adults who worked outdoors (farmers, foresters). The samples were at least 10 mL in volume. They were placed in heparinized tubes and refrigerated and flown to Japan for analysis at RERF. Chromosome analysis was performed at RERF and also by the IAEA Co-ordinated Research Programme in Blood Culture Methods.

The lymphocytes were cultured at RERF using the following culture method:

Culture medium: A total of 10.3 mL (RPMI 1640: 8.0 mL, L-glutamine: 0.1 mL, foetal bovine serum: 2.0 mL; PHA (Wellcome): 0.2 mL), to which 1.0 mL of heparinized whole blood was added.

Incubation of culture: Temperature: 37°C in CO_2 incubator with 95% air and 5% CO_2 gas.
Time: 48 h including the last 24 h for Colcemid treatment (0.2 g/mL).

Hypotonic solution: 1% sodium citrate solution (1 part) and 0.075M KCl solution (3 parts).

Fixative: Methanol (3 parts) and glacial acetic acid (1 part).

Harvest: Conventional air drying method. For each case 5 (4–6) slides were prepared.

Stain: 2% Giemsa solution (pH 6.8) for 15 min, and then all slides were mounted with a coverslip using Eukitt.

Of the 189 blood samples sent to RERF, 107 samples were cultured successfully. Cytogenetic examination was performed at RERF on the first 50 cases. For the remaining 57 cases, microscopic work was conducted, through the courtesy of the IAEA international research collaboration, by five cytogenetic laboratories in Europe and the USA. Attempts were made for each laboratory to score 200 well spread metaphases per sample for the presence of dicentrics, rings, fragments, and other aberrations of an unstable nature. However, the number of metaphases scored did not reach 200 in 4 out of the 50 samples examined at RERF.

Chromatid type aberrations were scored by some laboratories, but the data will not be included in the present analysis because of the lack of uniformity in scoring procedures among the laboratories.

2.7. Patient Flow

In the setting-up procedure at a given settlement, the most effective patient flow or traffic pattern was:

Reception
Introductory statements
Questionnaire
Height, weight, blood pressure, pulse
Haematology
Thyroid palpation
Thyroid ultrasound
Physical examination (review laboratory results)
Final checklist

In the following a sample of the HEALTH EFFECTS QUESTIONNAIRE is shown.

ВОПРОСНИК ПО ЭФФЕКТАМ ЧЕРНОБЫЛЯ НА ЗДОРОВЬЕ

CHERNOBYL HEALTH EFFECTS QUESTIONNAIRE

1. Деревня ____________________
Village of study

2. Идентификация пациента ____________________
Patient identification

3. Кого осматривают: Вас___, Вашего ребенка___
Who is being examined: you, your child

4. Сколько лет Вы учились в школе ______
Number of years of school that you have had

5. Фамилия человека, которого осматривают ________________
Family name of person being examined

6. Имя человека, которого осматривают ________________
Personal name of person being examined

7. Отчество человека, которого осматривают ______________
Surname of person being examined

8. Дата рождения человека, которого осматривают (день, месяц, год)
____ ____ ____
Birth date of person being examined (day, month, year)

9. Пол: М Ж
Sex: M F

10. Номер паспорта человека, которого осматривают ________________
Passport I.D. number of person being examined

11. Находились ли Вы в этой деревне первый месяц после аварии: да___, нет__
Were you in this village for the first month after the accident: yes, no

12. Если Вы не находились в этой деревне первый месяц после аварии, где Вы находились ________________
If you were not in this village the first month after the accident, where were you?

13. Жили ли Вы в деревне после 1986 года: да___, нет___
Have you lived in the village since 1986: yes, no

14. Если осматривают Вашего ребенка: жил ли он в этой деревне всю свою жизнь: да___, нет___
If your child is being examined, has he or she lived in this village since birth: yes, no

ДРУГИЕ ВОПРОСЫ ДЛЯ ОТВЕТА ПАЦИЕНТА ИЛИ ЕГО РОДИТЕЛЕЙ
OTHER QUESTIONS TO BE ANSWERED BY PATIENT OR PARENT

15. Какое домашнее животное у Вас имеется: корова__, коза__, никакое__
What farm animals do you have: cow, goat, neither

16. Ваша профессия ____________________
What is your occupation

17. Подчеркните нужное, относящееся к Вам:
Underline all that applies to you:

Работа на открытом воздухе	Work outdoors
Работа в помещении	Work indoors
Мать ребенка	Mother
Пенсионер	Retired
Ребенок	Child
Другое	Other

18. Сколько членов семьи живет с Вами _____
How many persons in your family live with you

19. Сколько килограммов кафтофеля потребляет Ваша семья в неделю _______
How many kilograms of potatoes does your family eat per week

20. Сколько килограммов хлеба потребляет Ваша семья в неделю _________
How many kilograms of bread does your family eat per week

21. Сколько раз в неделю Вы едите зеленые листовые овощи летом ________
At how many meals per week do you eat green vegetables at summertime

22. Сколько раз в неделю Вы едите мясо _________
At how many meals per week do you eat meat

23. Пили ли Ваши дети загрязненное молоко во время аварии или скоро после нее: да___, нет___
Did your children drink contaminated milk during or shortly after the accident

24. Сколько стаканов молока в день выпивают Ваши дети сейчас _________
How many glasses of milk do your children drink per day now

25. Молоко, которое пьет Ваша семья сейчас, загрязненное: да___, нет___
Is the milk your family drinks now contaminated: yes, no

26. Применяли ли Вы препараты стабильного йода: да___, нет___, не знаю___
Did you take stable Iodine: yes, no, don't know

27. Даты начала применения _______________
Date started

28. Даты конца применения _______________
Date ended

29. В каком виде: таблетки___, растворы___
In what form: tablets, solutions

30. Применяли ли Вы препараты стабильного йода больше чем в одном случае: да___, нет___, не знаю___
Did you take stable Iodine on more than one occasion: yes, no, don't know

31. Хотите ли Вы выехать из этой деревни: да___, нет___, не уверен___
Do you want to move from this village: yes, no, not sure

32. Вы употребляете крепкие напитки?
Никогда___, редко___, иногда___, часто___
Do you drink hard liquor? Never, rarely, sometimes, frequently

33. Курили ли Вы иногда в своей жизни: да___, нет___
Have you ever smoked: yes, no

34. Вы курите сейчас: да___, нет___
Are you smoking now: yes, no

35. Чувствуете ли Вы себя иногда таким усталым, что Вы утром совсем не встаете? да___, нет___
Do you sometimes feel so tired that you do not get up in the morning? yes, no

36. Сколько часов Вы в среднем спите ночью _____________
On the average how many hours do you sleep per night

Ответьте на нижеперечисленные вопросы, отметив один из предлагаемых ответов: согласен 1 не уверен в ответе 2 не согласен 3
Rate the following statements on a 3 point scale as follows:
agree 1, not sure 2, disagree 3

37. Уровень радиоактивного загрязнения снижается 1 2 3
The level of radiation contamination is going down

38. Наше молоко сейчас безопасно для питья 1 2 3
Our milk is now safe to drink

39. Правительство должно переселить всех людей, живущих здесь 1 2 3
The government should relocate all persons living here

40. Низкий уровень радиации безопасен 1 2 3
A small amount of radiation is safe

41. Я думаю, что я болен от облучения 1 2 3
I think I have an illness due to radiation

42. Моя семья не имеет достаточного количества безопасных продуктов
My family does not have enough healthy food to eat 1 2 3

43. Проблемы Чернобыля будут в основном решены за следующие 10 лет 1 2 3
The problems related to Chernobyl will be mostly solved within the next 10 years

ПРЕДШЕСТВУЮЩЕЕ СОСТОЯНИЕ ЗДОРОВЬЯ ЧЕЛОВЕКА, ОСМАТРИВАЕМОГО СЕГОДНЯ
PAST MEDICAL HISTORY OF THE PERSON BEING EXAMINED TODAY

Поставьте крестик, если осматриваемый сегодня человек имел перечисленные жалобы (признаки) в течение последних 2 месяцев
Put a check in the box if the person being examined today has had any of the following complaints during the last 2 months

44.___ Утомление
Fatigue

45.____ Головная боль
Headache

46.____ Потеря аппетита
Loss of appetite

47.____ Носовые кровотечения
Nosebleeds

48.____ Ангина
Sore throats

49.____ Выпадение волос
Hair loss

50.____ Нерегулярные менструальные циклы
Menstrual irregularity

51.____ Увеличение веса
Weight gain

52.____ Потеря веса
Weight loss

53.____ Боли в груди
Chest pains

54.____ Жидкий/задержанный стул
Diarrhea/Constipation

55.____ Психологическая депрессия
Mental depression

56.____ Онемение рук
Numbness in hands

57.____ Гипертония
Hypertension

58.____ Опухоли
Tumor

59.____ Нарушения или увеличение щитовидной железы
Thyroid abnormalities or goiter

60. Имеют другие члены семьи нарушения щитовидной железы: да___, нет___
Do any other persons in family have thyroid abnormalities: yes, no

61.____ Затрудненный слух
Difficulty hearing

62.____ Боли в шее
Neck pain

63.____ Потеря памати
Memory loss

64.____ Боли в пояснице
Low back pain

65.____ Кровь в стуле
Blood in stool

66.____ Кровь в моче
Blood in urine

67.____ Малокровие
Anemia (little blood)

68.____ Туберкулез
Tuberculosis

69.____ Частый кашель
Frequent cough

70.____ Сахарный диабет
Sugar diabetes

71.____ Снижение зрения
Decreased vision

72.____ Другие
Other

MEDICAL EXAMINATION (to be filled out by medical team)

73. Height _____ cm

74. Weight _____ kg

75. Blood pressure ____/____

76. Pulse _____/min

Check if abnormal — Abnormality:

77.____ Skin ______________________________

78.____ Eyes ______________________________

79.____ Ears ______________________________

80.____ Nasopharynx ______________________________

81.____ Thyroid

82. ____ Enlarged ______________________________

83. ____ Nodules

84.____ Heart ______________________________

85.____ Lungs ______________________________

86.____ Abdomen ______________________________

87.____ Kidneys ______________________________

88.____ Neurological examination ______________________________

89.____ Peripheral pulses ______________________________

90.____ Joints ______________________________

91. Comments: ______________________________

____

92. Physician Codes

______ ______

______ ______

______ ______

LABORATORY RESULTS

Hematologic Examination

93. Hb_____
94. Hct_____
95. RBC_____
96. MCV_____
97. MCHC____
98. WBC_____
99. Differential _____ granulocytes
100. _____ monocytes
101. _____ eosinophils
102. _____ lymphocytes
103. _____ reticulocytes
104. Platelet count _____

105. Blood smear made: yes____ no_____

Thyroid
106. TSH_____
107. Free T4_____
108. Blood spot for TSH_____

Ultrasound Thyroid
109. Homogenous: yes____ no____
110. Length mm _____ measure right lobe
111. Thickness mm _____
112. Width mm _____
113. Total volume _____ both lobes

114. Sample taken for lead: yes____ no____
115. Type of sample: blood___, blood spot___, hair___
116. Lead result ___________
117. Cytogenetic sample taken: yes____ no____
118. Cytogenetic dose estimate ___________

FINAL CHECKLIST
- Identifying information 2-10 _____
- Historical data 11-72 _____
- Medical 72-92 _____
- Laboratory 93-118 _____

3. Results of Missions

3.1. Biological Dosimetry

3.1.1. Rationale

Radioactive contamination from the Chernobyl accident occurred in three major areas. These were:

(1) Directly west of the plant from 0 to approximately 140 km. Central portions of this area have ^{137}Cs in excess of 15 Ci/km^2 (555 kBq/m^2). This area is predominantly in the UkrSSR, but does extend somewhat into the southern part of the BSSR.
(2) Areas from approximately 100 to 300 km northeast of the plant known as the Bryansk region. This is in the southeastern part of the BSSR and extends into the RSFSR.
(3) The Tula region in the RSFSR which is located approximately 700 km from the plant and is to the northeast in the direction of Moscow. Even though this is a long distance from the plant, contamination levels are up to 15 Ci/km^2 (555 kBq/m^2) of caesium.

A large portion of the dose to the population living in contaminated areas is due to ground contamination. Since there is only a fair correlation between environmental contamination and the internal deposition of radionuclides in the human body, it is important to review whole body counting data and dosimetry methodology. This was done under Task 3 and the results are presented in Part E.

For the purposes of this report it is important to review the measured and projected doses in the settlements that were visited by the medical team. In addition, environmental assessments in those settlements are also important. Some summary data will be presented in this section. As an additional measure, it was felt that it was important to do some carefully chosen biological dosimetry since lymphocytes can be cultured from blood and examined for chromosome aberrations (particularly for yield of dicentrics). Additionally, somatic cell mutations can be evaluated [1-9]. Such analyses usually yield positive results when the absorbed doses are in excess of 0.2 Sv. According to measurements made by the environmental teams, such accumulated whole body doses were, however, not estimated in contaminated settlements, but even negative results of biological dosimetry would provide some additional assurance that the upper limits of the whole body dosimetry estimates were correct.

3.1.2. Review of Official Data

See Part E (Report of Task 3).

It has been reported[1] that Soviet investigators made 5-10 cytogenetic examinations per contaminated settlement in 1986 in a few areas but that the dose estimates were unreliable since the dicentric response yield curve for chronic internal caesium contamination was not known.

3.1.3. Dosimetry Results of Field Trips

Actual results of Project environmental radionuclide measurements, external exposure measurements and the results of whole body counting in the settlements visited by the Health Effects teams are covered in Part D of this report.

3.1.3.1. External Exposure

External exposure was measured in some of the contaminated settlements by Task 2 teams. According to their measurements, the external gamma dose rate was for

Bragin, BSSR	outdoors	0.1-3.0 μSv/h
	indoors	0.1-0.3 μSv/h
Polesskoe, UkrSSR	outdoors	0.3-2.3 μSv/h
	indoors	0.1-0.7 μSv/h.

The mean external gamma dose rate in most surveyed control settlements was less than 0.15 μSv/h. In control settlements the ^{137}Cs surface activity was less than 1 Ci/km^2 (less than 37 kBq/m^2). The exact results are shown in Table 3.

3.1.3.2. Internal Body Burden

Internal body burdens of ^{137}Cs were calculated on the basis of whole body counting measurements. Part E reports in detail on these measurements.

For thyroid dose calculations it is useful to know what portion of the population actually took stable potassium iodide at the time of the accident in order to prevent radioiodine uptake. The results of the responses of adults from six control and seven contaminated settlements are shown in Table 4.

[1] Dr. A.M. Lyaginskaya (Moscow).

TABLE 3. External Gamma Dose Rate (μSv/h) in Surveyed Control Settlements

Republic	Settlement	Outdoors		Indoors	
		Range	Mean	Range	Mean
BSSR	Kirovsk	0.04–0.12	0.07 ± 0.02	0.04–0.10	0.08 ± 0.02
	Khodosy	0.06–0.09	0.07 ± 0.01	0.06–0.11	0.07 ± 0.01
RSFSR	Unecha	0.04–0.10	0.06 ± 0.02	0.04–0.10	0.07 ± 0.02
	Surazh	0.04–0.18	0.08 ± 0.04	0.04–0.15	0.08 ± 0.03
UkrSSR	Trokovichi	0.12–0.24	0.20 ± 0.04	0.18–0.25	0.22 ± 0.03
	Krasilovka	0.11–0.15	0.13 ± 0.01	0.15–0.18	0.13 ± 0.01

TABLE 4. Response of Adults Who Were Asked whether They Took Stable Iodine at the Time of the Accident

Response	Persons in contaminated settlements		Persons in control settlements		Total
	Number	%	Number	%	
Yes	58	22	9	4	
No	187	69	207	88	
Uncertain	25	9	20	8	
Total	264	100	236	100	500

It is instructive to summarize the dosimetry data and estimated absorbed doses. Because the measurements taken in the control settlements were close to natural background, total internal absorbed doses due to ^{137}Cs were estimated only for contaminated settlements. They are shown in Table 5.

3.1.3.3. Present and Projected Doses in Selected Contaminated Settlements

Most absorbed doses to date have been due to external deposition of ^{137}Cs. Total mean internal and external doses occurring in the surveyed contaminated settlements from 0–4 years as a result of the accident are about 30 mSv.

The Dosimetry Group (Task 3) also estimated average 70 year doses to inhabitants of some settlements. Detailed data are presented in Part E; however, a summary of the dose estimates of Task 3 as compared with the official Soviet value is shown in Table 6.

3.1.3.4. Cytogenetic Results

The field teams (Missions 8–10) obtained blood samples from persons in some contaminated and control settlements. These were obtained from adults who worked outdoors either as farmers or foresters. The rationale for this was twofold:

(a) The teams did not want to take large blood samples from children.
(b) Samples on this group of adults would allow an upper estimate of absorbed dose to the population as of the present time. Since these persons worked outdoors in areas where there had been little or no decontamination efforts, their absorbed doses should be higher than those of other adults who worked indoors.

TABLE 5. Estimated Internal Absorbed Doses Due to ^{137}Cs for Contaminated Settlements

Republic	Settlement	Population sample	Median dose (mSv/a)[a] and SD
BSSR	Bragin	1154	0.08 ± 0.2
	Korma	719	0.09 ± 0.2
	Veprin	1064	0.06 ± 0.2
RSFSR	Novozybkov	1455	0.11 ± 0.3
	Zlynka	998	0.17 ± 0.4
UkrSSR	Polesskoe	1003	0.08 ± 0.4

[a] In general the distributions of estimated dose had a long tail at the upper end of doses. Thus the median values are about 50–70% of the average. Doses in children are about 25–30% of those of adults. Maximum values were about 6 mSv/a in most settlements.

TABLE 6. 70 Year Projected Dose as a Result of the Accident for Surveyed Contaminated Settlements as Estimated by Task 3

Republic	Settlement	Project assessment (mSv)				Total (official Soviet value)
		External	Internal		Total	
			Cs-137	Sr-90		
BSSR	Veprin	127	27	1	155	369
	Korma	71	16	<1	88	148
	Bragin	105	23	4	132	268
RSFSR	Novozybkov	53	15	<1	78	149
	Zlynka	104	25	1	129	241
UkrSSR	Polesskoe	96	21	3	120	403
	Narodichi	67	15	2	84	681

TABLE 7. Results of Evaluation of Cytogenetic Data by RERF (Japan) and Frequency of Dicentrics and Rings

Evaluated by	Persons from contaminated areas						Persons from control areas					
	Number of persons	Sex		Mean age (years)	Dicentrics and rings		Number of persons	Sex		Mean age (years)	Dicentrics and rings	
		Male	Female		Mean per cell	SD		Male	Female		Mean per cell	SD
RERF	24	11	13	45.00	0.0047	0.0050	24	20	4	46.25[a]	0.0050	0.0044
IAEA[b]	43	27	16	51.00[c]	0.0035	0.0044						

Evaluated by	Persons from contaminated areas						Persons from control areas					
	Number of persons	Sex		Age (years)	Frequency of dicentrics and rings		Number of persons	Sex		Age (years)	Frequency of dicentrics and rings	
		Male	Female		Mean per cell	SD		Male	Female		Mean per cell	SD
RERF	18			40	0.0043	0.0047	11			40	0.0068	0.0046
	6			60	0.0059	0.0058	5			60	0.0041	0.0042
	0			Unknown			8			Unknown	0.0031	0.0037
		11			0.0047	0.0053		20			0.0050	0.0046
			13		0.0047	0.0048			4		0.0050	0.0041

[a] Excludes 8 with unknown age.
[b] Excludes 13 with outlying cytogenetic values (scored at one abnormality).
[c] Excludes 3 with unknown age.

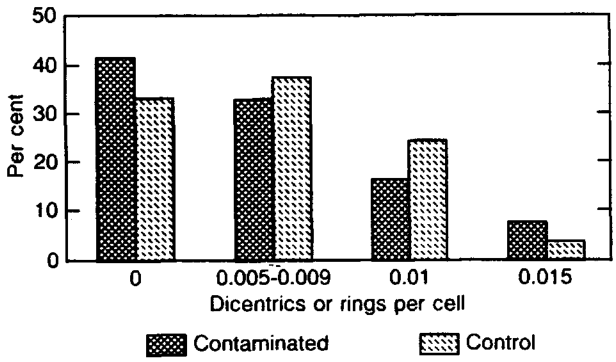


FIG. 2. Cytogenetic data: per cent of dicentrics or rings per cell.

It was recognized that there would be logistical difficulties in transporting the refrigerated samples to Japan, where the lymphocytes would be cultured. Blood samples need to be cultured within seven days (preferably less) from the time they are obtained. Samples were therefore obtained only during the last week of each of Missions 8–10, and for logistic reasons not for each settlement.

Dicentric Chromosome Analysis

RERF in Hiroshima, Japan, analysed blood culture samples with regard to information on dicentrics. The results of this analysis are shown in Table 7 and Fig. 2. Only those cases that were scored at RERF included both contaminated and control cases. Therefore, the main analysis was performed only on RERF cases. The frequency of aberrations in control areas was surprisingly high, corresponding to exposure of 0.5 Gy (gamma radiation). Reasons for this high frequency are unclear; however, the background rate of aberrations among different populations has been shown to be variable. Future studies on this subject are certainly worthwhile. Formal statistical analysis including age and sex as co-variables showed no significant difference in aberration frequencies between contaminated and control areas.

Somatic Mutation Analysis

In order to elucidate the effects of radiation exposure from the Chernobyl nuclear power plant accident on

TABLE 8. Time Frame for Mutation Assays for the First Three Groups

Group	Settlement		Date of		
	Contaminated	Control	Drawing of blood	Arrival of blood	Performance of mutation assays
Group 1	Polesskoe	—	10 September	16 September	17 September
	—	Kozolec	13 September	16 September	17 September
Group 2	Novozybkov	—	24 September	28 September	28/29 September
	Zlynka	—	26 September	28 September	28/29 September
Group 3	—	Khodosy	9 October	17 October	17 October
	Korma	—	13 October	17 October	17 October

TABLE 9. Glycophorin A Gene Mutation Frequency (per 10^6)

Type of mutation	Samples from contaminated areas		Samples from control areas	
	Mean	SD	Mean	SD
MO	6.815	8.164	3.421	3.355
MM	3.785	7.962	1.789	3.190
NO	9.831	4.989	9.211	8.297
NN	5.662	5.677	4.895	4.319
Sample size[a]	65		19	

[a] The total sample size for this table is 84. The remaining subjects (excluding one outlier) were not MN heterozygotes.

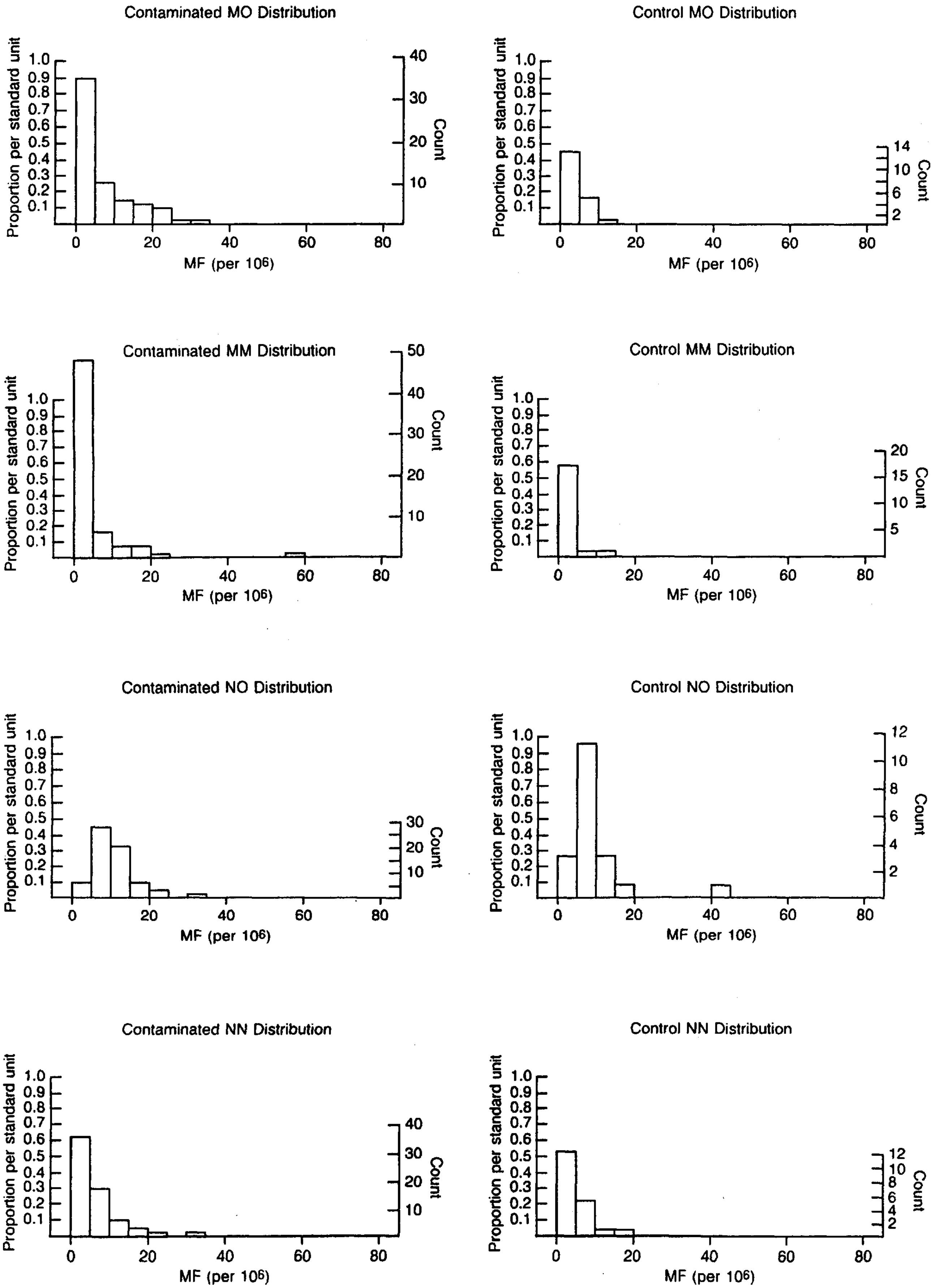


FIG. 3(a). Distribution of glycophorin A gene MO, MM, NO and NN mutation frequencies.

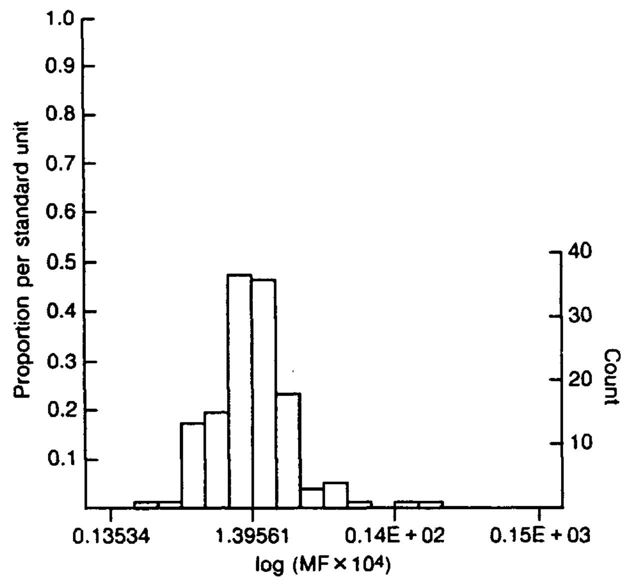


FIG. 3(b). Distribution of log transformed T cell receptor mutation frequency.

people residing in contaminated areas, the frequency of somatic mutation was measured in the (1) Glycophorin A (GPA) gene in erythrocytes, and (2) T cell antigen (TCA) receptor gene in lymphocytes [10–14].

Table 8 shows the time frame of mutation assays and where people were tested. There were long time intervals between blood drawing and sample testing. Lymphocytes die more quickly than erythrocytes and hence the TCA assay was more affected by the time delay.

The GPA gene mutation assay can only be performed on heterozygous (MN) individuals. The distribution of MO, MM, NO, and NN mutation frequencies (MF) per 10^6 cells may be assumed to be Poisson. However, the use of a stopping rule for limiting the total number of cells counted induces extra-Poisson sampling variation. We therefore used a negative binomial variance model. Frequencies are available from both cell sorter and microscopy. We used the latter in this analysis.

One individual from a contaminated region (Polesskoe) had excessively large NO and NN frequencies which grossly inflated the sample mean and variance;

TABLE 10. Estimates of Negative Binomial Models Fit to Glycophorin A Gene Mutation Frequencies (per 10^6 Cells)

Type of mutation	Parameter	Without adjustment for contamination		With adjustment for contamination	
		Mean	SD	Mean	SD
MO	Intercept[a]	1.800	0.134	1.230	0.277
	Difference[b]			0.689	0.311
MM	Intercept[a]	1.204	0.236	0.582	0.481
	Difference[b]			0.749	0.543
NO	Intercept[a]	2.271	0.066	2.220	0.142
	Difference[b]			0.0652	0.161
NN	Intercept[a]	1.703	0.107	1.588	0.227
	Difference[b]			0.146	0.257

[a] Overall mean for combined regions (without adjustment) or mean of control regions (with adjustment).
[b] Difference between contaminated and control regions.

TABLE 11. T Cell Antigen Receptor Gene Mutation Frequency (per 10^4 Cells)

	Samples from contaminated areas		Samples from control areas	
	Mean	SD	Mean	SD
	1.515	0.836	1.741	1.285
Sample size[a]	93		32	

[a] Total sample size for this table is 125; the remaining samples (189 − 125 = 64) could not be analysed because of insufficient numbers of surviving lymphocytes.
$p = 0.45$. Note: there is no statistically significant difference between control and contaminated settlements unless $p < 0.05$.

TABLE 12. T Cell Antigen Receptor Gene Mutation Frequency (per 10^4 Cells)

Age group	Sex	Samples from contaminated areas			Samples from control areas		
		Mean	SD	Sample size	Mean	SD	Sample size
<50 years	Males	1.645	0.650	15	1.657	0.303	2
≥50 years		1.538	0.257	6	0.548	0.127	2
<50 years	Females	1.402	1.039	18	1.418	0.515	17
≥50 years		2.202	1.153	10	1.570	0.912	4

these data are not included in this analysis, but the occurrence of such an extreme response should not be ignored. Table 9 summarizes the remaining mutation frequencies by contaminated versus control areas.

As may be seen in Fig. 3(a), there were no outstanding differences between MF distributions in the contaminated versus control regions. Note that, although the mean MF in Table 9 was consistently higher in contaminated regions, the standard deviations were quite large. Table 10 shows estimated parameters and approximate standard errors for fitted models with and without adjustment for radiation contamination using the negative binomial variance. In the MO mutant type, the estimated difference between regions was about twice the standard error, but for the other types of mutation the differences were obviously insignificant. Attaching statistical significance to the differences in Table 9 (if they are indeed real) would require substantially larger sample sizes.

The distribution of log transformed TCR (T cell receptor) mutation frequency (MF) was approximately normal (Fig. 3(b)). Therefore, analyses were based on simple regression theory for normally distributed data using log transformed frequencies.

There was no evidence of an overall effect of radiation contamination on mutation frequency ($p = 0.45$; Table 11). Adjustments for age and sex (Table 12) suggested a possible interaction between age and MF, with a higher MF among the older age group in contaminated areas. However, small cell sizes made it impossible to attach any statistical significance to this finding.

3.1.4. Summary of Dosimetry

In general, the project estimated doses from Task 3 for 4 and 70 years in selected settlements are about one half of those estimated by Soviet authorities. For persons in some seven highly contaminated settlements that were visited by the teams of Task 4, the average estimated total (internal and external) whole body dose during the four years after the accident was in the range of 1.8-3.3 rem (18-33 mSv).

At these dose levels, biological dosimetry (dicentric analysis) would be expected to be negative. This is because the radiation dose was smaller than that needed to observe an effect. In addition, the dose was protracted and this will reduce the effect. In spite of these considerations, estimates of dose indicated a long tail of absorbed doses extending into the higher levels in terms of internal body burden and personnel dosimeter measurements. Thus it was of interest to see that a few persons may have positive cytogenetic findings.

3.1.4.1. Conclusions of the Mutation Studies

The somatic mutation study did not offer any quantitative proof of the effect of radiation contamination on GPA or TCR gene mutation frequencies. However, the validity of statistical inferences may have been compromised to an unknown degree because of problems such as limited data, degeneration of samples, etc. Thus, it is difficult to draw any major conclusions from these data.

There are, however, some qualitative results which are slightly suggestive of possible radiation effects in the contaminated areas. These include possibly higher GPA mutation frequencies and, in older individuals, possibly increased TCR mutation frequency. The question of whether these are indeed real effects would require more rigorous testing based on a larger, more carefully designed sample of regions and individuals.

3.2. Haematology and Immunology Issues

3.2.1. Anaemia

3.2.1.1. Rationale

Anaemia refers to a lack of either red blood cells or adequate functional haemoglobin. The amount of reduction in haemoglobin necessary to make the diagnosis of anaemia is variable. The amount of haemoglobin varies with age (increasing as children get older). In many countries two normal ranges are used, one for adults and another for children. In other countries there are standardized curves that are used for each year of age. Since children have very rapid growth rates, their metabolic needs are relatively greater. As a result of this, anaemias are often much more evident and severe in children than in adults.

Examination of the blood smear as well as measurement of the amount of haemoglobin per erythrocyte and the erythrocyte size can provide useful clues as to the cause of an anaemia.

Hookworm and intestinal parasites are important causes of blood loss and iron deficiency in many countries. When these are present they are usually identified on the basis of the blood smear and analysis of faecal samples.

Many anaemias are primarily due to iron or vitamin deficiencies. Estimated dietary iron requirements for normal men, non-menstruating and non-pregnant women, infants and children are about 0.4–1.5 mg/d of absorbed iron and 5–10 mg/d in the food. Menstruating women have a requirement about 50% higher and pregnant women have about triple these requirements.

Severe iron deficiency can result in a number of disorders including dysphagia (from oesophageal webs), anorexia, flatulence, nausea, constipation, gastritis and cardiac failure. Usually the stained blood smear shows small erythrocytes (microcytosis) poorly filled with haemoglobin (hypochromia) and with a marked variation in size (anisocytosis) and shape (poikilocytosis). The mean corpuscular volume is usually less than 80 fL. With use of automated haematology analyser systems the mean corpuscular haemoglobin in anaemic persons may be in the low normal range and the key measurement becomes the mean cell volume. Either thrombocytosis or thrombocytopenia can be found with iron deficiency anaemias but this usually returns to normal after iron therapy. Appropriate iron therapy usually results in a rise of reticulocytes about the 5–7th day (peaking at about 2 weeks) and a return to normal haemoglobin in about 4–8 weeks.

Anaemia can be due to many different causes ranging from iron deficiency to congenital abnormalities of the haemoglobin synthesis. In the numerous studies of radiation related health effects during the last century, anaemia is rarely, if ever, mentioned. The reason for this is that the red blood cells are relatively resistant to radiation and have long lives in the bloodstream. Massive absorbed radiation exposure can reduce the level of erythrocytes, but in these circumstances the other more radiosensitive blood elements (such as white blood cells and platelets) are always significantly more depressed. [15–21].

Haematological findings were studied extensively in the atomic bomb survivors. Certainly, there were early effects related to very high doses. These generally were seen in the first few months after exposure and associated changes involved depressed white cell and platelet counts. Similar findings were seen in the Chernobyl firemen and other plant workers who suffered from the acute radiation syndrome [22]. The summary of late haematological effects of atomic bomb exposure in Hiroshima and Nagasaki indicates that there was no evidence of a late radiation effect resulting in primary disturbances of haematopoiesis in the absence of malignant disease [23]. Follow-up studies of the Chernobyl acute radiation syndrome survivors have not demonstrated the presence of anaemia as a radiation effect four years after exposure.

In areas affected by the Chernobyl accident, it often is not clear whether anaemias existed prior to the accident and, if so, to what extent. Typically, there was no screening of either children or adults who were not symptomatic. Thus, cases of anaemia could have been present but they might have gone undetected if they were not severe. After the Chernobyl accident there were reasons why potential anaemias might have existed even though, as indicated earlier, they would be unlikely as a direct result of radiation exposure. However, because of radioactive contamination of the food, there were many governmental restrictions placed on consumption of milk, meat and vegetables. In addition, it was certainly possible that many persons in the population were so afraid of even small amounts of radioactivity in food that they voluntarily restricted their diets to a detrimental amount. For these reasons as well as because of the Soviet concern expressed about anaemias, this matter was extensively examined during the field trips.

3.2.1.2. Review of Official Data

It has been reported[2] that anaemia is relatively common throughout the RSFSR. It was felt that the diet in the USSR was quite different from that in other countries such as the USA. The annual diet in the USSR consists of about 40 kg of meat per person contrasted with about 140 kg in the USA. Green vegetables are usually only available during summer and early fall. The definition of anaemia usually utilized in the USSR is < 110 g Hb/L blood for children less than 6 years old and < 120 g Hb/L for those over 6 years of age.

Based upon this definition, about 8–12% of the entire population of the USSR are anaemic, including about 30% of children under the age of 7 years.[2] There are no hard data on whether the incidence of anaemia has increased or decreased during the last four years in the contaminated areas.

---

[2] Dr. Rumyantsev (Moscow).

UkrSSR

In Ovruch, physicians informed the missions that they felt that anaemia was related to poor nutrition since it appears to be rare in children who go to kindergarten (where they are given food which includes fresh fruits and vegetables). They felt that the complaints, by children, of fatigue, dizziness and fainting were probably secondary to anaemia.

It was reported[3] that the best data available show that anaemia occurs in Kiev in about 5–12% of the paediatric population. About 20–30% of these cases are due to protein deficiency and the remainder to iron deficiency.

Anaemia was studied by the Moscow group[4] in 1987. Since they did not know which settlements were contaminated and which were not at the time of their investigation, they examined some of each by chance. Their conclusion was that there was no difference in incidence of anaemia between contaminated and non-contaminated areas. There also was no real difference in the incidence of anaemia between small settlements and large towns. The data from these studies were sent to the Ministry of Health and were not presented to the mission.

The Moscow group also visited the Mogilev and Gomel regions three times during 1986 and visited other areas in the BSSR in 1987. It was pointed out that there were two problems in the evaluation. These were:

(a) There were no previous data to use as a baseline.
(b) It was difficult to estimate what the effects of radiation might have been since there were other social and environmental factors such as food restrictions, iron deficiency, and possible lead and chemical pollution. The cases of nosebleeds reported might be due to allergies and rhinitis rather than a clotting disorder or radiation induced thrombocytopenia (platelet deficiency).

AUSCRM[5] has also studied the anaemia issue. It was pointed out that prior to the accident the only data collected were from children who were clearly sick. The data usually related to haemoglobin, erythrocyte sedimentation rate and white blood count. In their analysis most, but not all, anaemias are primarily due to iron deficiency. It was also indicated that the incidence of anaemia did not decrease in the period 1987–1990. AUSCRM agreed that anaemia in the USSR occurs in about 10% of adults and up to 30% of children. Some physicians indicated that both vitamin deficiency and parasites could be contributing to some portion of the anaemias. They estimated that about 30% and, possibly, as much as 70% of the children have some parasitic problem such as ascaris or toxoplasmosis. No hard data were available regarding this latter issue.

Another researcher[6] has examined the frequency of mild anaemia in both Narodichi and in a non-contaminated settlement, Yagatin, which is a 'clean' area 300 km from Chernobyl. She found that in Narodichi the incidence of mild anaemia was 31% for children under the age of 1 year, for those 1–3 years 28%, 4–6 years 17%, 7–10 years 6% and for children 10–14 years 5%. The rates were essentially the same for the control settlement Yagatin. In another control settlement, Glukhov, which has about 8000 children, the incidence of anaemia was also about 30%.

The same researcher studied the haemoglobin levels in various age groups of children in Yagatin. Her results showed no significant change from 1983 to 1989. They are given in Table 13.

TABLE 13. Per Cent of Children of Various Age Groups in Yagatin by Haemoglobin Level[a]

Age group (years)	Haemoglobin (g/dL)			
	<11	11–11.9	12–13	>13
<1	24	44	28	4
1–3	8	12	74	6
3–7	3	8	59	30
7–10	2	3	69	26
10–14	2	3	64	31

[a] Data of Dr. E.I. Stepanova (Kiev).

BSSR

Physicians in Gomel also reported finding anaemias of several types but indicated that these were, most probably or possibly, related to poor diet. Cardiovascular abnormalities were also reported in children and infants. Upon questioning, it appeared that these cases were mostly related to anaemia complications rather than to primary cardiac pathology. There are little data on anaemia in the BSSR from the time prior to the accident, and anaemias in most children are rapidly responding to treatment with vitamin B12 and iron supplements when such compounds can be obtained.

Another scientist[7] reported on field trips made with the specialists from Gomel; these visits take place

[3] Dr. Koshel (Moscow).
[4] Dr. Koshel's group.
[5] Dr. V.G. Bebeshko (Kiev).
[6] Dr. E.I. Stepanova (Kiev).
[7] Dr. A.M. Lyaginskaya (Moscow).

TABLE 14. Adults Reporting Past History of Anaemia

Previous history of anaemia	Persons in contaminated settlements		Persons in control settlements		Total
	Number	Per cent	Number	Per cent	
Yes	25	10	11	5	36
No	239	90	225	95	464
Total	236	100	264	100	500

p = 0.038.

TABLE 15. Haemoglobin Level (g/dL) (Mean and Standard Deviation)

Republic	Settlement	Sex	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1–5	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	Male	11.9	0.81	12.24	0.56	12.85	0.60	14.38	1.19	13.09	2.89	13.2	1.45	12.62	1.42
		Female	12	0.87	12.51	0.57	12.86	0.85	13.53	0.59	13.36	0.57	12.58	0.97	12.89	0.82
	Kirovsk	Male	11.4	1.04	12.11	0.78	12.78	0.35	15.71	0.81	14.53	0.63	12.89	1.51	12.89	1.64
		Female	12.4	0.75	11.83	0.70	12.74	0.53	12.99	0.73	13.68	1.04	12.69	0.88	12.85	0.97
	Khodosy	Male	11.6	0.88	11.81	0.74	12.56	0.53	15.07	0.39	13.99	1.28	13.38	1.34	12.94	1.48
		Female	11.4	0.61	12.23	0.40	13.01	0.91	13.66	0.86	13.54	0.78	12.33	1.42	12.76	1.16
	Veprin[a]	Male	11.6	1.03	11.96	0.53	12.94	0.66	17.3	1.70	14.98	0.93	14.28	2.26	12.92	1.74
		Female	10.9	1.47	12.25	1.03	12.38	0.44	12.7	0.88	13.41	0.50	12.78	1.78	12.35	1.08
	Korma[a]	Male	12.8	0.93	12.74	0.71	13.29	0.53	15.38	1.59	14.74	0.35	12.72	1.23	13.86	1.43
		Female	12.3	0.54	12.75	0.60	12.92	0.49	13.28	0.65	13.46	0.96	13.08	0.86	12.90	0.72
RSFSR	Unecha	Male	13	0.87	12.34	0.70	13.4	0.53	15.43	0.74	14.75	0.48	13.2	—	13.76	1.33
		Female	11.9	1.37	12.42	0.82	13.51	0.95	13.67	0.87	13.7	0.71	13.05	1.34	13.07	1.17
	Surazh	Male	12.8	0.88	12.43	0.50	13.64	0.84	15.18	0.49	15.33	0.85	—	—	13.47	1.31
		Female	12.7	0.26	12.43	0.66	13.06	0.83	13.13	1.20	14.17	1.05	—	—	13.21	1.11
	Novozybkov[a]	Male	12	0.81	12.21	0.47	13.51	0.63	15.79	0.81	15.43	1.22	—	—	13.68	1.71
		Female	12.1	0.80	12.15	0.54	12.95	0.78	13.86	0.73	13.8	0.75	9.9	—	13.06	1.06
	Zlynka[a]	Male	12.5	0.59	12.44	0.61	13.06	0.55	14.94	0.88	14.38	1.12	—	—	13.37	1.26
		Female	12.8	0.86	12.47	0.40	12.75	1.01	12.98	0.98	14.19	0.91	13.45	1.20	12.95	0.99
UkrSSR	Trokovichi	Male	11.1	2.07	11.85	0.89	12.55	0.79	15.4	0.90	14.93	1.25	13.36	1.59	12.64	1.85
		Female	11.7	1.37	12.14	0.52	13.13	1.01	13.08	0.85	13.25	1.14	13.06	1.52	12.77	1.15
	Narodichi[a]	Male	11.3	1.01	12.43	0.42	13.34	0.49	14.55	0.81	15.08	1.08	15.2	—	13.56	1.66
		Female	12.1	1.02	12.24	0.98	13.21	0.60	13.43	1.12	14.09	0.55	—	—	13.08	1.07
	Polesskoe[a]	Male	11.8	0.87	11.96	1.36	13.11	0.59	15.54	0.71	15.45	0.90	14.6	1.41	13.52	1.91
		Female	12	1.17	12.11	0.99	13.33	0.92	13.45	1.04	13.87	0.74	13	—	12.94	1.19
	Krasilovka, Chemer	Male	11.4	1.26	12.33	0.65	12.58	0.90	15.26	0.72	14.25	0.89	14.69	1.47	13.45	1.64
		Female	11.1	0.79	12.03	0.70	12.47	0.65	13.15	1.50	13.94	0.91	12.73	1.21	12.37	1.32
Total		Male	12.04	1.12	12.22	0.74	13.04	0.71	15.33	0.98	14.68	1.30	13.61	1.62	13.30	1.60
		Female	11.94	1.04	12.3	0.73	12.95	0.82	13.34	0.94	13.73	0.87	12.77	1.30	12.87	1.08

TABLE 15. (cont.)

Republic	Settlement	Sex	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1–5	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Surveyed contaminated	Male	12.04	0.98	12.34	0.68	13	0.61	15.32	1.60	14.29	1.80	13.43	1.75	13.16	1.60
		Female	11.9	1.07	12.49	0.75	12.68	0.63	13.26	0.70	13.4	0.66	12.79	1.22	12.74	0.90
	Surveyed control	Male	11.5	0.95	11.99	0.77	12.64	0.47	15.35	0.70	14.18	1.11	13.18	1.40	12.91	1.55
		Female	11.86	0.85	12.06	0.57	12.89	0.76	13.35	0.90	13.64	0.94	12.51	1.18	12.80	1.07
RSFSR	Surveyed contaminated	Male	12.3	0.72	12.33	0.55	13.31	0.63	15.36	0.90	14.8	1.25	—	—	13.51	1.49
		Female	12.4	0.86	12.32	0.49	12.81	0.93	13.51	0.90	13.95	0.82	12.27	2.22	13.01	1.02
	Surveyed control	Male	12.9	0.86	12.4	0.58	13.5	0.67	15.38	0.70	15.06	0.74	13.2	—	13.63	1.32
		Female	12.2	1.13	12.42	0.74	13.31	0.91	13.28	1.10	13.91	0.89	13.05	1.34	13.14	1.14
UkrSSR	Surveyed contaminated	Male	11.6	0.92	12.14	1.11	13.22	0.54	15.21	0.90	15.27	0.99	14.72	1.25	13.54	1.80
		Female	12	1.09	12.18	0.96	13.26	0.75	13.44	1.10	13.98	0.63	13	—	13.01	1.13
	Surveyed control	Male	11.2	1.66	12.06	0.81	12.56	0.83	15.28	0.70	14.49	1.05	13.91	1.66	13.11	1.77
		Female	11.3	1.08	12.08	0.62	12.84	0.92	13.12	1.20	13.54	1.08	12.97	1.44	12.57	1.25
Total	Surveyed contaminated	Male	12	0.91	12.29	0.74	13.15	0.61	15.31	1.20	14.78	1.45	13.62	1.74	13.37	1.62
		Female	12.1	1.02	12.37	0.76	12.9	0.78	13.38	0.89	13.74	0.76	12.78	1.25	12.89	1.01
	Surveyed control	Male	12.09	1.32	12.14	0.74	12.92	0.78	15.34	0.68	14.54	1.04	13.61	1.57	13.23	1.57
		Female	11.78	1.04	12.2	0.66	13.01	0.88	13.28	1.01	13.73	0.96	12.77	1.33	12.86	1.17

[a] Settlements in a contaminated area.

several times a year to study children in the areas around Cherchersk (north of Gomel) and Krasnopole (near Veprin), a relatively clean settlement (about 2 Ci/km^2 (74 kBq/m^2)). These specialists make physical examinations and draw blood for haemoglobin and often for TSH or microsomal antibodies. They have reported anaemia in at least 30% of the children. The anaemia incidence is reported to be increasing in the years since the accident, at least in children up to the age of 16.

Other field trips are being made to the settlements, and in these about 1200 children are examined once or twice a year. Reportedly, the anaemia observed one to two years after the accident was not equally prevalent in 1990 and this was probably due to earlier dietary problems.

Obninsk Register

There are some data on anaemias in the Obninsk register. However, the data are markedly different from those reported elsewhere. For example, of the 125 000 or so children and adolescents in the register there are only several hundred cases of anaemia reported per region, or less than 1%. In addition, there are marked variations in reported cases for a given region from 1987 to 1988. For example, in the Mogilev region, the number of cases reported was 107 in 1987 and 834 in 1988. During the same period the register indicates that in the Bryansk region there were 122 cases in 1987, decreasing to 25 cases in 1988. Such large and disparate variations are unlikely to reflect the true prevalence of anaemia.

3.2.1.3. Results of Field Trips

Data were initially collected from the health effects questionnaire. Adults were asked whether they thought they had or had been told that they had anaemia. The results for both control and contaminated settlements are presented in Table 14.

Haematocrit, haemoglobin, erythrocyte number and erythrocyte mean corpuscular volume were obtained for over 1600 persons who lived in contaminated and control settlements. All analysis on site was performed with a Coulter T 660 donated by Coulter Corporation (Hialeah, Florida). All persons had a blood smear performed which was fixed, stained and subjected to individual microscopic analysis. In addition, there was analysis of leucocyte number and type and of platelet number. The results of these analyses are given in either tabular or graphic form. These data are presented in unadjusted or adjusted form and, sometimes, in both. The unadjusted data are raw data. Indication is given as to whether they have been adjusted for age, sex or both.

TABLE 16. Haemoglobin Levels

Group	< 11 No.	< 11 %	≥ 11 < 12 No.	≥ 11 < 12 %	≥ 12 < 13 No.	≥ 12 < 13 %	≥ 13 No.	≥ 13 %	Unknown No.	Unknown %	Total No.	Total %
Males in contaminated area												
1	8	9.52	29	34.52	30	35.71	8	9.52	9	10.71	84	100
2	2	2.56	24	30.77	36	46.15	16	20.51	0	0.00	78	100
3	0	0.00	4	5.19	27	35.06	46	59.74	0	0.00	77	100
4	0	0.00	0	0.00	1	1.89	52	98.11	0	0.00	53	100
5	2	2.82	0	0.00	2	2.82	67	94.37	0	0.00	71	100
6	1	2.86	5	14.29	8	22.86	20	57.14	1	2.86	35	100
Total	13		62		104		209		10		398	
Males in control area												
1	10	14.93	15	22.39	25	37.31	15	22.39	2	2.99	67	100
2	4	5.63	22	30.99	35	49.30	9	12.68	1	1.41	71	100
3	0	0.00	7	9.33	32	42.67	35	46.67	1	1.33	75	100
4	0	0.00	0	0.00	0	0.00	53	100	0	0.00	53	100
5	1	2.08	0	0.00	0	0.00	46	95.83	1	2.08	48	100
6	1	1.56	8	12.50	14	21.87	39	60.94	2	3.12	64	100
Total	16		52		106		197		7		378	
Females in contaminated area												
1	6	9.68	16	25.81	24	38.71	11	17.74	5	8.06	62	100
2	5	5.75	17	19.54	46	52.87	18	20.69	1	1.15	87	100
3	0	0.00	11	13.25	33	39.76	39	46.99	0	0.00	83	100
4	1	1.20	5	6.02	16	19.28	61	73.49	0	0.00	83	100
5	0	0.00	1	1.72	7	12.07	49	84.48	1	1.72	58	100
6	3	4.00	11	14.67	23	30.67	35	46.67	3	4.00	75	100
Total	15		61		149		213		10		448	
Females in control area												
1	12	20.00	16	26.67	25	41.67	5	8.33	2	3.33	60	100
2	1	1.89	15	28.30	32	60.38	4	7.55	1	1.89	53	100
3	0	0.00	6	10.17	23	38.98	30	50.85	0	0.00	59	100
4	1	1.49	5	7.46	18	26.87	43	64.18	0	0.00	67	100
5	0	0.00	4	5.88	11	16.18	53	77.94	0	0.00	68	100
6	7	6.60	20	18.87	29	27.36	48	45.28	2	1.89	106	100
Total	21		66		138		183		5		413	

TABLE 17. Haematocrit as a Percentage of Blood Volume (Mean and Standard Deviation)

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1-5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	35.82	2.10	36.63	1.60	38.04	1.84	39.92	2.42	39.22	5.39	37.89	3.29	37.78	3.08
	Kirovsk	35.71	2.30	35.58	2.19	37.86	1.63	41.15	4.16	41.46	2.85	37.82	3.04	38.23	3.75
	Khodosy	34.28	2.02	35.30	1.67	37.50	2.12	41.89	2.81	41.21	3.07	38.02	4.02	38.02	3.84
	Veprin[a]	35.02	2.42	36.22	2.25	37.64	1.62	41.01	6.09	42.16	2.95	39.49	6.51	37.87	3.68
	Korma[a]	37.41	2.37	38.05	1.72	38.90	1.70	43.05	4.45	42.55	2.40	38.98	2.53	39.94	3.51
RSFSR	Unecha	35.57	4.67	35.58	1.99	38.25	1.97	42.15	3.11	39.93	2.24	37.47	3.20	38.25	3.90
	Surazh	36.55	2.27	35.66	1.70	38.21	2.37	39.11	3.56	42.27	2.97	—	—	38.37	3.48
	Novozybkov[a]	35.21	2.18	35.78	1.56	38.40	1.90	42.74	3.42	41.86	3.39	30.90	—	38.88	4.02
	Zlynka[a]	36.88	1.89	36.81	1.51	37.92	2.22	41.65	3.29	42.31	2.60	39.65	3.89	38.82	3.24
UkrSSR	Trokovichi	34.41	4.15	36.14	2.31	38.39	2.40	41.56	3.94	41.32	3.78	38.88	5.36	38.02	4.08
	Narodichi[a]	33.95	3.58	36.11	2.24	38.36	1.59	40.17	2.75	43.12	3.04	43.10	—	38.82	3.89
	Polesskoe[a]	34.80	3.02	34.97	3.15	38.29	2.25	41.03	3.69	43.08	3.24	41.10	4.30	38.34	4.47
	Krasilovka, Chemer	33.14	2.62	35.24	2.49	36.61	2.07	42.44	3.44	40.78	2.62	40.23	4.62	37.74	4.35
Total		35.39	2.99	36.06	2.16	38.02	2.02	41.37	3.63	41.63	3.29	38.71	4.47	38.39	3.82
BSSR	Surveyed contaminated	36.14	2.41	36.93	1.97	38.16	1.78	41.26	4.13	41.29	4.04	38.63	4.31	38.52	3.53
	Surveyed control	34.98	2.25	35.45	1.95	37.65	1.92	41.55	3.47	41.34	2.92	37.93	3.57	38.12	3.79
RSFSR	Surveyed contaminated	36.12	2.17	36.34	1.60	38.14	2.07	42.25	3.36	42.08	3.00	36.73	5.75	38.85	3.63
	Surveyed control	36.00	3.81	35.62	1.83	38.23	2.13	40.63	3.65	41.05	2.84	37.47	3.20	38.31	3.70
UkrSSR	Surveyed contaminated	34.53	3.17	35.49	2.79	38.33	1.91	40.63	3.27	43.10	3.10	41.43	3.93	38.56	4.21
	Surveyed control	33.72	3.40	35.71	2.41	37.52	2.39	42.17	3.55	41.04	3.18	39.31	5.15	37.87	4.22
Total	Surveyed contaminated	35.74	2.62	36.42	2.17	38.20	1.89	41.38	3.69	42.08	3.52	38.73	4.34	38.63	3.75
	Surveyed control	35.02	3.31	35.59	2.07	37.81	2.16	41.37	3.58	41.14	2.95	38.70	4.56	38.11	3.89

[a] Settlement in a contaminated area.

As an example, the adjustment methodology for sex is such that a separate value for each parameter was calculated for males and females. The data were then recalculated to show what the results would be if exactly 50% of the persons examined in an age group in each settlement were male and 50% female. A similar methodology was employed when age adjustment was specified. This methodology allowed the detection of any sampling bias. A comparison of mean haemoglobin, haematocrit and red cell volume by age groups of the study population in contaminated settlements and in surveyed control settlements is given in Tables 15–19 and Figs 4–11.

These data show no significant differences between control and contaminated settlements. Note should be made that the Coulter Counter T 660 gives a haematocrit value that is calculated from the red cell number, the size and the volume of sample. Thus, the results will be slightly lower than results obtained by the conventional haematocrit calculated by centrifugation of blood.

The data indicate that there is a non-statistically significant difference in mean haemoglobin level between control and contaminated settlements for children of ages 2 and 5. At these ages the haemoglobin is slightly higher in the contaminated settlements.

The data do not show any significant difference either between control and contaminated areas or between settlements.

Leucocyte (white blood cell) values were determined for all persons examined. This was important because the percentages of different types of leucocytes are directly related to the magnitude and type of infections. The differential analysis was done by microscopic analysis. Data are presented in Tables 20–25 and Figs 12–15.

The level of thrombocytes (platelets) was determined by direct counting of samples from all persons utilizing the Coulter T 660 Counter. In two settlements

TABLE 18. Red Blood Cell Counts (Millions per mm^3) (Mean and Standard Deviation)

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1-5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	4.50	0.37	4.38	0.22	4.48	0.22	4.38	0.39	4.38	0.53	4.42	0.36	4.43	0.34
	Kirovsk	4.52	0.37	4.31	0.28	4.42	0.21	4.52	0.48	4.52	0.26	4.34	0.34	4.45	0.34
	Khodosy	4.29	0.28	4.30	0.28	4.50	0.33	4.58	0.27	4.56	0.41	4.46	0.46	4.45	0.33
	Veprin[a]	4.22	0.64	4.32	0.32	4.49	0.25	4.36	0.64	4.54	0.31	4.38	0.66	4.39	0.41
	Korma[a]	4.60	0.23	4.56	0.26	4.58	0.25	4.66	0.45	4.61	0.24	4.45	0.24	4.60	0.29
RSFSR	Unecha	4.56	0.65	4.30	0.24	4.54	0.24	4.63	0.37	4.42	0.23	4.56	0.53	4.50	0.40
	Surazh	4.52	0.26	4.27	0.23	4.50	0.30	4.42	0.33	4.71	0.41	—	—	4.48	0.34
	Novozybkov[a]	4.35	0.46	4.27	0.27	4.56	0.27	4.65	0.37	4.69	0.39	3.92	—	4.50	0.39
	Zlynka[a]	4.49	0.22	4.42	0.21	4.48	0.31	4.56	0.35	4.49	0.28	4.46	0.34	4.48	0.27
UkrSSR	Trokovichi	4.68	0.44	4.31	0.31	4.47	0.29	4.60	0.43	4.60	0.45	4.50	0.50	4.51	0.39
	Narodichi[a]	4.34	0.55	4.34	0.29	4.51	0.23	4.44	0.38	4.70	0.58	4.20	—	4.48	0.42
	Polesskoe[a]	4.36	0.39	4.21	0.41	4.52	0.28	4.49	0.29	4.68	0.37	4.61	0.42	4.45	0.38
	Krasilovka, Chemer	4.22	0.36	4.25	0.36	4.31	0.25	4.60	0.37	4.50	0.40	4.57	0.47	4.38	0.37
Total		4.44	0.43	4.33	0.29	4.49	0.27	4.53	0.39	4.57	0.39	4.45	0.45	4.47	0.36
BSSR	Surveyed contaminated	4.46	0.44	4.42	0.27	4.51	0.24	4.48	0.46	4.51	0.39	4.42	0.44	4.47	0.36
	Surveyed control	4.40	0.34	4.30	0.28	4.47	0.29	4.55	0.38	4.54	0.34	4.40	0.41	4.45	0.34
RSFSR	Surveyed contaminated	4.43	0.35	4.35	0.25	4.52	0.29	4.61	0.36	4.59	0.35	4.28	0.39	4.49	0.33
	Surveyed control	4.45	0.51	4.28	0.24	4.52	0.26	4.52	0.36	4.56	0.36	4.56	0.53	4.49	0.37
UkrSSR	Surveyed contaminated	4.36	0.44	4.27	0.36	4.52	0.25	4.47	0.33	4.69	0.48	4.54	0.41	4.46	0.40
	Surveyed control	4.43	0.45	4.28	0.33	4.39	0.28	4.60	0.39	4.55	0.42	4.53	0.49	4.44	0.39
Total	Surveyed contaminated	4.43	0.41	4.36	0.30	4.52	0.26	4.52	0.40	4.59	0.41	4.42	0.43	4.48	0.36
	Surveyed control	4.46	0.44	4.29	0.28	4.46	0.28	4.55	0.37	4.55	0.37	4.47	0.46	4.46	0.37

[a] Settlement in a contaminated area.

(Narodichi and Bragin) the results were not utilized. This was because quality control methods utilized at the time indicated technical problems (electrical noise) that artificially raised the number of platelets. For other settlements the results are considered valid. Platelet determination is important since platelets are an integral part of the clotting process for blood, and because they are somewhat radiosensitive. The results are given in Tables 26 and 27, and Figs 16 and 17.

3.2.1.4. Summary of Haematological Profile

Anaemia was often discussed in Soviet investigations the medical team reviewed. The word anaemia was used without strict definitional criteria. For this reason Project data have been presented in terms of haemoglobin and erythrocyte levels for different settlements and age groups. This will allow various investigators to compare their results with those of the medical team.

The medical team was able to corroborate the findings of Soviet physicians in regard to low haemoglobin levels in some young children in control and contaminated settlements. The field trips of the medical team were adequate to document the range of haemoglobin levels in various age groups in the area and to determine that there was no significant difference in haemoglobin levels in persons living in areas with little or no contamination from those living in highly contaminated settlements. This had also been the finding reported previously by many Soviet researchers.

For comparison, age adjusted values for some haematological parameters in the United States are presented in Table 28.

The studies of the medical team did not, however, allow the determination of the cause of the low haemoglobin levels. It is suspected that limited iron intake and bioavailability may be only one factor among a number of causes of the low haemoglobin in the young children since in many of the cases seen the erythrocytes were normal size (normocytic). This raises the question relative to other deficiencies such as vitamins. The medical teams did not perform an analysis of either vitamin intake (see Section 3.7, 'Nutrition') or of blood levels of vitamins.

Compared to United States values the size of red cells in the Soviet children the team studied was the same. The haemoglobin value was lower. As will be discussed in Section 3.7, 'Nutrition', lower haemoglobin was not due to lead poisoning. No significant differences were seen in adult haematological values between the Soviet and the United States values.

Normal values of leucocytes in the United States are shown in Table 29.

While the number of leucocytes appears to be slightly higher in the Soviet population than in the population of the United States, this difference is not significant. The distribution of leucocyte types is not different.

The number and percentages of various types of leucocyte are not different in persons who live in control and in contaminated settlements. This indicates that there is probably no difference in the rate of infections. The lack of significant eosinophilia suggests that, if parasitic infestation is present, it is not a major clinical problem. The number of leucocytes is highest in children. This is a normal finding in most populations. Specific data relative to lymphocytes are presented in the next section.

The Chernobyl accident does not appear to have had a statistically significant effect on the major haematological parameters of the population. From the calculated and measured radiation dose levels, no changes

TABLE 19. Mean Corpuscular Volume (fL) of Red Blood Cells (Mean and Standard Deviation)

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1-5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	80.00	5.71	83.67	2.47	84.91	2.01	91.48	4.40	89.35	5.27	85.88	5.14	85.55	5.72
	Kirovsk	79.45	6.97	82.66	2.43	85.57	2.43	91.26	4.44	91.67	3.74	87.24	4.88	85.90	6.49
	Khodosy	79.98	3.03	82.17	3.55	83.43	3.12	91.37	4.12	90.48	3.32	85.36	3.70	85.40	5.71
	Veprin[a]	80.39	3.37	83.92	2.13	84.04	3.00	94.25	5.88	92.79	3.08	90.08	4.59	85.74	5.63
	Korma[a]	81.33	2.40	82.66	5.30	85.10	2.46	92.43	3.82	92.35	4.47	87.62	4.55	86.67	6.05
RSFSR	Unecha	78.46	6.87	82.88	1.99	84.37	2.70	91.27	4.43	90.46	4.09	82.33	2.73	85.25	6.55
	Surazh	80.91	2.95	83.59	2.34	84.89	2.38	88.56	3.96	89.90	3.50	—	—	5.63	4.49
	Novozybkov[a]	81.37	5.25	83.98	2.89	84.70	3.84	92.00	2.95	89.39	2.62	78.80	—	86.42	5.25
	Zlynka[a]	82.16	2.52	83.37	2.31	84.68	2.31	91.43	4.00	94.35	4.29	88.90	1.84	86.64	5.57
UkrSSR	Trokovichi	75.62	9.68	83.90	3.67	86.01	2.62	90.30	2.74	89.92	5.83	87.44	7.40	84.67	7.41
	Narodichi[a]	78.54	4.12	83.21	3.43	85.07	2.11	90.67	5.86	92.41	6.81	102.70	—	86.74	6.58
	Polesskoe[a]	79.80	2.41	83.15	2.30	84.75	2.69	91.28	4.81	92.26	5.26	88.98	2.38	86.13	6.04
	Krasilovka, Chemer	78.63	4.10	83.02	3.19	84.91	2.34	92.50	6.46	90.82	4.28	88.09	4.65	86.06	6.62
Total		79.83	5.19	83.27	3.02	84.76	2.68	91.35	4.57	91.22	4.62	87.24	5.57	85.91	6.02
BSSR	Surveyed contaminated	80.52	4.33	83.44	3.48	84.66	2.53	92.25	4.45	91.42	4.64	87.53	5.10	85.97	5.81
	Surveyed control	79.72	5.28	82.43	2.98	84.31	3.02	91.32	4.22	91.09	3.54	86.25	4.37	85.64	6.09
RSFSR	Surveyed contaminated	81.80	3.97	83.65	2.57	84.69	3.07	91.74	3.43	91.80	4.30	85.53	5.97	86.53	5.41
	Surveyed control	79.52	5.61	83.23	2.18	84.59	2.55	89.92	4.37	90.20	3.78	82.33	2.73	85.43	5.67
UkrSSR	Surveyed contaminated	79.40	3.03	83.18	2.84	84.92	2.38	91.00	5.26	92.34	6.00	91.27	5.99	86.41	6.28
	Surveyed control	77.21	7.33	83.52	3.44	85.48	2.52	91.84	5.65	90.40	5.01	87.65	6.63	85.41	7.01
Total	Surveyed contaminated	80.67	4.01	83.44	3.08	84.74	2.64	91.72	4.44	91.82	4.96	87.68	5.20	86.26	5.82
	Surveyed control	78.94	6.09	83.05	2.94	84.78	2.73	90.94	4.70	90.55	4.12	86.97	5.79	85.50	6.23

[a] Settlement in a contaminated area.

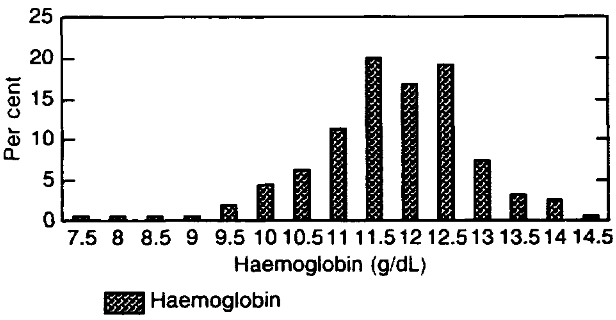


FIG. 4. Haemoglobin distribution for children of age 2, all settlements combined. 10%: 10.6 g/dL; 50%: 12.1 g/dL; 90%: 13.1 g/dL.

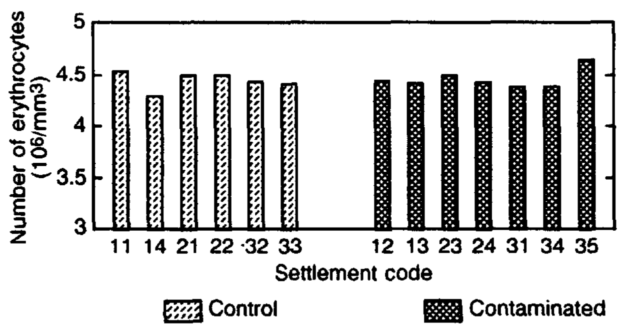


FIG. 8. Mean erythrocyte count by settlement, adjusted for age and sex. SD: ±0.05.

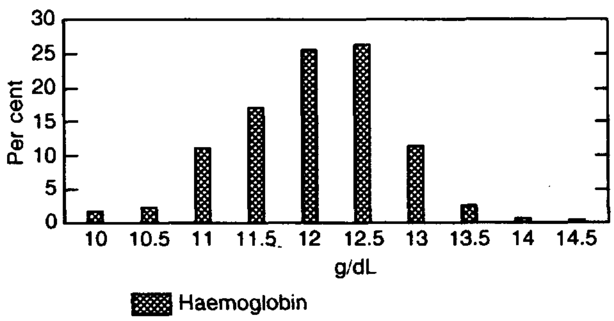


FIG. 5. Haemoglobin distribution for children of age 5, all settlements combined. 10%: 11.3 g/dL; 50%: 12.3 g/dL; 90%: 13.2 g/dL.

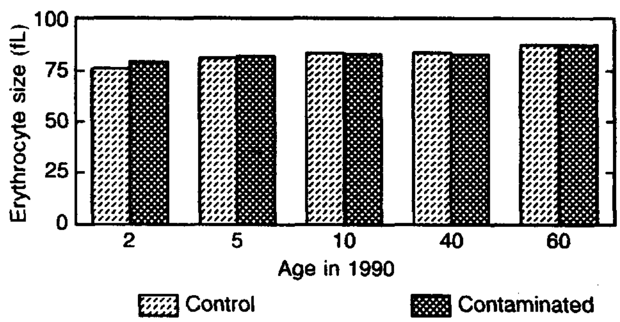


FIG. 9. Erythrocyte size by age in control and contaminated settlements. SD: 9–16.

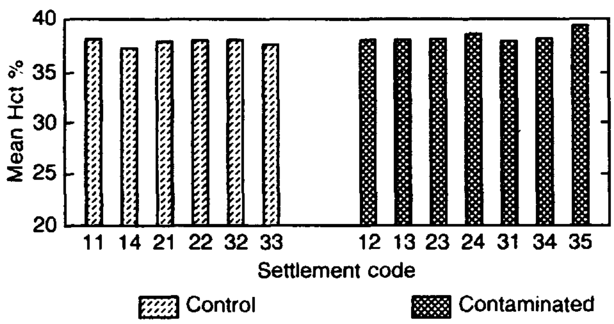


FIG. 6. Mean calculated haematocrit (Hct), adjusted for age and sex. SD: ±0.3%.

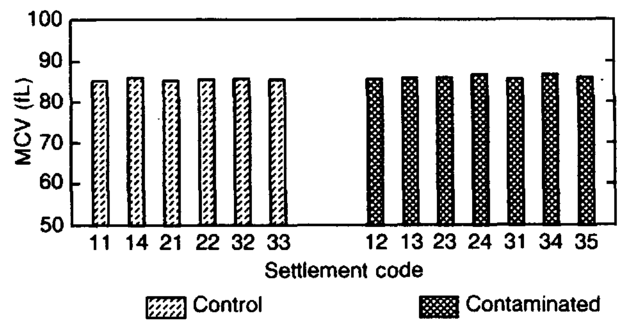


FIG. 10. Mean erythrocyte volume by settlement, adjusted for age and sex. SD: ±1 fL. (MCV: mean cell volume).

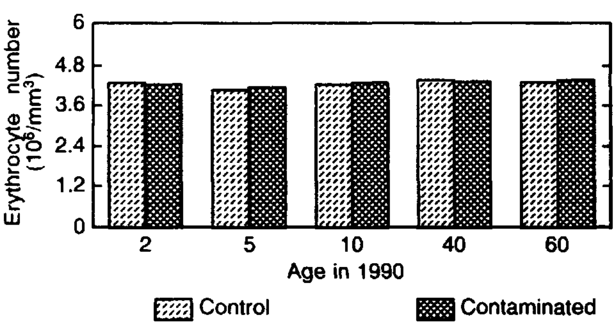


FIG. 7. Mean erythrocyte count by age in control and contaminated settlements.

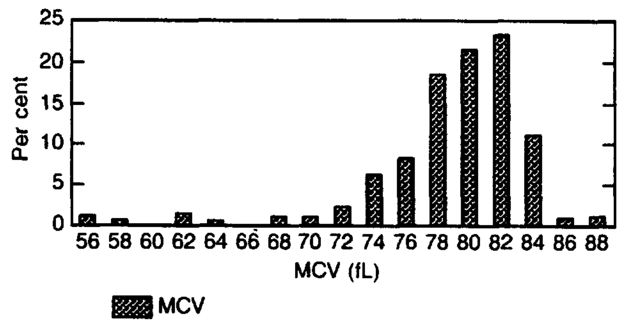


FIG. 11. Erythrocyte size distribution for children of age 2, all settlements combined. 10%: 74.9 fL; 50%: 80.6 fL; 90%: 84.4 fL. (MCV: mean cell volume).

TABLE 20. White Blood Cell Counts (Thousands per mm^3) (Mean and Standard Deviation)

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1–5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	9.78	2.72	9.91	2.31	10.32	2.78	7.01	1.47	8.65	2.49	8.43	2.33	9.21	2.65
	Kirovsk	11.33	2.38	9.50	2.54	8.17	1.40	7.96	1.69	7.47	1.97	9.09	3.20	8.97	2.47
	Khodosy	9.58	1.88	9.14	1.77	8.71	1.98	8.36	1.86	8.13	1.72	8.55	1.87	8.79	1.89
	Veprin[a]	9.21	2.69	8.42	1.96	7.94	2.22	7.94	2.52	9.55	1.64	7.91	2.06	8.54	2.15
	Korma[a]	10.28	1.85	9.84	2.47	8.05	2.50	7.4	1.66	7.28	1.25	8.52	1.97	8.58	2.35
RSFSR	Unecha	12.93	3.13	9.26	2.21	7.81	1.71	8.25	1.87	8.21	1.99	10.77	3.01	9.37	2.98
	Surazh	13.00	4.16	9.84	1.74	8.29	2.09	8.25	1.81	7.85	2.93	—	—	9.42	3.25
	Novozybkov[a]	10.96	3.59	10.54	2.25	7.81	2.07	7.65	2.04	9.02	3.29	10.1	—	9.16	2.98
	Zlynka[a]	11.00	2.70	8.67	2.11	8.06	1.38	8.13	2.24	8.52	1.98	7.25	2.47	8.91	2.35
UkrSSR	Trokovichi	10.04	3.12	10.60	4.69	9.54	4.74	8.11	1.41	8.33	1.99	9.24	3.15	9.51	3.81
	Narodichi[a]	11.34	3.06	10.71	1.82	7.98	1.65	8.27	1.27	8.56	1.14	8.50	—	9.11	2.13
	Polesskoe[a]	10.54	4.06	8.84	2.01	8.25	2.63	7.55	1.85	8.63	2.26	9.74	5.27	8.78	2.84
	Krasilovka, Chemer	9.23	1.90	9.19	2.74	7.25	1.42	8.23	1.88	7.51	1.47	8.18	1.85	8.27	2.07
Total		10.77	3.14	9.56	2.52	8.34	2.44	7.91	1.79	8.25	2.15	8.69	2.60	8.97	2.66
BSSR	Surveyed contaminated	9.80	2.46	9.45	2.33	8.80	2.72	7.30	1.55	8.36	2.05	8.31	2.16	8.82	2.44
	Surveyed control	10.43	2.29	9.33	2.20	8.49	1.77	8.18	1.78	7.79	1.85	8.80	2.58	8.88	2.19
RSFSR	Surveyed contaminated	10.98	3.10	9.51	2.34	7.95	1.71	7.87	2.12	8.77	2.71	8.20	2.40	9.03	2.67
	Surveyed control	12.96	3.57	9.55	1.99	8.02	1.88	8.25	1.82	8.04	2.45	10.77	3.01	9.39	3.10
UkrSSR	Surveyed contaminated	10.79	3.74	9.71	2.12	8.11	2.15	7.89	1.63	8.59	1.76	9.53	4.74	8.93	2.53
	Surveyed control	9.59	2.51	9.93	3.91	8.42	3.68	8.20	1.73	7.89	1.76	8.91	2.85	8.84	3.05
Total	Surveyed contaminated	10.43	3.05	9.53	2.28	8.37	2.34	7.65	1.78	8.56	2.20	8.38	2.34	8.91	2.53
	Surveyed control	11.13	3.20	9.6	2.83	8.30	2.56	8.21	1.77	7.91	2.05	8.90	2.74	9.05	2.81

[a] Settlement in a contaminated area.

should have been expected as a direct result of radiation exposure. Secondary effects (such as dietary restrictions) could have played a role in the period early after the accident, but, if this happened, no lasting haematological effects can be identified.

3.2.2. Immune System

3.2.2.1. Rationale

The immune response is mediated primarily by two cell types, the lymphocyte and the macrophage. Both of these cell types circulate in the bloodstream and are present in the lymphatic system and organs. The role of the macrophage is not well understood but appears to be primarily regulatory in nature. The lymphocytes are responsible for recognition of foreign substances, inducing and regulating the immune response, and for immunological memory.

Small lymphocytes are very sensitive to radiation, so sensitive that the level in peripheral blood can be used as a biological dosimeter. Acute whole body doses of 0.5 Gy cause a measurable, but temporary, reduction in lymphocytes. There are two major subcategories of lymphocytes, T and B cells. B lymphocytes appear to be somewhat more radiosensitive than T lymphocytes [24–30].

Other aspects of the immune system, such as immunoglobulin levels, have also been studied. In patients who have received large doses of radiation during radiation therapy (at whole body dose levels of 1–4 Gy), there have been reports of reduction in the levels of IgA, IgM and IgG. In persons who have received localized radiation therapy to the thymus, there can be a persistent depression of T cells [31, 32].

TABLE 21. White Blood Cell Counts

Group	White blood cells (μL^{-1}) ≥3000 < 10 000[a]		≥10 000 < 15 000		≥15 000		Unknown		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Males and females in contaminated area										
1	70	47.62	52	35.37	11	7.48	14	9.52	147	100
2	92	55.42	69	41.57	4	2.41	1	0.60	166	100
3	132	82.50	26	16.25	2	1.25	0	0.00	160	100
4	124	91.18	12	8.82	0	0.00	0	0.00	136	100
5	101	78.29	25	19.38	2	1.55	1	0.78	129	100
6	85	75.22	23	20.35	1	0.88	4	3.54	113	100
Total	604		207		20		20		851	
Males and females in control area										
1	48	37.80	65	51.18	12	9.45	2	1.57	127	100
2	81	63.78	40	31.50	4	3.15	2	1.57	127	100
3	109	81.34	23	17.16	1	0.75	1	0.75	134	100
4	103	85.83	17	14.17	0	0.00	0	0.00	120	100
5	99	85.34	15	12.93	1	0.86	1	0.86	116	100
6	124	70.45	39	22.16	8	4.55	5	2.84	176	100
Total	564		199		26		11		800	

[a] No count was less than 3000 per microlitre.

Immune function has been studied in the atomic bomb survivors. The proportion of T cells in the peripheral lymphocytes of the heavily exposed survivors was not affected by age or radiation dose. There did, however, appear to be a difference in lymphocyte function with regard to mitogen. Another study of this group involved looking for increased susceptibility to infection. There was no correlation between radiation dose and antibody to Epstein–Barr virus to suggest increased infections in the exposed group. In another study there was evaluation of the phagocytic and bactericidal activities of leucocytes from atomic bomb survivors and fallout victims. There was no evidence of a radiation effect in this regard [23, 33, 34].

To some extent, an indirect measure of the immune response is provided by haematological analysis and the presence and number of circulating lymphocytes. Another indirect measure is the general frequency of disease and infections. These are important since a major function of the immune system is to protect the body from infection. Data in this regard are presented and discussed in Section 3.5, 'General Health'.

3.2.2.2. Review of Official Data

With regard to the immune system it was indicated[8] that 5–7% of the children have transient leukopenia, lymphopenia and thrombocytopenia. These changes have been mild. This group from Moscow has studied some such children and concluded that there are environmental problems since when the children are placed in a hospital for diagnostic workup these changes disappear. Another possibility is simply that these children may have values at the lower end of the normal range. It is also estimated that about 25% of children have chronic infections of the nasopharynx. Another physician[9] felt that the varying lymphadenitis and lymphocytosis/penia may be viral and therefore seasonal.

[8] Dr. Rumyantsev (Moscow).
[9] Dr. Koshel (Moscow).

TABLE 22. Eosinophils as a Percentage of White Blood Cells (Mean and Standard Deviation)

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1-5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	3.84	3.45	2.59	2.21	2.87	2.94	3.52	2.06	3.88	4.32	2.78	2.64	3.29	2.97
	Kirovsk	5.32	3.27	5.32	4.55	6.61	4.43	2.29	2.12	1.79	1.32	3.13	2.80	4.26	3.80
	Khodosy	6.43	4.56	6.30	5.41	7.08	5.43	2.83	2.50	3.94	3.70	5.25	4.20	5.39	4.71
	Veprin[a]	6.07	5.72	6.87	4.37	7.08	4.22	2.50	1.77	2.91	2.21	3.70	3.05	5.83	4.46
	Korma[a]	4.94	3.60	5.35	3.63	4.24	3.55	2.37	2.03	3.74	3.81	3.39	5.05	4.16	3.49
RSFSR	Unecha	6.90	4.52	5.30	4.85	4.05	3.02	2.86	1.88	3.36	2.72	—	—	4.45	3.76
	Surazh	6.16	3.76	7.35	5.45	5.95	3.53	1.27	1.28	2.70	2.56	—	—	4.60	4.20
	Novozybkov[a]	4.30	3.50	5.59	3.20	4.10	2.41	2.59	2.95	2.71	3.55	1.00	—	3.86	3.28
	Zlynka[a]	4.92	4.28	5.33	3.98	4.88	4.04	1.68	2.08	1.95	2.15	8.00	5.66	3.96	3.82
UkrSSR	Trokovichi	3.18	4.35	3.45	4.60	1.70	1.96	2.44	2.96	2.29	2.17	1.73	2.67	2.61	3.42
	Narodichi[a]	3.50	2.22	6.17	5.19	7.45	3.83	2.89	2.21	2.37	1.83	3.50	3.54	4.66	3.93
	Polesskoe[a]	8.33	11.62	5.50	4.26	4.17	3.97	2.91	3.45	2.63	2.43	4.20	4.66	4.74	6.45
	Krasilovka, Chemer	7.35	5.17	6.19	4.32	4.58	2.95	1.15	0.93	1.15	1.42	4.00	7.15	4.00	4.13
Total		5.53	5.28	5.41	4.42	5.01	4.01	2.43	2.32	2.70	2.82	3.19	4.04	4.28	4.16
BSSR	Surveyed contaminated	4.73	4.18	4.81	3.86	4.81	4.01	2.94	2.05	3.59	3.64	3.20	3.38	4.28	3.73
	Surveyed control	5.89	3.98	5.79	4.94	6.89	4.99	2.58	2.32	2.81	2.89	4.12	3.66	4.85	4.33
RSFSR	Surveyed contaminated	4.64	3.91	5.45	3.62	4.51	3.36	2.17	2.60	2.35	2.96	5.67	5.69	3.91	3.57
	Surveyed control	6.54	4.13	6.33	5.20	4.98	3.38	2.05	1.77	3.05	2.63	—	—	4.53	3.98
UkrSSR	Surveyed contaminated	6.77	9.84	5.82	4.67	5.98	4.18	2.90	2.91	2.50	2.13	4.00	4.08	4.70	5.40
	Surveyed control	5.26	5.16	4.79	4.62	3.00	2.83	1.55	1.86	1.68	1.87	2.45	4.66	3.34	3.86
Total	Surveyed contaminated	5.18	5.97	5.24	3.99	5.03	3.90	2.69	2.51	2.85	3.05	3.33	3.49	4.28	4.20
	Surveyed control	5.92	4.39	5.62	4.92	4.98	4.16	2.13	2.04	2.53	2.55	3.11	4.36	4.28	4.11

[a] Settlement in a contaminated area.

UkrSSR

AUSCRM[10] has reported that deviation from the normal white count was found in both contaminated and control regions. The control region was the Poltava district. Some suspected etiologic factors were the presence of herbicides and pesticides. Scientists at AUSCRM have done limited immunological analysis of 68 controls and 187 affected persons from contaminated regions who were 'randomly' selected. The randomization methodology was not clear and the children were those who were having blood drawn for other unspecified reasons. This study was begun only one year ago. At the present they are studying the total leucocyte and lymphocyte counts, T cell subpopulations of lymphocytes, enzyme activities and surface antigens. The initial results do not demonstrate any difference in total leucocyte or lymphocyte counts. The results of lymphocyte subpopulation studies are inconsistent and the authors of these data are continuing to work on the radioimmunoassay and cell sorting methodology.

[10] Dr. V.G. Bebeshko (Kiev).

BSSR

In Bragin, local health authorities reported lymphocytosis of undetermined cause as well as transient asymptomatic lymphadenopathy in children. Exact data were not available to the Project team. In Minsk there were reports concerning differences between the antibody level after immunizations in different groups of children. The medical team was unable to understand the unusual methodology used in the report from Minsk, even after further enquiries by the immunologist of the team. No data were supplied for review.

TABLE 23. Monocytes as a Percentage of White Blood Cells (Mean and Standard Deviation)

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1-5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	8.40	4.42	6.93	3.42	6.83	2.44	8.12	3.70	8.31	2.96	8.10	3.19	7.67	3.51
	Kirovsk	7.05	3.08	7.14	3.01	6.44	2.59	7.48	2.73	7.05	2.30	6.44	3.02	7.05	2.74
	Khodosy	12.22	4.39	11.00	4.08	12.00	4.76	12.42	4.60	11.65	4.57	11.54	4.14	11.90	4.44
	Veprin[a]	8.86	4.91	9.26	4.36	9.76	3.73	6.63	3.66	6.55	4.37	8.11	2.65	8.72	4.29
	Korma[a]	7.18	3.52	9.30	5.43	10.48	6.43	8.89	2.88	5.63	2.61	5.83	2.77	8.40	4.77
RSFSR	Unecha	6.90	3.19	4.20	2.65	4.10	3.27	5.67	2.50	5.55	2.89	—	—	5.28	3.04
	Surazh	3.74	2.33	3.85	2.56	6.25	2.53	3.50	2.50	3.15	2.08	—	—	4.09	2.61
	Novozybkov[a]	7.20	3.79	2.64	2.52	1.81	1.94	2.23	2.25	3.10	1.55	5.00	—	3.34	3.12
	Zlynka[a]	4.08	1.95	3.44	1.95	3.92	2.75	3.63	1.80	4.95	3.34	4.00	1.41	3.96	2.41
UkrSSR	Trokovichi	7.00	3.28	4.86	3.09	4.70	3.07	4.00	2.65	5.71	2.69	6.43	3.11	5.31	3.09
	Narodichi[a]	8.20	4.24	6.78	2.94	7.27	2.95	5.05	2.55	5.26	2.56	9.00	1.41	6.36	3.10
	Polesskoe[a]	7.86	2.95	7.80	3.37	9.11	3.45	1.55	1.34	2.37	1.80	3.80	1.79	5.64	4.11
	Krasilovka, Chemer	9.12	4.51	4.95	5.23	2.00	1.86	6.55	2.96	6.70	2.41	5.52	3.29	5.79	4.23
Total		7.49	4.15	6.29	4.28	6.63	4.60	5.94	4.18	5.71	3.58	7.26	3.61	6.42	4.23
BSSR	Surveyed contaminated	8.14	4.27	8.41	4.51	9.00	4.64	8.17	3.43	6.78	3.36	7.63	3.06	8.20	4.19
	Surveyed control	9.69	4.58	8.98	4.02	9.73	4.84	10.11	4.54	9.22	4.20	8.82	4.38	9.57	4.44
RSFSR	Surveyed contaminated	5.50	3.30	3.08	2.23	2.93	2.61	2.88	2.15	3.98	2.69	4.33	1.15	3.66	2.79
	Surveyed control	5.36	3.20	4.03	2.58	5.15	3.09	4.56	2.70	4.40	2.79	—	—	4.69	2.89
UkrSSR	Surveyed contaminated	7.97	3.35	7.32	3.17	8.10	3.27	3.17	2.64	3.82	2.63	5.29	2.98	5.98	3.68
	Surveyed control	8.06	4.03	4.91	4.22	3.48	2.90	5.76	3.07	6.24	2.55	6.14	3.18	5.56	3.73
Total	Surveyed contaminated	7.21	3.93	6.52	4.30	6.99	4.61	5.02	3.79	4.97	3.24	7.35	3.10	6.19	4.14
	Surveyed control	7.79	4.38	5.99	4.26	6.18	4.58	6.99	4.37	6.50	3.78	7.20	3.91	6.68	4.32

[a] Settlement in a contaminated area.

3.2.2.3. Results of Field Trips

Information relating to the immune system can be obtained both from the number of lymphocytes as well as the presence of bacterial and allergic processes. In the majority of these cases there is a change in the distribution of white cell types seen in the peripheral circulation. All smears and slides of peripheral blood were analysed at the University of Hiroshima. The results relative to lymphocyte count and percentage are shown in Tables 30-32 and Figs 18-21.

3.2.2.4. Summary of Immune Issues

Analysis of the immune system in detail requires a very time consuming, expensive and technically demanding study. Analysis of lymphocyte subtypes requires special monoclonal antibody kits, laser cell sorters and great experience in order to have reproducible results. In well developed countries there are usually only a few scientific groups and laboratories capable of carrying out such studies. In addition to these problems, lymphocytes are quite fragile and must be rapidly transported to the site of analysis. During the team's field trips, conducted in rural settlements, a detailed analysis of the immune system was not possible. The medical team did attempt to transport blood samples for later analysis; however, the transport times and other logistical problems precluded achieving results that were scientifically valid. In the future, more detailed studies may be conducted if logistical, equipment and other problems can be overcome. One should keep in mind, however, that on the basis of studies of other populations and at the dose levels experienced by the population in contaminated settlements, clinically significant changes in the immune function should not be expected.

Review of the data on lymphocyte counts and percentages does not reveal any significant abnormalities in either the populations of either control or contaminated settlements. There is also no difference in number or per cent of lymphocytes between those persons living in control and in contaminated settlements. This would suggest that the claims of a radiation related increase in viral infections as a result of the accident cannot be substantiated. The lack of a difference also indicates that there is no evidence that the level of radiation has been sufficient to decrease the number of lymphocytes. This latter aspect would not have been expected on the basis of the radiation levels present in the settlements.

The independent medical team remains unable to state absolutely that there are not some subtle immunologic changes in the population; however, if there are such changes they appear to be of little clinical importance. In support of this is the lack of a radiation related effect on TCR assays from persons in these settlements. In this regard the independent medical team agrees with the very limited official data it reviewed.

Data on general health (which may reflect immunocompetence) are discussed in Section 3.5.

3.3. Thyroid and Endocrinology Issues

3.3.1. Thyroid Function

3.3.1.1. Rationale

The Chernobyl accident released a large amount of radioactive iodine. If the thyroid glands of persons in the exposed population are not blocked with stable iodine and if food supplies are not carefully controlled, the thyroid gland can accumulate radioactive iodine. If the

TABLE 24. Neutrophils as a Percentage of White Blood Cells (Mean and Standard Deviation)

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1-5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	38.96	9.68	48.44	11.42	51.96	9.85	51.64	9.15	59.94	11.91	48.63	10.50	49.37	12.06
	Kirovsk	40.73	11.58	43.59	7.81	43.83	9.18	53.24	9.91	52.37	9.86	51.44	11.78	46.64	10.85
	Khodosy	35.87	9.02	46.25	14.04	45.92	10.23	58.63	6.05	56.18	7.81	47.79	10.77	48.24	12.62
	Veprin[a]	45.29	14.23	44.96	12.86	51.36	13.66	54.25	12.58	57.36	7.34	53.67	11.73	49.59	13.26
	Korma[a]	42.29	10.99	45.83	11.22	48.57	9.88	54.16	10.65	58.11	9.56	46.67	11.34	49.76	11.68
RSFSR	Unecha	31.55	9.84	38.55	7.80	43.57	10.05	55.86	7.45	53.32	11.24	—	—	44.84	12.95
	Surazh	36.89	8.66	40.85	10.88	42.30	10.59	57.73	11.07	56.10	9.54	—	—	47.09	13.18
	Novozybkov[a]	41.70	14.85	47.23	9.90	44.33	8.59	58.95	10.66	58.38	9.95	63.00	—	50.25	12.93
	Zlynka[a]	34.67	10.23	41.48	12.21	46.00	9.71	56.16	11.72	57.32	9.48	49.00	15.56	46.12	13.55
UkrSSR	Trokovichi	35.18	11.89	45.09	8.86	48.13	15.15	59.56	5.39	56.71	12.68	49.25	12.30	47.69	14.07
	Narodichi[a]	35.00	12.89	40.22	10.49	43.05	12.67	53.68	8.53	53.95	10.53	45.00	7.07	46.20	12.85
	Polesskoe[a]	38.10	12.70	40.05	11.12	42.78	12.91	56.32	8.52	53.68	10.15	51.60	14.83	46.30	13.28
	Krasilovka, Chemer	45.88	11.40	47.14	10.09	49.58	16.35	60.35	9.98	56.30	11.57	53.83	12.10	52.01	13.06
Total		38.45	11.75	43.98	11.07	46.42	11.86	56.13	9.63	56.02	10.27	50.16	11.70	47.99	12.89
BSSR	Surveyed contaminated	41.55	11.43	46.52	11.77	50.71	11.32	52.96	10.14	58.57	9.84	49.80	11.28	49.56	12.23
	Surveyed control	38.24	10.52	44.86	11.15	45.07	9.76	56.11	8.43	54.17	9.03	49.73	11.37	47.47	11.80
RSFSR	Surveyed contaminated	37.86	12.89	44.06	11.49	45.22	9.14	57.66	11.11	57.88	9.62	53.67	13.65	48.12	13.38
	Surveyed control	34.15	9.55	39.70	9.42	42.95	10.21	56.81	9.41	54.64	10.43	—	—	45.95	13.08
UkrSSR	Surveyed contaminated	37.10	12.63	40.13	10.68	42.93	12.62	55.10	8.52	53.82	10.21	49.71	12.85	46.26	13.04
	Surveyed control	40.53	12.69	46.09	9.42	48.79	15.53	60.10	8.72	56.49	11.92	50.70	12.36	49.96	13.68
Total	Surveyed contaminated	39.26	12.29	44.25	11.64	47.08	11.53	55.05	10.11	56.89	10.02	49.92	11.34	48.23	12.87
	Surveyed control	37.55	11.10	43.63	10.33	45.61	12.24	57.36	8.95	55.09	10.49	50.32	11.95	47.71	12.92

[a] Settlement in a contaminated area.

TABLE 25. Basophils as a Percentage of White Blood Cells (Mean and Standard Deviation)

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1-5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	0.04	0.20	0.07	0.27	0.04	0.21	0.00	0.00	0.00	0.00	0.05	0.22	0.03	0.18
	Kirovsk	0.09	0.29	0.05	0.21	0.06	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.20
	Khodosy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Veprin[a]	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.35	0.00	0.00	0.00	0.00	0.01	0.11
	Korma[a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.24	0.00	0.00
RSFSR	Unecha	0.10	0.31	0.20	0.41	0.19	0.51	0.43	0.68	0.45	0.60	—	—	0.28	0.53
	Surazh	0.00	0.00	0.15	0.37	0.45	0.94	0.05	0.21	0.00	0.00	—	—	0.13	0.48
	Novozybkov[a]	0.00	0.00	0.00	0.00	0.05	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.10
	Zlynka[a]	0.04	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.09
UkrSSR	Trokovichi	0.29	0.59	0.14	0.35	0.17	0.39	0.22	0.44	0.00	0.00	0.19	0.47	0.16	0.40
	Narodichi[a]	0.10	0.32	0.00	0.00	0.27	0.70	0.32	0.58	0.05	0.23	0.00	0.00	0.16	0.48
	Polesskoe[a]	1.29	5.23	0.00	0.00	0.11	0.32	0.00	0.00	0.16	0.37	0.20	0.45	0.32	2.41
	Krasilovka, Chemer	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.37	0.05	0.22	0.28	0.53	0.04	0.20
Total		0.16	1.54	0.05	0.21	0.10	0.40	0.09	0.32	0.06	0.26	0.10	0.33	0.09	0.73
BSSR	Surveyed contaminated	0.02	0.13	0.03	0.16	0.01	0.12	0.02	0.14	0.00	0.00	0.03	0.18	0.02	0.13
	Surveyed control	0.04	0.21	0.02	0.15	0.02	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14
RSFSR	Surveyed contaminated	0.02	0.15	0.00	0.00	0.02	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.10
	Surveyed control	0.05	0.22	0.18	0.38	0.32	0.76	0.23	0.53	0.24	0.48	—	—	0.20	0.51
UkrSSR	Surveyed contaminated	0.90	4.31	0.00	0.00	0.20	0.56	0.15	0.42	0.11	0.31	0.14	0.38	0.24	1.79
	Surveyed control	0.15	0.44	0.07	0.26	0.10	0.30	0.17	0.38	0.03	0.16	0.22	0.49	0.10	0.31
Total	Surveyed contaminated	0.23	2.11	0.01	0.11	0.06	0.32	0.05	0.25	0.03	0.18	0.04	0.20	0.08	0.93
	Surveyed control	0.08	0.30	0.09	0.28	0.14	0.48	0.13	0.38	0.10	0.32	0.13	0.39	0.11	0.36

[a] Settlement in a contaminated area.

resultant absorbed doses are high enough and enough parenchymal cells of the thyroid are destroyed, hypothyroidism can result [35]. This hypothyroidism may be either clinical or subclinical and initially may be manifested as a rise in thyroid stimulating hormone (TSH). If the thyroid cannot respond sufficiently to this hormone there will be a subsequent decrease in thyroid produced hormone, most notably, tetraiodothyronine (T4).

There is extensive experience with the use of radioactive ^{131}I in the treatment of both hyperthyroid states as well as thyroid cancer. Such experience would indicate that clinically significant hypothyroidism is unlikely at absorbed doses from radioiodine of less than 10 Gy. Thyroid function has been studied in survivors at Hiroshima and Nagasaki who received direct external exposure to the thyroid. The prevalence of hypothyroidism (as determined by a battery of laboratory tests) was 4.5% and hypothyroidism due to Hashimoto's disease was 2%. This was observed in the radiation dose range 0.01–0.5 Gy. The frequency of hypothyroidism in the control group was 2% and approximately 3% in the 0.5–1.0 Gy group [36].

Various studies have been performed in the past to try to elucidate the time course of hypothyroidism after radioiodine therapy for Graves' disease. In general, the incidence of hypothyroidism rises quite rapidly over the first four years after exposure and then levels off somewhat [37].

One possible ramification of thyroid hypofunction is that when this causes an increase in the level of TSH there is secondary stimulation of the thyroid cells which may cause more thyroid nodules and/or cancer to develop than would otherwise be the case.

There is a widespread opinion that the regions contaminated by the Chernobyl accident are endemic goitre regions and that there was a fairly high prevalence of thyroid abnormalities prior to the accident. Endemic

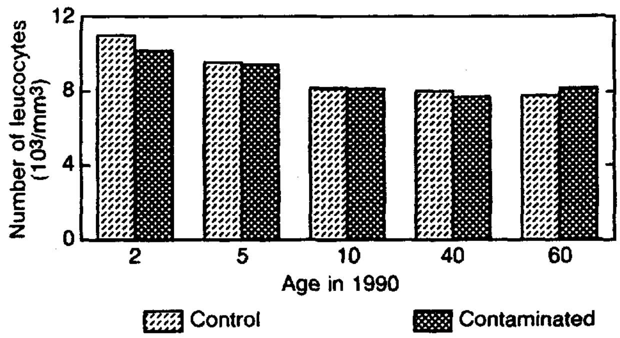


FIG. 12. Mean leukocyte count by age in control and contaminated settlements.

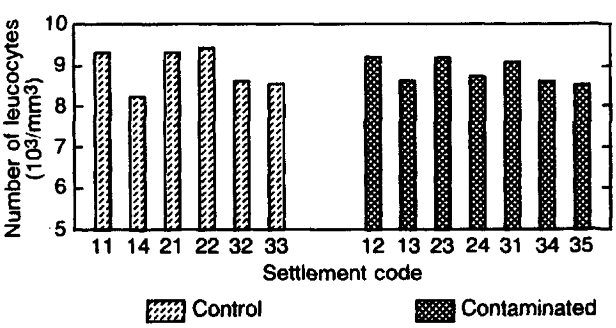


FIG. 13. Mean leukocyte count by settlement, adjusted for age and sex. SD: ±0.3 k (k = 1000).

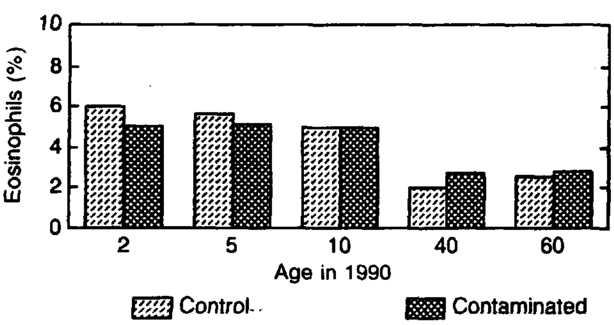


FIG. 14. Per cent eosinophils by age in control and contaminated settlements.

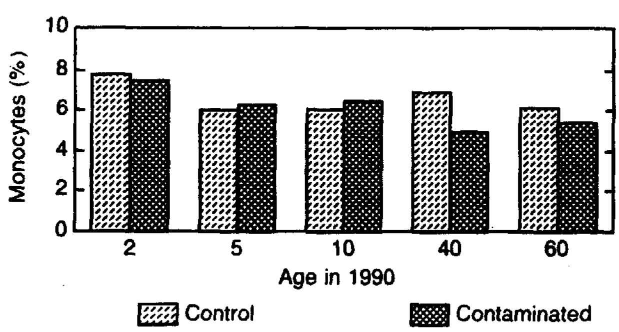


FIG. 15. Per cent monocytes by age in control and contaminated settlements.

goitre is an adaptive disease which usually develops when the amount of dietary iodine required for thyroidal metabolism is insufficient. Typical changes which occur when iodine deficiency is present are an increase in TSH, hyperplasia of the thyroid with related development of nodules, an increase of iodine trapping, changes in the size of iodine stores and a relative increase in the synthesis of tri-iodothyronine (T3).

An increase in TSH levels has clearly been observed in populations where the dietary iodine supply is low; however, there are large variations in the serum TSH levels and normal levels can be observed in persons who have a goitre. Also, increased TSH levels can be found in populations with a low iodine supply but who have no excess of goitre present [38].

During the missions of the medical team, many Soviet citizens, physicians and scientists expressed their concerns relative to thyroid function (particularly in children). For all of the above reasons thyroid function and collected data were examined. The medical team also wanted to elucidate thyroid function in a possibly endemic goitre area.

3.3.1.2. Review of Official Data

Most reliable assays of either TSH or free T4 are performed with radioimmunoassays. This requires the availability of reliable radioimmunoassay kits as well as the gamma spectrometers to count the samples. During the missions to the USSR, the needed instrumentation was seen in most of the major institutes and hospitals. However, in many cases the instruments were idle. This apparently was the result of inability to obtain the required number of radioimmunoassay kits. In general, the few kits that were seen were imported from Germany.

UkrSSR

In Ovruch, the missions were told that approximately 13 500 persons had been tested for thyroid hormone level. Some of these tests apparently demonstrated subclinical hypothyroidism. However, the methodology and data were not presented.

Scientists at the Institute of Endocrinology in Kiev reported that in 1986 there was an increase of circulating thyroid hormones in the blood of some persons without evidence of clinically evident thyrotoxicosis. This was reported in 20–30% of young children who had received thyroid absorbed doses in the range of 2 Gy and higher. They also indicated that no clinical hypothyroidism was seen in the first year but that laboratory hypothyroidism had increased approximately 1–2% above the 'spontaneous level' by 1989.

TABLE 26. Mean Platelet Count (Thousands per mm^3) and Standard Deviation

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1–5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a,b]	388.08	74.82	407.52	67.33	393.00	58.22	278.24	55.42	300.94	80.67	347.11	95.77	359.61	84.58
	Kirovsk	394.82	81.86	334.22	71.48	334.39	74.08	284.00	67.85	268.47	42.93	329.94	82.07	324.83	81.56
	Khodosy	387.74	102.82	340.00	72.12	371.35	60.96	297.00	59.51	279.22	52.97	335.76	78.39	337.71	82.04
	Veprin[a]	351.29	73.50	356.87	81.65	334.60	59.73	252.50	53.54	278.31	48.43	299.61	70.10	326.86	74.59
	Korma[a]	379.33	66.96	361.35	61.78	337.23	72.30	262.90	52.14	270.74	67.59	320.26	78.87	323.14	78.56
RSFSR	Unecha	261.00	117.08	345.30	56.55	319.88	49.18	279.18	55.44	282.59	74.60	302.00	127.29	296.58	80.34
	Surazh	309.47	139.25	350.75	79.98	323.20	62.81	302.91	60.88	272.45	58.45	—	—	311.60	86.84
	Novozybkov[a]	347.25	90.00	350.91	66.32	301.67	48.53	263.17	50.88	269.38	59.11	396.00	—	305.70	73.29
	Zlynka[a]	310.29	120.31	348.07	61.76	352.56	60.46	264.16	61.84	292.75	67.38	302.00	103.24	317.68	83.69
UkrSSR	Trokovichi	246.93	192.34	373.05	94.47	337.14	73.41	284.33	44.71	264.24	54.30	303.60	83.93	310.34	113.73
	Narodichi[a,b]	440.10	103.89	426.89	73.47	363.73	83.33	316.47	83.70	296.21	73.86	256.00	—	360.55	96.92
	Polesskoe[a]	269.27	101.79	334.86	77.94	310.40	76.91	285.64	66.02	245.95	42.63	289.60	116.39	289.63	80.83
	Krasilovka, Chemer	309.11	76.55	359.15	78.90	298.10	49.46	257.33	49.49	253.84	47.12	274.80	43.59	295.43	71.77
Total		334.96	117.34	361.32	76.08	338.23	68.44	280.32	61.12	274.89	61.25	316.20	82.66	320.03	86.31
BSSR	Surveyed contaminated	376.28	72.36	378.60	73.47	355.68	68.19	268.57	53.79	283.22	68.18	326.56	86.36	338.70	81.57
	Surveyed control	391.20	92.18	336.91	70.98	356.23	68.32	291.07	63.07	273.70	47.71	333.01	79.64	331.54	81.87
RSFSR	Surveyed contaminated	327.09	108.02	349.35	63.18	329.33	60.44	263.62	55.39	280.78	63.59	333.33	90.96	311.91	78.90
	Surveyed control	281.93	127.90	348.03	68.42	321.33	54.88	291.05	58.78	277.76	66.78	302.00	127.29	303.61	83.58
UkrSSR	Surveyed contaminated	322.66	128.93	377.33	88.16	338.33	83.81	299.93	75.38	271.08	64.70	284.00	105.00	322.13	95.17
	Surveyed control	281.68	140.97	366.43	86.63	318.07	65.19	265.43	48.98	258.75	50.18	294.51	74.60	302.28	93.44
Total	Surveyed contaminated	347.11	102.82	369.61	75.14	343.55	71.09	276.49	63.03	278.84	65.40	324.40	87.16	326.06	85.29
	Surveyed control	321.84	130.40	350.38	76.24	331.82	64.79	284.65	58.83	270.50	56.23	310.95	79.45	312.96	87.02

[a] Settlement in a contaminated area.
[b] Values in Bragin and Narodichi were artificially elevated by electrical noise during the analysis.

In addition, scientists reported that some of the first children who were evacuated from Pripyat to their institute immediately after the accident experienced a transient rise in T4. It was more pronounced in younger children with higher estimated doses than in others. The gland was also subjectively enlarged at that time. The Kiev scientists felt that the aetiology may be radioactive iodines or the stable iodine prophylaxis. Data relating to this phenomenon were not shown.

AUSCRM[11] indicated that in the Narodichi district (presumably in 1987–1988) 18% of control children had an elevated total T4 level as compared to about 30–40% in children with thyroid doses above 0.3 Gy. There was no major difference between those children with 0.31–1.0 Gy (35% had elevated total T4) and those in the >5.0 Gy group (29% had elevated total T4). The basic biological mechanism whereby total T4 should rise at all in these groups was unclear. The situation became even more confusing when TSH was considered. Usually with damage to the thyroid hormonal cells the circulating thyroid hormone levels decrease, the TSH increases and the T4 returns to normal or stays reduced. In the children the TSH level decreased rather than increased with increasing radiation exposure. It was reported that 11% of controls showed increased or elevated TSH whereas only 5% of children receiving thyroid doses above 5.0 Gy had increased TSH.

There also were reports that Ukrainian scientists had seen ultrasonographically evident structural changes in the thyroid, thought to represent fibrosis. The criteria, methodology, control groups and actual data were not presented.

[11] Dr. A.K. Cheban.

TABLE 27. Platelet Counts

Group	<100 × 10³		≥100 × 10³ <500 × 10³		500 × 10³		Unknown		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Males and females in contaminated area										
1	1	0.68	123	83.67	9	6.12	14	9.52	147	100
2	0	0.00	157	94.58	8	4.82	1	0.60	166	100
3	0	0.00	155	96.87	5	3.12	0	0.00	160	100
4	0	0.00	136	100	0	0.00	0	0.00	136	100
5	0	0.00	128	99.22	0	0.00	1	0.78	129	100
6	0	0.00	104	92.04	5	4.42	4	3.54	113	100
Total	1		803		27		20		851	
Males and females in uncontaminated area										
1	7	5.51	105	82.68	11	8.66	4	3.15	127	100
2	0	0.00	119	93.70	6	4.72	2	1.57	127	100
3	0	0.00	132	98.51	1	0.75	1	0.75	134	100
4	0	0.00	120	100	0	0.00	0	0.00	120	100
5	0	0.00	115	99.14	0	0.00	1	0.86	116	100
6	0	0.00	166	166	4	2.27	6	3.41	176	100
Total	7		757		22		14		800	

Platelet counts (μL^{-1})

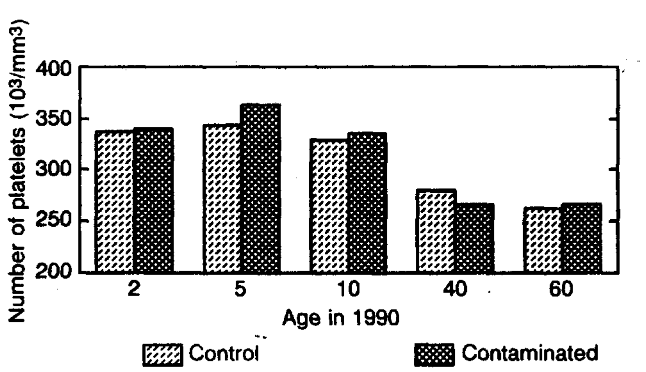


FIG. 16. Mean thrombocyte (platelet) count by age in control and contaminated settlements. SD: 70–100 k (k = 1000).

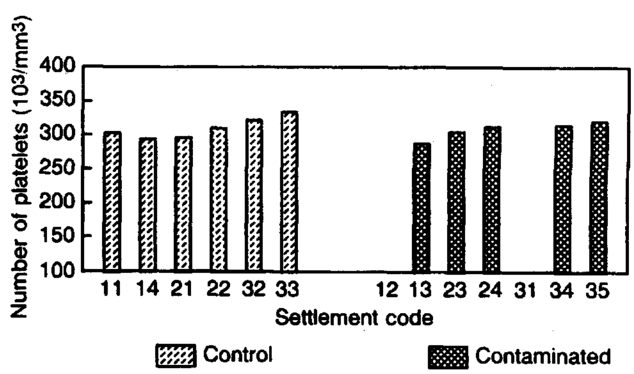


FIG. 17. Mean thrombocyte (platelet) count by settlement, adjusted for age and sex. SD: ±10 k (k = 1000).

TABLE 28. Haematological Parameters of Various Age Groups in the United States of America

Age group	Percentile	Haemoglobin (g/dL)		Mean corpuscular volume (fL)	
		Males	Females	Males	Females
2 years	10%ile	11.7	11.5	75	73
	50%ile	12.5	12.5	79	78
	90%ile	13.6	13.6	85	84
5 years	10%ile	11.9	11.8	77	75
	50%ile	12.8	12.9	82	81
	90%ile	13.8	14.0	87	87
10 years	10%ile	12.2	12.4	80	77
	50%ile	13.5	13.8	86	84
	90%ile	15.0	15.3	92	90
Adults		16.0 ± 2	14.0 ± 2	90 ± 7	90 ± 7

Age group	Red blood cells (millions per mm^3)	
	Males	Females
3 months to 10 years	4.5 ± 0.7	4.5 ± 0.7
11 to 15 years	4.8	4.8
Adults	5.4 ± 0.9	4.8 ± 0.6

TABLE 29. Distribution and Percentage of Leucocytes in the Population of the United States of America

Distribution	Per cent	Average	Minimum	Maximum
Total number of leucocytes per mm^3		7000	4300	10 000
Neutrophils, juvenile and band	1–21	520	100	2 100
Neutrophils, segmented	25–62	3000	1100	6 050
Eosinophils	0.3–5	150	0	700
Basophils	0.6–1.8	30	0	150
Lymphocytes	20–53	2500	1500	4 000
Monocytes	2.4–11.8	430	200	950

TABLE 30. Lymphocyte Counts (Thousands per mm^3) Performed on Coulter Counter (Mean and Standard Deviation)

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1–5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	5.12	2.02	4.33	1.23	3.85	0.75	2.46	0.55	2.65	0.97	3.46	1.04	3.78	1.56
	Kirovsk	4.97	1.50	3.93	1.04	3.31	0.77	2.82	0.30	2.66	0.74	3.34	1.30	3.58	1.28
	Khodosy	4.73	0.88	3.65	0.95	3.39	0.70	2.84	0.66	3.01	1.06	3.57	1.01	3.53	1.07
	Veprin[a]	4.27	1.44	3.72	0.96	3.06	0.53	2.79	0.33	3.36	0.47	3.08	0.82	3.47	0.96
	Korma[a]	4.73	1.07	3.95	1.11	3.06	0.65	2.66	0.69	2.58	0.61	3.42	0.85	3.39	1.16
RSFSR	Unecha	5.85	1.57	3.67	0.85	2.89	0.58	2.43	0.64	2.50	0.60	5.20	2.03	3.53	1.62
	Surazh	6.39	2.37	3.64	0.85	2.84	0.64	2.50	9.71	2.30	0.45	—	—	?.49	1.89
	Novozybkov[a]	4.69	1.81	4.19	1.00	2.99	0.70	2.39	0.67	2.63	0.68	3.40	—	3.36	1.37
	Zlynka[a]	5.50	1.32	3.59	1.00	3.07	0.72	2.72	0.42	2.69	0.53	2.80	1.41	3.57	1.36
UkrSSR	Trokovichi	5.29	1.75	4.15	2.32	3.45	0.50	2.74	0.50	2.72	0.69	3.61	1.79	3.74	1.69
	Narodichi[a]	5.78	1.37	4.93	0.98	3.20	0.92	2.67	0.50	2.93	0.64	3.70	—	3.67	1.40
	Polesskoe[a]	4.74	1.91	3.62	0.89	3.18	1.22	2.22	0.57	2.65	0.76	3.00	1.39	3.30	1.46
	Krasilovka, Chemer	4.39	0.96	3.31	0.58	2.83	0.57	2.56	0.49	2.39	0.66	2.73	1.03	3.08	0.96
Total		5.12	1.67	3.90	1.18	3.17	0.76	2.58	0.60	2.68	0.73	3.38	1.29	3.50	1.40
BSSR	Surveyed contaminated	4.79	1.64	4.03	1.14	3.33	0.74	2.58	0.58	2.81	0.79	3.34	0.94	3.57	1.30
	Surveyed control	4.84	1.22	3.80	1.00	3.36	0.72	2.83	0.52	2.83	0.91	3.47	1.15	3.55	1.17
RSFSR	Surveyed contaminated	5.13	1.60	3.86	1.03	3.03	0.70	2.54	0.59	2.66	0.61	3.00	1.06	3.47	1.37
	Surveyed control	6.08	1.94	3.66	0.84	2.87	0.60	2.46	0.67	2.40	0.54	5.20	2.03	3.51	1.75
UkrSSR	Surveyed contaminated	5.06	1.81	4.23	1.14	3.19	1.06	2.43	0.58	2.79	0.71	3.12	1.28	3.47	1.44
	Surveyed control	4.79	1.41	3.75	1.76	3.15	0.61	2.62	0.56	2.55	0.68	3.33	1.63	3.38	1.38
Total	Surveyed contaminated	4.97	1.66	4.03	1.11	3.21	0.83	2.52	0.58	2.76	0.71	3.32	0.96	3.51	1.36
	Surveyed control	5.28	1.67	3.74	1.26	3.12	0.67	2.64	0.61	2.59	0.74	3.42	1.47	3.49	1.46

[a] Settlement in a contaminated area.

Summary results were presented from the Kiev Institutes of Paediatrics and of Obstetrics and Gynaecology. Since May 1986 staff have done about 20 000 T4 and TSH tests by filter paper blood spot methodology on newborns, including 560 in Narodichi and 1126 in Polesskoe. In 1986 they detected slightly higher TSH and T4, but this was not seen later. In both settlements over the four years, 14 cases of newborns were found with increased TSH, but none of these proved to be hypothyroid when a more extensive workup was done.

BSSR

In Bragin there were reports of persons with initial hyperthyroidism in the first year, returning to normal in the next few years and currently to a hypothyroid state. Actual numbers and methodology were not presented.

A doctor from Minsk[12] has made field trips to the Khojniki and Narovlya areas near Bragin to study about 500 children who had received high doses of radioactive iodine. About 10% of these had elevated TSH levels.

In addition, bar graphs that compare the thyroid function studies in Bragin during June and December 1986 and January 1988 were prepared. The results are confusing and show increased T3, T4 and TSH in June 1986, normal results in December 1986 and decreased T3 but increased TSH in 1988.

Information was given that many children in Bragin are receiving laevothyroxine therapy for their goitres and that this included about 25% of the children.

Abnormal (increased and decreased) echogenicity of the thyroid in 26% of those in contaminated regions versus 4% in the 'control' area was also reported.

[12] Dr. L.M. Astakhova.

TABLE 31. Lymphocyte Percentage (Thousands per mm^3) Measured by Microscope (Mean and Standard Deviation)

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1-5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	48.76	10.12	41.96	12.75	38.30	8.37	36.72	8.18	27.88	10.22	40.41	10.33	39.63	11.83
	Kirovsk	46.82	12.59	43.91	8.30	43.06	8.64	37.00	8.51	38.79	9.65	39.00	10.99	42.01	10.20
	Khodosy	45.48	8.05	36.45	11.47	35.00	8.60	26.13	7.21	28.24	7.42	35.43	7.86	34.47	10.94
	Veprin[a]	39.79	16.65	38.91	9.89	31.80	10.84	36.50	12.41	33.18	8.69	34.52	9.85	35.85	11.90
	Korma[a]	45.59	11.01	39.52	13.26	36.71	11.35	34.58	9.09	32.53	7.82	44.06	10.78	37.68	11.44
RSFSR	Unecha	54.55	12.15	51.65	7.31	48.10	9.94	35.19	7.92	37.27	10.32	—	—	45.13	12.28
	Surazh	53.21	11.57	47.80	13.70	45.05	9.64	37.45	11.49	38.05	10.37	—	—	44.09	12.70
	Novozybkov[a]	46.80	14.16	44.55	8.20	49.71	8.60	36.23	9.90	35.81	10.03	31.00	—	42.54	11.60
	Zlynka[a]	56.29	10.40	49.67	11.57	45.17	9.51	38.47	10.49	35.79	8.95	39.00	11.31	45.90	12.48
UkrSSR	Trokovichi	54.35	13.53	46.45	9.45	45.30	14.16	33.78	6.16	35.24	11.70	42.40	11.72	44.22	13.54
	Narodichi[a]	53.20	14.03	46.56	12.22	41.95	12.15	38.05	7.86	38.37	9.66	42.50	12.02	42.56	11.92
	Polesskoe[a]	44.38	10.82	46.65	8.70	43.78	12.62	39.23	7.75	41.16	8.94	40.20	9.07	42.98	9.99
	Krasilovka, Chemer	37.65	12.33	41.71	11.12	43.84	15.06	31.80	9.87	35.80	11.11	36.34	9.78	38.15	12.50
Total		48.37	12.87	44.25	11.43	41.84	11.84	35.41	9.51	35.50	10.17	39.28	10.73	41.21	12.27
BSSR	Surveyed contaminated	45.55	12.59	40.23	12.01	35.46	10.50	35.90	9.10	31.07	9.04	39.33	10.76	37.94	11.78
	Surveyed control	46.13	10.42	40.36	10.51	38.30	9.41	31.20	9.50	33.81	10.08	37.33	9.75	38.10	11.22
RSFSR	Surveyed contaminated	51.98	13.01	47.37	10.42	47.29	9.28	37.27	10.11	35.80	9.41	36.33	9.24	44.27	12.15
	Surveyed control	53.90	11.73	49.73	11.01	46.61	9.80	36.35	9.86	37.64	10.23	—	—	44.61	12.47
UkrSSR	Surveyed contaminated	47.23	12.44	46.61	10.37	42.78	12.24	38.68	7.73	39.76	9.29	40.86	8.95	42.78	10.91
	Surveyed control	46.00	15.31	44.14	10.45	44.64	14.42	32.41	8.82	35.54	11.22	40.49	11.44	41.04	13.32
Total	Surveyed contaminated	48.11	12.92	43.93	11.61	40.82	11.75	37.17	9.05	35.26	9.84	39.34	10.53	41.21	12.00
	Surveyed control	48.66	12.86	44.66	11.24	43.08	11.88	33.39	9.67	35.77	10.54	39.24	10.88	41.22	12.60

[a] Settlement in a contaminated area.

Unfortunately, sonographic images were only taken when the operator saw any pathology.

It was also reported that the average dose to the thyroid of children evacuated in the BSSR was about 4.5 Sv. A study of children in the Chernigov district was conducted which indicated that 30% of children 1–4 years of age at the time of the accident had elevated TSH (>4.5). About 10% of older children had elevated TSH results.

In summary, the data supplied by the UkrSSR and BSSR scientists were conflicting and confusing. They were very unusual from the standpoint of accepted pituitary–thyroid physiology and pathology. In most circumstances, serum TSH levels and thyroid hormone levels are inversely related. In the data presented to the independent medical team, the levels were directly correlated, not correlated and inversely correlated. The prevalence of hypothyroidism was very different among the various studies and indicated that hypothyroidism is significant and increasing in the BSSR but not in the UkrSSR. This is also unusual since radioiodines are rather volatile and should have come out of the reactor early when the wind direction was toward the UkrSSR.

3.3.1.3. Results of Field Trips

The field trips of the independent medical team concentrated heavily upon examination of thyroid size, structure and function.

During the health effects field trips, blood samples were taken for blood TSH levels. These were analysed by two independent radioimmunoassay (immunometric) methods. In addition, analysis was performed of free T4. Since resources were limited, analysis was directed toward children, particularly those who were infants at the time of the accident and who were expected to have the highest thyroid doses (Group 2, children born in 1985). The data indicate that there were no statistically significant differences in TSH levels at any age between control and contaminated settlements. The mean thyroid stimulating hormone and free T4 levels are shown in Tables 33 and 34 and Figs 22 and 23. Only two persons (both adults) were found to be hypothyroid. There was one each from a contaminated and a control settlement.

3.3.1.4. Summary of Thyroid Function

Following analysis of both TSH and free T4 levels in both adults and children, there is no evidence that thyroid function has been affected in a way that can be detected either clinically or by laboratory testing at this time. Studies of other populations have indicated that while there may be delayed hypothyroidism in some radiation exposed individuals, more than half of the cases should be apparent within five years [39]. It is unlikely, therefore, that hypothyroidism will be a widespread health effect of the Chernobyl accident. It should be pointed out, however, that there may be specific instances in which certain children or other specific population groups can reasonably be suspected of having received very high thyroid doses. In such cases limited continued screening may well be of value. There does not appear to be any scientific evidence at this time to justify widespread screening of the general population for thyroid hypofunction.

The contention that the area may be an endemic goitre region will be discussed in Sections 3.5 and 3.7. However, if there is some element of iodine deficiency, the population has compensated to the point that thyroid

TABLE 32. Lymphocyte Percentage (Thousands per mm^3) Measured by Coulter Counter (Mean and Standard Deviation)

Republic	Settlement	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total groups 1-5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BSSR	Bragin[a]	51.63	6.91	43.86	8.10	38.74	8.08	35.67	6.20	30.84	7.99	41.65	7.26	40.94	10.04
	Kirovsk	44.11	9.49	41.81	6.81	40.86	6.75	36.87	8.05	36.41	8.53	37.55	8.09	40.13	8.40
	Khodosy	50.12	8.15	40.31	8.69	39.69	6.95	33.39	6.55	37.11	7.50	41.57	5.80	40.12	9.35
	Veprin[a]	46.11	6.27	42.77	10.71	40.40	8.32	36.5	7.93	35.8	5.77	40.66	11.10	40.92	8.90
	Korma[a]	46.74	8.91	41.33	10.86	39.94	9.09	35.26	11.22	35.27	4.66	40.70	7.29	39.66	10.04
RSFSR	Unecha	45.80	8.36	40.45	7.54	37.78	6.31	30.32	8.11	31.36	6.65	46.90	6.29	37.41	9.35
	Surazh	47.61	8.57	37.37	7.65	35.33	8.12	30.93	7.94	31.64	7.71	—	—	36.35	9.84
	Novozybkov[a]	43.40	10.19	40.13	6.97	39.35	6.90	31.98	6.52	31.22	8.88	33.6	—	37.09	9.15
	Zlynka[a]	50.64	7.90	42.39	10.23	38.53	7.55	35.24	8.38	32.17	6.18	37.7	6.79	40.31	10.30
UkrSSR	Trokovichi	53.04	8.60	39.78	9.24	40.35	10.32	34.04	5.82	33.57	8.05	39.01	10.02	40.71	10.99
	Narodichi[a]	52.79	11.94	46.34	7.99	40.25	7.32	32.67	4.94	34.42	6.97	43.9	—	40.03	10.04
	Polesskoe[a]	45.83	7.95	41.47	6.26	39.16	8.31	29.89	5.82	31.38	7.47	31.56	4.14	37.65	9.36
	Krasilovka, Chemer	48.03	7.26	37.65	7.11	39.33	7.21	31.98	6.50	32.63	8.43	34.35	8.72	37.83	9.17
Total		47.99	8.78	41.31	8.63	39.20	7.80	33.23	7.55	33.26	7.52	39.36	8.74	39.14	9.71
BSSR	Surveyed contaminated	48.72	7.78	42.78	9.72	39.68	8.39	35.64	8.51	33.87	6.54	41.12	8.44	40.51	9.73
	Surveyed control	47.18	9.24	41.11	7.68	40.17	6.81	34.98	7.40	36.75	7.94	39.68	7.22	40.13	8.88
RSFSR	Surveyed contaminated	47.35	9.62	41.37	8.90	38.90	7.20	33.46	7.51	31.68	7.60	36.33	5.35	38.76	9.87
	Surveyed control	46.57	8.40	38.91	7.65	36.72	7.18	30.63	7.94	31.49	7.08	46.90	6.29	36.92	9.57
UkrSSR	Surveyed contaminated	48.00	9.74	43.71	7.43	39.73	7.73	31.18	5.54	32.90	7.29	33.61	6.25	38.74	9.73
	Surveyed control	50.39	8.21	38.76	8.27	39.85	8.85	32.60	6.28	33.07	8.15	37.52	9.83	39.17	10.14
Total	Surveyed contaminated	48.10	8.86	42.58	8.97	39.47	7.85	33.62	7.58	32.88	7.12	40.57	8.43	39.50	9.80
	Surveyed control	47.88	8.74	39.62	7.89	38.87	7.75	32.79	7.53	33.68	7.96	38.58	8.87	38.71	9.60

[a] Settlement in a contaminated area.

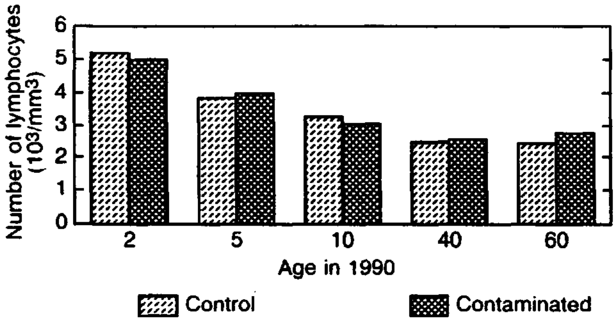


FIG. 18. Absolute lymphocyte count by age in control and contaminated settlements.

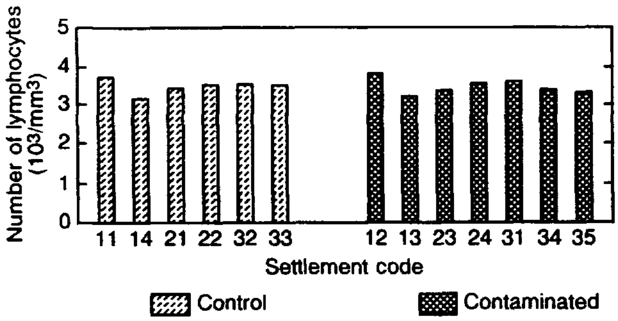


FIG. 19. Mean lymphocyte count by settlement, adjusted for age and sex. SD: ±0.15 k (k = 1000).

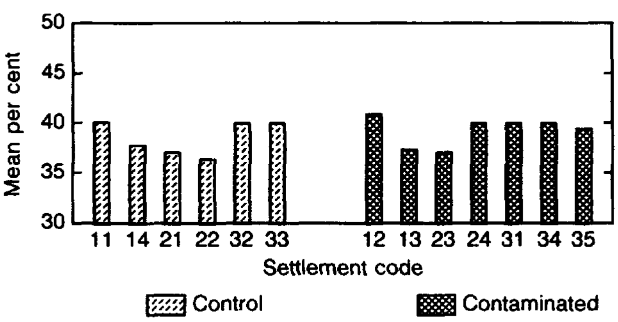


FIG. 20. Lymphocyte per cent, adjusted for age and sex. SD: ±0.7%.

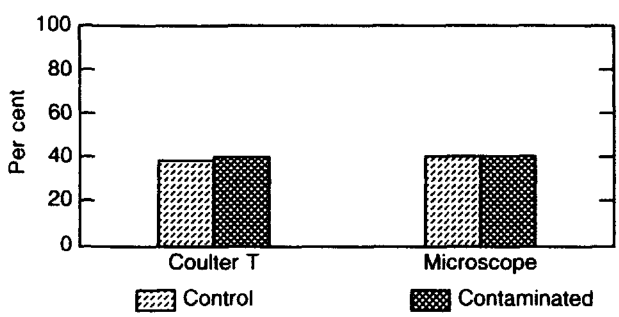


FIG. 21. Lymphocyte per cent: comparison of methods.

hormone production and TSH are normal. In endemic goitre areas there often is an increase in serum TSH which correlates inversely with the level of serum T4 and this correlation is not found for serum T3. Thus low T4 and high TSH levels associated with normal serum T3 concentrations are common patterns in severe endemic goitre areas. The fact that TSH and T4 were normal is an indication that, if the area has a goitre tendency, it is mild.

The team did not collect data relative to the issue of transient rise in the circulating thyroid hormones immediately following the accident. Official data were limited in this regard and there was no scientific basis to pursue this issue on the basis of the projected thyroid doses, the results of the thyroid function studies, and the Project team's assigned task.

In the review of official data, there was an indication that many children were receiving various thyroid medications or preparations. The Project data suggest that few, if any, are receiving such medications on a regular basis that affects thyroid function.

There was good correlation between the serum radioimmunoassay and the filter paper methodology for detection of hypothyroidism and elevated TSH. The two definitely hypothyroid adults were detected with either method. The filter paper methodology is significantly easier on a logistical basis and may be useful in similar screening settings.

3.3.2. Thyroid Size and Structure

3.3.2.1. Rationale

Goitre was first recognized in eastern and southeastern Europe in 1887 by Myrdacz [40]. It was recognized early on that there was some relationship between the urinary iodine content and the percent of goitre in a population. The confidence limit on assessment of the probability of goitre by measuring micrograms of iodine per litre of urine is extremely wide. Iodine deficiency is the principal aetiologic factor in endemic goitre [41, 42]. The method most commonly used to assess dietary intake is measuring daily urinary excretion of stable iodine. Iodine intake is usually below 50 mg per day in the majority of persons in endemic goitre regions. Utilization of the iodine to creatinine ratio in a single urine specimen is useful since in most endemic goitre regions it is not possible to collect 24 hour urine samples.

In addition to dietary iodine deficiency, there are other causes of goitre. There are a large number of dietary goitrogens including brassica vegetables (such as cabbage), pinon nuts, etc., which contain thiocyanate and other goitrogens. In spite of this, natural goitrogens generally are not the major aetiological factor in an

TABLE 33. TSH and Free T4 Levels Observed in the Six Study Groups (Mean and Standard Deviation)

Group[a]	TSH (normal range 0.6–4.96 μIU/mL)						Free T4 (normal range 0.7–17 ng/dL)					
	Contaminated settlement			Control settlement			Contaminated settlement			Control settlement		
	Mean	SD	Sample	Mean	SD	Sample	Mean	SD	Sample	Mean	SD	Sample
1	1.65	0.80	45	1.96	1.00	46	1.24	0.14	30	1.43	0.35	40
2	1.94	0.86	140	2.12	1.05	102	1.30	0.19	116	1.38	0.30	79
3	2.08	0.90	136	2.01	0.92	105	1.36	0.47	118	1.53	0.59	89
4	1.99	1.44	113	2.38	6.09	83	1.22	0.29	99	1.37	0.36	72
5	2.44	9.06	103	1.61	1.23	62	1.14	0.28	85	1.32	0.35	56
6	2.16	1.46	33	1.84	1.03	68	1.19	0.34	32	1.65	0.75	62

[a] As in many other tables of this report, groups 1–5 refer to ages 2, 5, 10, 40 and 60, respectively. Group 6 are all other ages.

TABLE 34. Number of Thyroid Function Tests Outside the Normal Range[a] in Contaminated and Control Settlements

Settlement		TSH		Free T4	
		High	Low	High	Low
Contaminated	Narodichi	2	5	0	1
	Polesskoe	1	5	0	0
	Novozybkov	1	4	6	1
	Zlynka	0	5	1	0
	Bragin	0	5	0	1
	Veprin	0	0	1	0
	Korma	1	2	0	0
	Total	5	26	8	3
	Per cent of tests	1	5	2	1
Control	Trokovichi	0	0	2	0
	Krasilovka, Chemer	2	3	19	0
	Unecha	1	8	4	1
	Surazh	0	6	1	0
	Kirovsk	0	2	0	1
	Khodosy	0	2	0	0
	Total	3	21	26	2
	Per cent of tests	1	5	7	1

[a] Results outside the 'normal range' of ten represent persons who have questionable thyroid function but are not definitely hyper- or hypothyroid.

endemic goitre area. Genetic factors in the aetiology of endemic goitre have also been studied and appear to play some role [38, 43].

Comprehensive information on endemic goitre in European and Asian territories of the USSR can be found in a monograph by Arndt [44] and in a review by Kelly and Snedden [45], but the authoritative report was written by Nikolaev [46].

A large scale antigoitre programme was started in the USSR during the 1930s. One of the most extensive goitre surveys was made in 1933 in the Kabarda on the northwestern slope of the Caucasus and in neighbouring plains. Goitre was found in 85% of the population. After five years of iodine prophylaxis of salt, only 10 to 15% of goitrous persons were found.

The fact finding trips were told that most of the endemic goitre prophylaxis programmes in the USSR were phased out in the 1960s and that currently the iodinization of salt is not complete and the process is not stable unless the salt is kept in tightly closed containers. In Minsk, physicians and scientists indicated that there was a policy in some areas of the BSSR to administer stable iodine for goitre prophylaxis to school children on a weekly basis.

The incidence of endemic goitre that is identified in certain regions depends on the technique of goitre examination used in the various epidemiological surveys [47, 48]. In 1960, the World Health Organization proposed a classification for international use based on a 'grading' of the size of the goitre into four categories:

Grade 0 subjects without a goitre
Grade 1 subjects with a palpable goitre
Grade 2 subjects with a visible goitre
Grade 3 subjects with a very large goitre.

In this classification scheme, the problem between Grade 0 and Grade 1 consists of defining at which

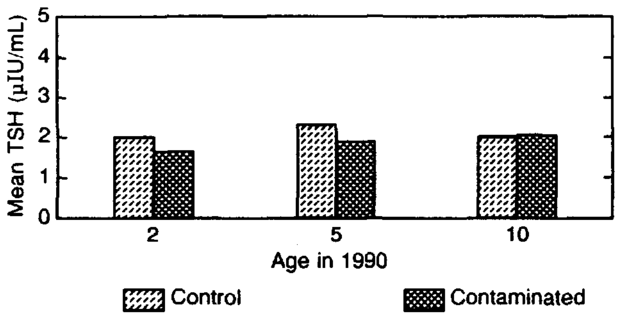


FIG. 22. Mean thyroid stimulating hormone (TSH) in children of control and contaminated settlements. μIU stands for micro-International Unit (see text). Normal range: 0.6–5.0 μIU.

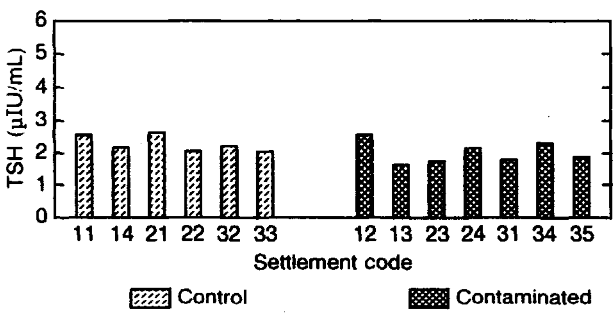


FIG. 23. Thyroid stimulating hormone (TSH) in children of age 5 by settlement. 1 μIU stands for micro-International Unit. Normal range: 0.6–5.0 μIU.

degree of enlargement one considers that there is sufficient pathologic alteration of the gland in order to speak of a goitre. In general, Grade 1 is defined as a gland whose lateral lobes are more voluminous than the last phalanx of the examiner's thumb. Some authors use 2 subgroups in Grade 1, 1A and 1B, depending on whether the palpable gland is or is not visible with the neck in extension [49].

There were many reports, both in the settlements and in the cities that were visited, of an increased incidence of goitre in the regions surrounding Chernobyl. Many persons indicated that this was the result of the accident while others felt it was simply due to the area being an iodine deficient endemic goitre region.

Whether an area is, in fact, an endemic goitre area has to be defined by statistical criteria. One also needs to consider that thyroid hypertrophy or the presence of a small diffuse goitre is physiological and is present in about 4% of young girls at puberty. In addition, a goitre incidence of 5% is found in many countries where iodine intake is sufficient. As a result, it is customarily considered that a region is endemic for goitre when goitre affects more than 10% of the population. There are various ways of classifying regions by the severity of endemic goitre; these are based on 24 hour urinary iodine excretion or the iodine/creatinine ratio. Generally, when iodine excretion is more than 50 mg/g of creatinine in the urine the presence of goitre in a population is not a clinically significant problem.

The results of most epidemiological goitre surveys are very difficult to compare and their reproducibility has been a problem. The reasons for the lack of comparability of goitre frequency in most studies are the different methods of classification, the estimation of gland volume and the very subjective nature of palpation [47]. The findings of palpation depend upon the general shape of the neck, the thickness of subcutaneous tissue, the disposition of overlying muscle, the examiner's experience and/or fatigue, circumstances of illumination and the time devoted to the examination. It is clear that, even in exceptionally well controlled clinical conditions, thyroid volume cannot be estimated to within closer than 25%. When using the international classifications, the frequency of goitre can only be estimated to within 10% if there is a high natural frequency in the population or within 5% when there is a low frequency in the population. Utilization of the four grade system that is used by many authors results in only one third of the subjects being placed in the same classification when examined by three different experienced examiners. The situation relative to interference by overlying tissue may be improved by the use of ultrasound although even with the use of ultrasound the thyroid volume can only be consistently estimated to within 85–115% of the actual volume.

In endemic goitre areas there are usually large numbers of persons who have nodules of various sizes either within a gland of normal size or within an enlarged gland. There may be multiple nodules or only a single nodule. The frequency of nodules increases with age and introduces two complications into the classification of goitre for epidemiological purposes. The number of nodules palpated often does not reflect the true situation but depends on the examiner's sensitivity, the size of various nodules and the firmness or softness of the surrounding thyroid tissue. Additional difficulties arise in distinguishing between the nodularity of a gland or local induration, prominence or swelling of tissue. A number of observers have pointed out the difficulties in palpation of nodules in endemic areas whose goitres have been treated. Typically an increase in frequency of nodules is observed simply due to the fact that the surrounding tissue becomes softer after treatment and the nodules are more readily identifiable.

Some observers consider the presence of a nodule as an indication of thyroid abnormality and classify the person as having a goitre even if the volume of the gland is not enlarged. Often such persons are assigned to Grade 1. While the nodule may indicate pathology in the gland it introduces substantial variation in the classification of goitre. Most observers therefore continue to record volume and nodularity as two separate and independent findings.

There is some literature concerning the normal frequency of nodules and some relating goitre, nodules and radiation exposure [9, 50–59]. In Nagasaki, the frequency of single nodular goitre was approximately 1% in the control group and slightly over 5% in the 1.0 Gy group. About one third of these goitres were benign, 1/3 malignant and 1/3 of an unknown status. Prevalence of a nodular goitre of any type in groups exposed to fallout was approximately 1% in the control group and 4 to 5% in the fallout group. There is an argument in the literature concerning whether there is an increased frequency of thyroid cancer in regions of endemic goitre [38, 60]. At present the issue appears to be unresolved.

3.3.2.2. Review of Official Data

The majority of data and previous comments related to the Chernobyl accident indicate that the area is an endemic goitre region. There were no comprehensive surveys that the Project team could locate to confirm this widely held belief. There are some studies that are related to specific settlements or relatively restricted areas.

One of the major problems in the present review of official data was that the definition of a 'goitre' was not uniform. In some studies the WHO classification was used, in some the reference was to a nodule of any type and in others the reference was to an enlarged gland. In addition, in some areas, there was reference to a Grade 1 goitre which was felt to be a normal variant and not indicative of pathology. In many of the data presented to the Project team the definition of goitre was not clear, nor was the similarity or difference between the terms hyperplasia and goitre clear.

UkrSSR

AUSCRM[13] reported data on the frequency of thyroid hyperplasia by absorbed dose for the years 1986 and 1988 in the Narodichi district. The overall incidence of hyperplasia was 20–40% with no clear relation to either absorbed thyroid dose or year.

The western UkrSSR was a major goitre region and there were goitre prevention hospitals before the 1950s but these were phased out and no longer exist.

BSSR

Abnormalities in thyroid hyperplasia were reported in Korma in 1989, as follows: Grade 1 (31.6%), Grade 2 (6.2%), Grade 3 (0.2%). There was no identifiable change in thyroid function.

The Health Ministry in Gomel indicated that goitre was present both pre- and post-accident although they were not sure whether the incidence had changed. The team was told that many of the population in the area were getting iodine preparations and had been taking them since the time of the accident to avoid goitre.

The Ministry reports that there were no data available concerning radioactive iodine concentration in the thyroid within the first two months after the accident. In general, there was no stable potassium iodide prophylaxis available for most of the children during the course of the accident.

Data[14] are available that indicate that about 3–4% of children in the Khojniki and Narovlya areas have a Grade 2 or 3 goitre and about 40% have a Grade 1 goitre. This was determined by physical palpation and not by sonography. There was a study concerning ultrasonography of the thyroid on 700 children in the Khojniki region, where the thyroid dose was generally greater than 200 rem (2 Sv), with a group of control children in the Vitebsk region. All studies were done by the same person with the same Toshiba machine but they were separated by about 6–12 months. The control region was chosen as an endemic goitre region north of Minsk.

Abnormal (increased and decreased) echogenicity of the thyroid was also reported in 26% of those in contaminated regions versus 4% in the control area.[15] Unfortunately, the sonographic images were only printed when the operator saw pathology.

Many children in the region of Bragin supposedly have been placed on laevothyroxine when they have a Grade 2 or 3 goitre diagnosed. The parents may not know what kind of pills their children are taking and are probably unable to distinguish them from vitamins. Where the children get access to these medications was not clear since (based upon the Project team's casual inspection) availability of such preparations in most settlements seemed to be negligible. The children theoretically may be kept on these preparations prophylactically for years. It was estimated[16] that as many as 25% of children in Bragin were receiving such therapy.

RSFSR

It has been reported[17] that about 8000 to 9000 children in the Bryansk region and in particular in Novozybkov have been studied three to four times each. Initially, the researchers looked at height and weight as well as

[13] Dr. A.K. Cheban.

[14] Dr. L.M. Astakhova (Minsk).

[15] Dr. L.M. Astakhova (Minsk).

[16] Dr. L.M. Astakhova (Minsk).

[17] Dr. Knyazev (Moscow).

doing a physical examination of the thyroid. They also had special seminars with the local doctors. By palpation they estimated the prevalence of goitre at 24% initially and 37% in the later studies.

The incidence of thyroid hyperplasia by age was reported to be:

1–3 years	52%
3–6 years	73%
6–10 years	75%
10–15 years	85%.

In terms of percentage the hyperplasia degree was:

1st degree	41%
1st to 2nd degree	28%
2nd degree	25%
3rd degree	6%.

It was found[18] that, when ultrasound was used to study the thyroid, an incidence of 19.5% with goitre (all stages 1–3 combined) in the contaminated regions versus 14.5% in the control areas of Karachev and Brasov was observed. How 'goitre' was defined for purposes of an ultrasound study was not clear. It was felt that perhaps these control areas were not endemic for goitre and the Valenskij region was studied as well.

When ultrasound became available, 1000 boys and 1000 girls of different ages were examined to obtain control data on thyroid size:

The total gland size (cm^3) was for

Boys:	5 years old	2.05 ± 0.96
	10 years old	4.13 ± 1.30
Girls:	5 years old	1.74 ± 0.57
	10 years old	4.51 ± 1.39.

The salt was checked occasionally for iodine. It was found both that the iodine content was lower than what the USSR standards called for and that there usually was improper storage of the salt.

Data from the Kaluga region regarding thyroid size (as measured by ultrasound) were also given.[19] Data relevant to the field trips study groups are as follows:

The total gland size (cm^3) was for

Males:	5 years old	2.11 ± 1.09
	10 years old	4.14 ± 1.57
	31–40 years old	14.33 ± 5.43
	51–60 years old	14.10 ± 5.86
Females:	5 years old	1.86 ± 0.68
	10 years old	4.55 ± 1.35
	31–40 years old	13.05 ± 5.47
	51–60 years old	12.40 ± 5.12.

[18] Dr. Knyazev (Moscow).

[19] Dr. V.S. Parshin (Obninsk).

3.3.2.3. Results of Field Trips

Each trip included an experienced thyroid endocrinologist as well as experienced thyroid ultrasonographers. In the questionnaire adults were asked whether they had been told that they had either thyroid enlargement, nodules or a goitre. The resulting data are shown in Table 35. There was a significant difference in past history relative to both thyroid problems and anaemia when control and contaminated settlements were compared. Essentially 25% of all persons examined in contaminated settlements had been told or thought they had a thyroid problem.

Data from the health effects questionnaire were collected relative to the percentage of children and adults in control and contaminated settlements in whom enlarged thyroids or thyroid nodules were found. The results are given in Tables 36 and 37 and Figs 24 and 25.

These data show that thyroid gland volume increases until about age 40 and then decreases slightly (Figs 26–29). The gland size is quite variable for persons of a given age and there is a small percentage of persons with quite large glands. There is no clear evidence that settlements in a particular area have inhabitants who as a group have markedly enlarged glands. Overall mean thyroid size in the area studied by the Project team appeared to be slightly larger than values reported for some other areas of the USSR (Figs 30–34).

The frequency of thyroid nodules varies since the detection methodology with ultrasound yields values about threefold higher than palpation (Figs 35 and 36). Nodules are rare in children but occur in 5–15% (depending upon the detection method) of adults. No significant difference was found between surveyed control and contaminated settlements.

Thyroid size and nodularity were assessed both by thyroid palpation and by thyroid ultrasound. Palpatory examination of the neck involved cervical extension, neutral position and flexion. Palpation also included examination during swallowing as well as visual examination. Glands were classified following palpation as either normal size (WHO Grade 0) or enlarged (WHO Grade 1 or greater). With use of thyroid ultrasound, thyroid homogeneity was determined by real time ultrasound examination with thermal printer images made of both normal and abnormal glands. A structural abnormality, cystic or solid, was recorded when the diameter exceeded 5 mm.

In some settlements, for example Khodosy, the Project team carefully questioned the children, their parents and teachers relative to what goitre prevention practices were actually being carried out. In most instances the children were not receiving stable iodine on a regular basis. In some areas of the BSSR stable iodine is being given to kindergarten children and to some children in the sixth grade level, who receive it for one or two months in the year.

TABLE 35. Adults Reporting Past History of Goitre

	Persons in contaminated settlements		Persons in control settlements		Total
	Number	Per cent	Number	Per cent	
Yes	66	24.9	25	10.6	91
No	199	75.1	211	89.4	410
Total	265	100	236	100	501

$p = 0.001$.

TABLE 36. Children Ages 5 and 10 Found by Physical Examination to Have an Enlarged Thyroid or Thyroid Nodules

	Contaminated settlements		Control settlements		Total
	Number	Per cent	Number	Per cent	
Thyroid enlarged	18	0.5	19	7.5	37
Thyroid normal	307	99.5	236	92.5	543
Total	325	100	255	100	580
Nodules present	2	0.6	2	0.8	4
Normal	323	99.4	253	99.2	576
Total	325	100	255	100	580

TABLE 37. Adults Ages 40 and 60 Found by Physical Examination to Have an Enlarged Thyroid or Thyroid Nodules

	Contaminated settlements		Control settlements		Total
	Number	Per cent	Number	Per cent	
Thyroid enlarged	27	10.5	16	7.0	43
Thyroid normal	230	89.5	213	93.0	443
Total	257	100	229	100	486
Nodules present	9	3.5	5	2.2	14
Normal	248	96.5	224	97.8	472
Total	257	100	229	100	486

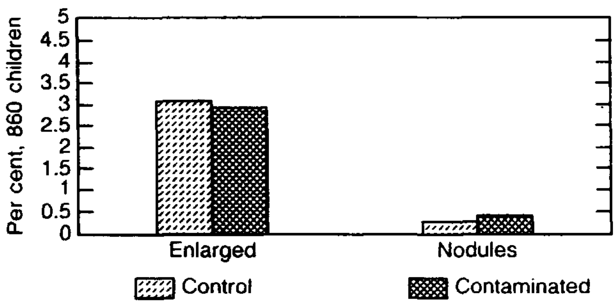


FIG. 24. **Thyroid abnormalities as determined by physical examination in children of ages 2–10.** p = non-significant.

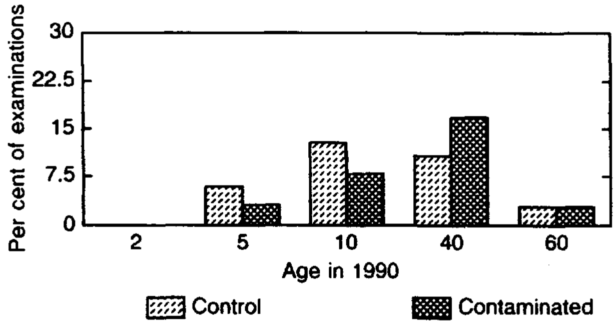


FIG. 25. **Thyroid enlargement as determined by physical examination in persons of different ages in control and contaminated settlements.**

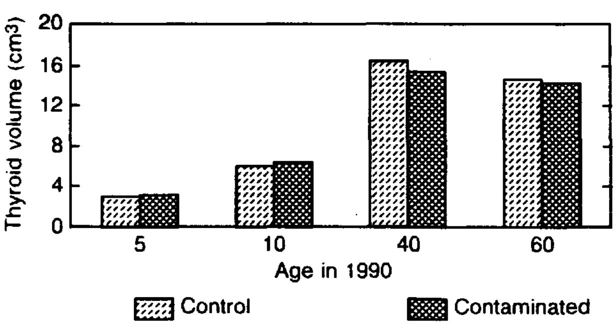


FIG. 26. **Thyroid volume as determined by ultrasound examination in persons of different ages in control and contaminated settlements.**

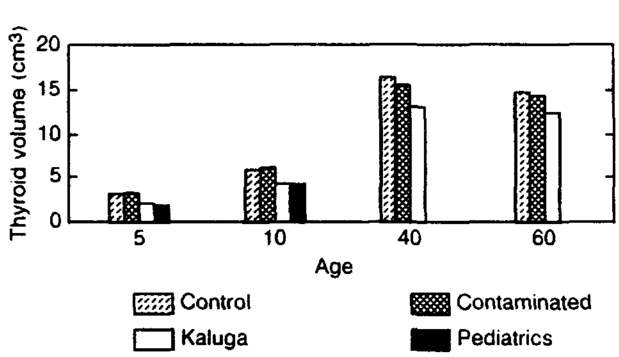


FIG. 27. **Thyroid volume versus published data for persons of different ages (both sexes).**

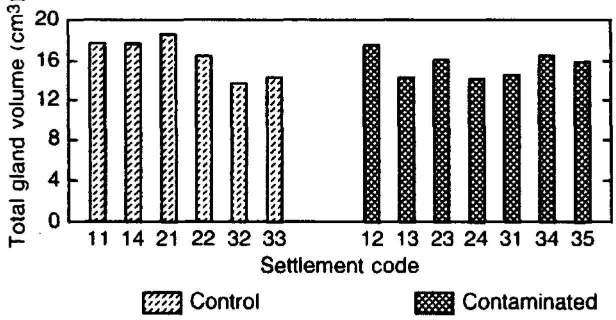


FIG. 28. **Total volume of thyroid by settlement, adjusted for age and sex.** SD: ± 1.5 cm^3.

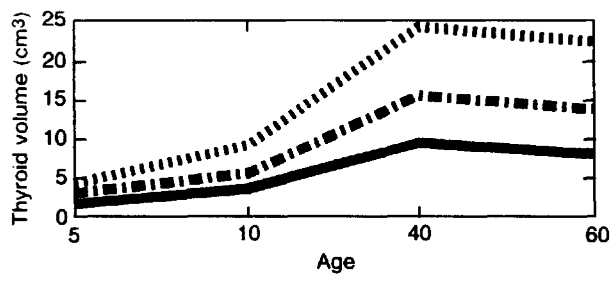


FIG. 29. **Thyroid volume distribution by age as determined by ultrasound.**

3.3.2.4. Summary of Goitre Issues

The team's review of official data was complicated by lack of standardized terminology and methodology. In addition, there was (as is common to most goitre studies around the world) substantial difficulty in reproducible classification of the Grade 0 and 1 glands on a clinical basis. There was a statistically significant difference between control and contaminated settlements, in the number of persons in contaminated areas thinking or having been told that they have a goitre. The team was unable to confirm any significant difference between settlements either by palpation or by ultrasound examination. Gland size as measured by ultrasound in the team's studies appears to be a little larger than that reported by other investigators for other areas of the USSR. There certainly were persons examined by the team who had enlarged glands, but the frequency appeared comparable to other populations with whom the examiners of the team were familiar.

In the study there was only a fair agreement between the findings by physical palpation and those of ultrasound. This is understandable since the size of a gland judged by palpation is influenced by the amount of overlying tissue (muscle and fat) as well as by the consistency of the gland. We found about 8% of the population with an enlarged thyroid gland by palpation and thus were unable to confirm the region as a true

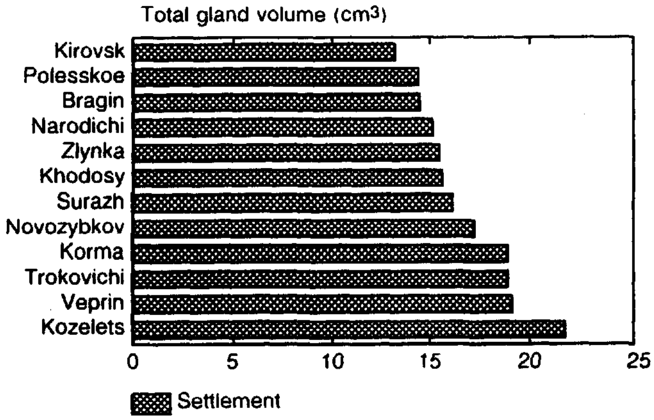


FIG. 30. Thyroid volume determined by ultrasound for 40 year old adults in different settlements.

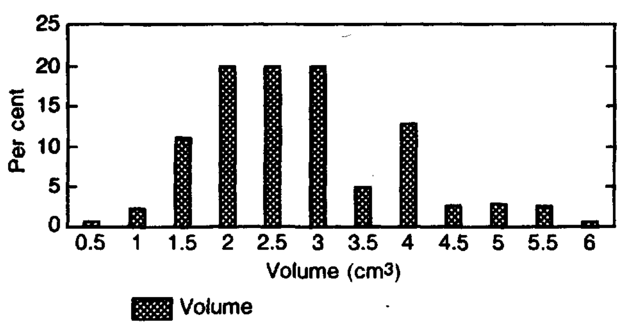


FIG. 31. Thyroid volume distribution for children of age 5, determined by ultrasound, for all settlements. 10%: 1.8 cm^3; 50%: 2.8 cm^3; 90%: 4.2 cm^3.

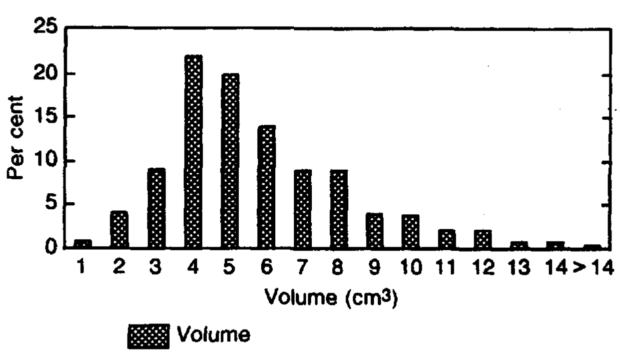


FIG. 32. Thyroid volume distribution for children of age 10, determined by ultrasound, for all settlements. 10%: 3.6 cm^3; 50%: 5.6 cm^3; 90%: 9.2 cm^3.

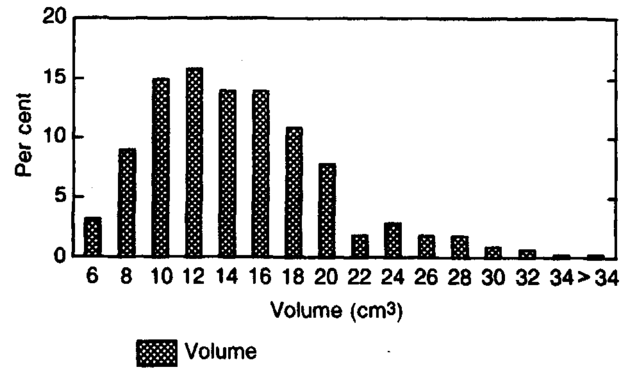


FIG. 33. Thyroid volume distribution for persons of age 40, determined by ultrasound, for all settlements. 10%: 9.8 cm^3; 50%: 15.8 cm^3; 90%: 24.8 cm^3.

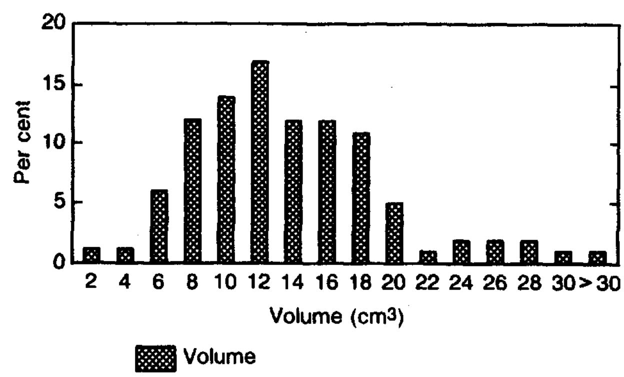


FIG. 34. Thyroid volume distribution for persons of age 60, determined by ultrasound, for all settlements. 10%: 8.4 cm^3; 50%: 14.2 cm^3; 90%: 23.0 cm^3.

endemic goitre region (utilizing the WHO definition of greater than 10% of the population having enlarged glands by physical palpation). These clinical data are also supported by the normal thyroid function data as well as the data on dietary iodine intake and urinary iodine excretion which are presented later in the nutrition section of this report.

The team's study does not exclude the fact that endemic goitre regions may exist in other areas of the Republics nor that there may be localized settlements with a goitre problem.

In future decades there may be some increase in the percentage of enlarged or nodular glands as a result of radiation exposure. Enlarged thyroid glands have not been a problem of major clinical significance in the Japanese atomic bomb survivors and therefore probably will not be an important issue for the population as a whole residing around Chernobyl.

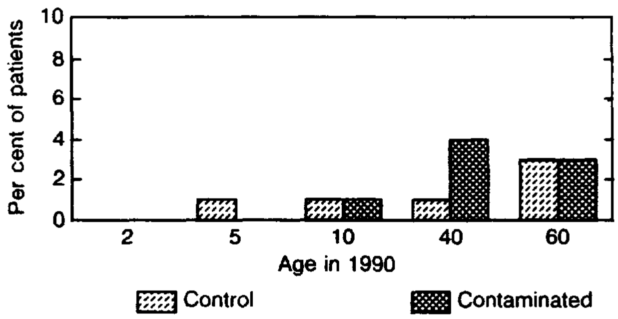


FIG. 35. Thyroid nodularity as determined by physical examination for different age groups in control and contaminated settlements.

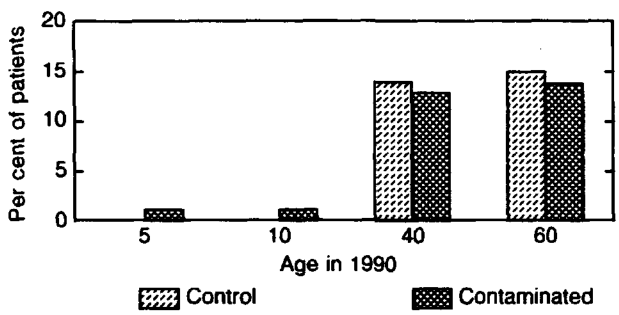


FIG. 36. Thyroid nodularity as determined by ultrasound examination for different age groups in control and contaminated settlements. Nodule: >5 mm diameter.

Nodule formation in glands will undoubtedly be a major issue. Our data have shown that nodules can be palpated in about 5% of adults and in less than 0.5% of children in both control and contaminated settlements. This is very similar to data reported for the US population. When the technology of ultrasound is utilized, structural abnormalities can be recognized in about 15% of adults as a non-radiation related finding. It certainly is not feasible or desirable to biopsy all such areas. Many of them are too small to be biopsied reliably; the vast majority represents benign changes, and the number of biopsies would overwhelm the availability of biopsy staff and qualified thyroid pathologists. The relatively poor correlation between palpatory findings and ultrasound detection of small lesions raises yet another problem. The true prevalence of all thyroid nodules in normal unexposed populations may actually approach 40–50%, as shown by autopsy studies in the United States.

It is not reasonable to adopt a single screening or diagnosis algorithm for all groups of persons. Massive screening programmes of persons in areas whose projected thyroid doses are less than 0.05 Gy are not feasible or reasonable. At the high end of the probability spectrum for radiation effects in the thyroid are those who were exposed as children, are female, had high estimated thyroid doses in excess of several Gy, who have a lesion that is palpable clinically and appears solid on ultrasound examination. These should clearly be biopsied. The biopsy should preferably be done by fine needle aspiration technique. Such biopsy techniques in experienced hands can determine the benign or malignant nature of a lesion in 80% of cases. At the other end of the spectrum are elderly females, who received a calculated thyroid dose of less than 0.2 Gy, and who have a lesion which appears cystic on ultrasound examination. Such a lesion might simply be followed. Different algorithms need to be developed for various population groups on the basis of the probability of a lesion being malignant or benign. An aggressive protocol calling for surgical exploration of all detected nodules will almost certainly do more harm than good. Thyroid cancer is discussed in more detail in Section 3.11.

3.3.3. Microsomal Antibodies and Autoimmune Thyroiditis

3.3.3.1. Rationale

The issue of antithyroid antibodies (antithyroglobulin and antimicrosomal antibody) has been studied in euthyroid and hypothyroid patients after medical therapy with radioactive iodine. There have been no significant differences in the antibody titres reported.

Autoimmune thyroid disease has been reported in some patients who have had prior radiation to the head and neck. However, the clinical importance of this thyroiditis is uncertain. Increases in autoimmune thyroiditis in patients exposed to multiple fluoroscopic examination during tuberculosis therapy have also been reported. The data regarding the survivors at Hiroshima and Nagasaki suggest but are not conclusive in regard to low dose radiation causing chronic thyroiditis and subsequent hypothyroidism [36].

3.3.3.2. Review of Official Data

UkrSSR

Scientists at AUSCRM in Kiev have questioned whether there is an autoimmune basis of the thyroid disease that they have seen since there are decreased lymphocytes in the blood of some of these patients and since there may be some abnormality in the ratio of

T-helper to suppressor lymphocytes. They also indicated that antithyroid globulins are currently observed and that there are antibodies to the microsomal fraction. The Endocrinology Institute in Kiev had not looked at this issue.

Data on the children in the Narodichi district concerning thyroglobulin antibody level versus absorbed dose were presented.[20] The frequency of increased antibody level was 27–42% with no clear relation to dose. The prevalence of elevated levels in the control group was 27%, whereas it was 29% in the 0.5 Gy group. The highest level was found in the 0–0.3 Gy group (42% with increased antibodies). Similar findings were found when elevated antibodies to the microsomal fraction were examined (11–30% at a 1:8 dilution).

RSFSR

It was reported by a researcher[21] that there was no evidence of chronic thyroiditis in his studies.

BSSR

The researchers from Kiev and Minsk differ concerning the antimicrosomal bodies issues. One of them[22] has studied microsomal antibodies with a Soviet agglutination kit. There is some uncertainty about the accuracy of this kit but it showed 50% of children in contaminated areas as being positive while only 2% of the control group was positive.

3.3.3.3. Summary of Autoimmune Thyroid Issues

Interestingly enough there are some areas in the world in which the quantity of iodine in the diet is sufficient and yet endemic goitre persists. While this may be due to genetic factors or natural goitrogens, chronic thyroiditis also has been implicated as a possible cause of endemic goitre in some areas. On the evidence of animal experiments, some authors have suggested that the classic histologic picture of Hashimoto's thyroiditis could be the basic pathological abnormality in 20 to 30% of the goitre cases in the USA [38].

It remains uncertain whether excess iodine plays a role in the development of chronic thyroiditis or merely aggravates goitre in patients who have an underlying thyroiditis.

The issue of autoimmune thyroiditis was considered in the design of the team's field studies. Unfortunately, the kits that the team was considering using were required to be kept frozen until use. Logistical considerations precluded the use of such kits in the field. In addition, there is known to be a high positivity rate (as much as 10%) for most kits among populations that are considered clinically normal.

The official data that were reviewed indicated that there was no relation to calculated thyroid dose from radioiodine. The thyroid function studies do reveal that, if such thyroiditis is present, it is not clinically significant in more than a few per cent of the population. Project thyroid endocrinologists on the field trips did see a few patients who appeared to have chronic thyroiditis based upon clinical examination.

3.4. Cardiovascular Issues

3.4.1. Rationale

Definitions of hypertension are numerous. However, there are two groups who have come up with operational definitions. In 1978, the World Health Organization recommended the following criteria:

Normotensive:	Systolic ≤140 and diastolic ≤90 mmHg.
Borderline:	Systolic 141–159 and diastolic 91–94 mmHg.
Hypertension:	Systolic >160 and/or diastolic >95 mmHg.

The Fourth Joint National Committee (JNC-4) criteria indicate that initial elevated readings should be confirmed on at least two subsequent visits with average diastolic blood pressures of 90 mmHg or greater or systolic blood pressures of 140 mmHg or greater required for the diagnosis of hypertension [61–62].

Significant hypertension in children and adolescents has been classified as being above the following values:

Age (years)	Systolic	Diastolic
>2	112	74
3–5	116	76
6–9	122	78
10–12	126	82
13–15	136	86
16–18	142	92

High blood pressure is a major risk factor for premature death and disability. The main burden of illness is associated not with severe disease but from the large number of people with minimally elevated pressures. Various estimates have been made relative to the consequences of hypertension; however, a persistently higher diastolic blood pressure of 5 mmHg is associated with approximately a 30% increase in stroke risk and a 20% increase in risk of coronary heart disease [63, 64].

[20] Dr. A.K. Cheban (AUSCRM).

[21] Dr. Knyazev (Moscow).

[22] Dr. L.M. Astakhova (Minsk).

TABLE 38. Diastolic Blood Pressure (mmHg) Published for the Populations of Moscow and Leningrad

City	Sex	Age group (years)	Mean	SD	Percentile						
					5	10	25	50	75	90	95
Moscow	Males	20–29	75.6	0.8	56	62	68	75	83	91	94
		30–39	81.9	0.8	63	67	74	82	89	96	102
		40–49	88.2	0.9	67	71	79	87	97	105	113
		50–59	90.1	0.9	70	74	81	89	98	106	110
		60–69	84.6	1.0	63	69	74	83	93	101	111
	Females	20–29	69.1	0.8	54	56	61	67	77	82	85
		30–39	75.7	0.7	59	62	69	74	81	90	96
		40–49	82.3	0.8	63	67	72	82	90	99	105
		50–59	86.2	0.9	67	69	76	84	95	106	110
		60–69	85.4	0.8	66	69	76	84	94	103	109
Leningrad	Males	20–29	76.5	0.8	56	62	68	75	83	91	94
		30–39	81.9	0.8	63	67	74	82	89	96	102
		40–49	88.2	0.9	67	71	79	87	97	105	113
		50–59	90.1	0.9	70	74	81	89	98	106	110
		60–69	84.6	1.0	63	69	74	83	93	101	111
	Females	20–29	72.9	0.6	56	60	67	73	79	86	91
		30–39	77.7	0.5	62	64	71	77	84	91	98
		40–49	83.9	0.5	67	70	75	82	91	100	106
		50–59	89.2	0.6	70	73	80	88	98	107	113
		60–69	88.1	0.7	68	71	79	88	96	105	111

Blood pressure, particularly systolic blood pressure, increases progressively with age. This, typically, is an isolated systolic elevation which may be defined as a diastolic pressure below 90 and a systolic pressure above 160 mmHg and it is present in about one-fourth of people over the age of 65. Isolated systolic hypertension is a problem and those with this entity have a three or four times higher risk of stroke than those without it. Isolated systolic hypertension is usually a reflection of rigid and atherosclerotic arteries [65].

Data on diastolic and systolic blood pressure in males and females in Moscow and Leningrad are given in Tables 38 and 39.

In the USA, the percentage of persons with borderline or definitely elevated blood pressure is as given in Table 40.

These data are based upon a single measurement made during a physical examination. Borderline or definite hypertension (column 1) was classified as systolic pressure of at least 140 mmHg or diastolic of at least 90 mmHg or both. Definite elevated hypertension (column 2) was defined as systolic of at least 160 mmHg or diastolic pressure of at least 95 mmHg or both.

There is some discussion as to whether systolic or diastolic blood pressures are more important indicators of risk. A number of studies suggest that systolic elevations are more a determinant of cardiovascular risk than are diastolic over the entire adult age range and high pressure generated during systole puts a direct and immediate burden on the heart.

Headache is the most common symptom of those with hypertension. Only about 20% of unrecognized hypertensives complain of headache. However, of those who know they are hypertensive, approximately 70% complain of headaches. Clearly, there is a significant psychological or perceptual component in the latter cases.

Hypertension accelerates the development of atherosclerosis within all vessels including the coronary arteries. Hypertension is felt by many to be the largest risk factor for coronary artery disease and in several long term studies the incidence of myocardial infarction among those who are hypertensive was more than twice that of normotensive persons.

The methodology for taking and recording blood pressure can critically affect the results obtained. The width of the cuff of the sphygmomanometer should be equal to 2/3 of the distance between the axilla and the antecubital space and the bladder width of the cuff should be enough to encircle 80% of the arm. A cuff that is too short or too narrow will give erroneously high readings. The patient should be relaxed and the arm must be supported. No tight clothing should constrict the arm. The cuff should be level with the heart and the stethoscope diaphragm placed over the brachial artery. The cuff should be inflated to occlude the pulse and should be deflated at 2–3 mmHg per second. Several readings should be taken since both high and low readings tend toward the mean on subsequent examinations.

The causes of primary hypertension include a number of factors [61]. Heredity appears to play a role and the level of blood pressure is strongly familial. The reasons for this remain uncertain. Only some of the many mechanisms of hypertension will be mentioned here. Excess dietary sodium does appear to be involved in the

TABLE 39. Systolic Blood Pressure (mmHg) Published for the Populations of Moscow and Leningrad

City	Sex	Age group (years)	Mean	SD	Percentile						
					5	10	25	50	75	90	95
Moscow	Males	20–29	122.5	0.9	103	106	113	121	132	141	146
		30–39	123.8	1.0	103	107	114	123	132	142	152
		40–49	135.0	1.5	105	109	120	130	146	163	176
		50–59	144.5	1.6	108	115	128	142	160	177	187
		60–69	152.0	1.7	109	118	134	151	167	186	201
	Females	20–29	112.6	0.9	93	96	105	112	120	128	133
		30–39	118.1	0.9	99	102	108	116	125	137	143
		40–49	129.7	1.3	102	106	115	126	138	159	176
		50–59	145.6	1.8	112	114	123	140	163	183	193
		60–69	167.3	1.8	125	133	146	163	187	202	218
Leningrad	Males	20–29	120.8	0.8	100	104	112	120	128	137	142
		30–39	124.8	0.8	104	108	115	123	132	144	151
		40–49	134.7	0.4	107	112	120	132	145	162	172
		50–59	146.1	0.6	114	119	129	142	160	178	192
		60–69	154.0	1.5	118	123	135	148	171	191	201
	Females	20–29	112.8	0.8	93	97	104	112	121	128	134
		30–39	118.9	0.8	98	102	108	117	127	140	147
		40–49	131.6	0.9	103	107	116	127	141	163	175
		50–59	153.5	1.2	115	121	132	148	170	195	208
		60–69	166.5	1.5	119	127	143	164	187	209	223

TABLE 40. Percentage of Persons with Borderline or Definitely Elevated Blood Pressure in the United States of America

Age group	Males		Females	
	Hypertension	Definite hypertension	Hypertension	Definite hypertension
25–34	31.5	12.2	10.4	3.2
35–44	37.6	15.2	24.6	9.9
45–54	52.0	28.6	40.1	20.1
55–64	57.6	29.7	53.1	24.4
65–74	60.6	32.7	63.0	35.0

pathogenesis of primary hypertension. Even though many populations have diets that contain much more than the daily adult sodium requirement, only part of the population may be susceptible to deleterious effects, perhaps because of inherited renal defects in sodium excretion. In most western countries, there are high sodium diets yet only 20% or so of people will develop hypertension.

Hypertension is about three times more common in obese people than in non-obese persons. The elevated insulin levels seen with obesity may play a significant role in the hypertension. In the Framingham cardiovascular study [66], adiposity (as measured by subscapular skin fold thickness) was a major controllable contributor to hypertension with estimates of 78% of hypertension in men and 64% in women attributable to obesity. Mechanisms by which obesity leads to hypertension are likely to involve an increase in blood volume, stroke volume, and cardiac output. Children seem particularly vulnerable to the hypertensive effects of weight gain and the best predictor of high blood pressure in young adults is childhood obesity.

There are only a few relatively well controlled studies that have examined the effect of weight loss on hypertension. There remains a fair amount of debate as to whether weight loss alone can lower blood pressure [67]. Some authors feel that sodium restriction is also necessary. Dietary restriction of sodium down to about the level of 70–100mM per day can lower the blood pressure.

Stress and sympathetic nervous activity can be related to hypertension via a number of possible pathways. Sympathetic nervous hyperactivity may be one of the primary factors leading to vascular hypertrophy, which can be a cause of hypertension by itself. The role of epinephrine is not only in transient raising of blood pressure under the well known 'fight or flight' response to stress. Repeated stress can lead to hypertension and whether this is the result of hormonal or psychological issues is not clear. It is known that air traffic controllers and factory workers who work under high levels of stress develop hypertension at greater rates than would be expected. People may become hypertensive not just because they are stressed but because they are the type of person who responds differently to stress. Higher levels of emotional reactivity and repression may be responsible for greater activation of the sympathetic nervous system and the development of hypertension.

It is interesting to examine the effects of high carbohydrate diet particularly in relation to the population around Chernobyl. High carbohydrate intake for a brief period can cause sodium retention but usually no increase in blood pressure [68]. On the other hand, plasma insulin levels which are already high in most hypertensives can be made higher by such diets. Smoking and caffeine can both acutely raise blood pressure. Tolerance to these effects develops so that neither coffee consumption nor cigarette smoking are associated with a higher frequency of hypertension [69].

Cardiovascular diseases of all types were reported to the team as being increased since the Chernobyl accident. This included entities such as hypertension, myocardial infarction, stroke and cardiac failure.

The cardiovascular system is known to be relatively resistant to direct effects of radiation. Direct effects usually require fractionated absorbed doses in excess of 30 Gy [70–73]. What was not clear was the possible interaction between the psychological effects or stress from the accident or the relation of other factors such as diet, smoking and alcohol. On its first mission the team was told in several places that there was concern about an increase in cardiovascular diseases. For example, physicians in Ovruch (UkrSSR) reported an increase of 27% in the incidence of hypertension. In Korma (BSSR), a 100% increase in cardiovascular diseases was reported. Very little hard data were presented in these

TABLE 41. Death Rates in the USSR from Cardiovascular Causes

Region	Per number of persons	1985	1986	1987	1988
Kiev	100 000	855	749	807	805
Zhitomir		759	674	673	744
Entire UkrSSR		**670**			
Bryansk		831	715	736	767
Entire RSFSR		**611**			
Gomel		641	583	613	614
Entire BSSR		**597**			

initial settlement meetings. As a result of all the above factors, an examination of these issues was felt to be important.

3.4.2. Review of Official Data

The only data received on prevalence of cardiovascular diseases in the contaminated settlements were from the Cardiology Department, AUSCRM.[23]

Myocardial infarct (MI) rates as determined from electrocardiographs and submitted hospital statistics are between 4 and 7.2 per 10 000 annually. The rates of hypertension and ischemic disease as well as MI were examined; from 1984–1989, the highest levels were found in 1985 before the Chernobyl accident.

Decontamination workers who came to the Institute for other reasons were also examined and divided into dose groups. Parameters examined included ultrasonically determined left ventricular wall thickness, and stress ejection fractions. There was no relation to absorbed dose, and in fact the decontamination workers had better performance than control groups. Unfortunately, there was no consideration of age, smoking, etc., and the decontamination workers were younger than the control group. Data were supplied on the epidemiology of cardiovascular diseases in the cities of Moscow and Leningrad. These data are important for comparison with the data collected during Project field trips.

The team was given Ministry of Health data relative to the death rates from cardiovascular disease as shown in Table 41.

[23] Professor Hamazuk.

3.4.3. Results of Field Trips

Blood pressures were not taken on 2 year old subjects since such measurements were felt by paediatricians of the team to be unreliable. On all others, the blood pressure was obtained after the person had been sitting for at least five minutes and prior to blood drawing or other portions of the examination process. All high values were verified by a second blood pressure determination by a different examiner at least 20 minutes later and prior to the person leaving the clinic. Figures 37–40 present Project data on diastolic and systolic blood pressure.

The mean diastolic blood pressure of adults was 87 mmHg although 10% of the 40 year olds had diastolic pressures above 100 mmHg and 10% of the 60 year olds had diastolic pressures in excess of 110 mmHg. The mean systolic pressure of adults was 145 mmHg.

Data from the field trip questionnaire indicated that about half of the adults complained about chest pains.

Examination by the team's physicians revealed that about 1% of the children and 5% of the adults had either clearly significant auscultatory abnormalities, cardiac arrhythmias or signs of cardiac decompensation that suggested that the person should be under medical supervision or treatment. Of course, there must have been other persons with disease that would have been detected if other tests (for example, electrocardiograph or chest X ray) had been performed.

3.4.4. Summary of Cardiovascular Issues

There appears to be a large proportion of adults in both control and contaminated settlements who have borderline or definite hypertension. Most of the

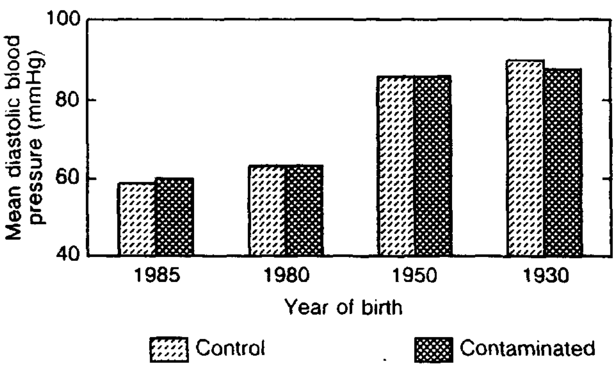


FIG. 37. Mean diastolic blood pressure by age in control and contaminated settlements.

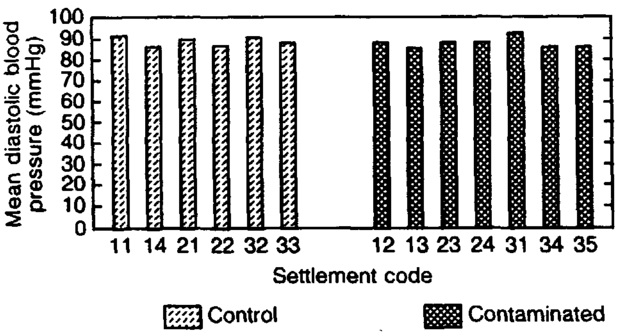


FIG. 38. Mean diastolic blood pressure of 40 and 60 year old adults, by settlement. Adjusted for sex 50:50; SD: ±3 mmHg.

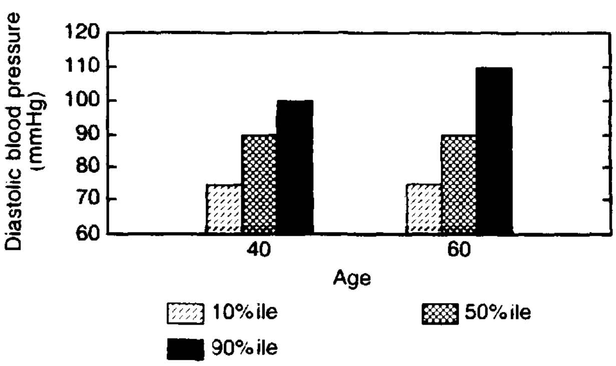


FIG. 39. Diastolic blood pressure of adults.

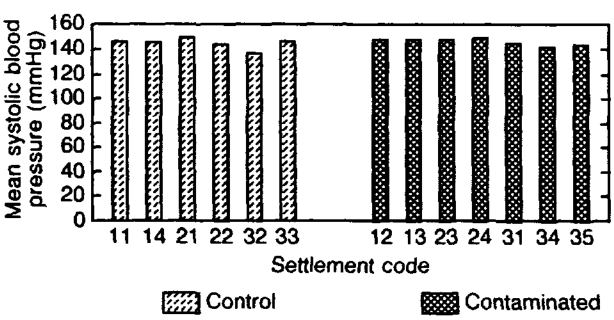


FIG. 40. Mean systolic blood pressure of 40 and 60 year old adults, by settlement. Adjusted for sex 50:50; SD: ±5 mmHg.

individuals we found who had hypertension had already been notified of the fact by local physicians and had already had the level of hypertension documented in their clinical records. In this regard we were able to corroborate existing data and to ascertain that the measurements were of good quality.

The cause of the hypertension was not identified by our study. In fact, the causes are probably different in different persons. In the nutrition section the team documents that the amount of sodium consumed in the typical diet is large. The team has also ascertained in that section that a large proportion of the population is overweight by WHO criteria. Since these are major causes of hypertension in the rest of the world, it can be speculated that they represent part of the problem in the areas studied by the team.

The interaction of psychological stress and hypertension cannot be ascertained. As we will see in the section on psychological issues, persons in control settlements are also under a significant amount of stress. Thus the fact that there is no difference in blood pressure between control and contaminated settlements does not exclude a psychological component. Official data by Republic do not show an increase in death rate from cardiovascular diseases during the period 1985–1988. What the death rates are in clean versus contaminated settlements area is not known to the medical team.

3.5. General Health

3.5.1. Rationale

Large epidemiological studies investigating radiation health effects in the past have not shown evidence of an increase in all types of general diseases that could be directly attributed to radiation exposure. These issues have been extensively covered in UNSCEAR [74].

Although shortening of life span is a real consequence of irradiation, a very large body of evidence in experimental animals indicates that this effect is essentially due (at low to intermediate doses and dose rates) to the induction of specific neoplastic diseases. The epidemiological data collected on the survivors of Hiroshima and Nagasaki point to the same conclusion.

Even though no direct effects of radiation from the Chernobyl accident may have caused either an increase in general diseases or a shortened life span as of yet, there may well have been non-radiation problems related to the accident (such as poor nutrition, stress, etc.) which may have contributed to an increase in general diseases. Determination and documentation of such a possible increase in general diseases is plagued by many of the same issues related to epidemiology of neoplasms. These confounding factors include increased numbers of visits to clinics due to concern about radiation effects for problems which previously would have been self-treated. There also may be increased detection by physicians due to more careful examination and workup since the accident. One cannot dismiss the premise that there may be an increased incidence of ulcers, etc. due to stresses incurred as a result of and since the accident.

The team is aware that thousands of children from the USSR were sent to other countries (Cuba, France, Germany and Israel) for treatment of 'radiation effects'. Most of these children are selected because they are felt to be sick and not all come from contaminated areas. Data from such children are unlikely to be objective because of the selection process. To date, however, none of the investigators in these countries have reported finding definite radiation related health abnormalities.

With this in mind, an age matched controlled study of persons living in contaminated and relatively clean areas would be useful. In addition, the team thought it would be useful to review and analyse the existing official data.

3.5.2. Review of Official Data

3.5.2.1. Obninsk

The All-Union Distributed Register (AUDR) located at Obninsk has limited data that have been collected relative to all classes of diseases. For children and adolescents there are data for the years 1987 and 1988 for the regions of Bryansk, Kiev, Zhitomir, Gomel and Mogilev. There is a slight increase in diseases but it is not clear what types of disease this represents. Unfortunately, there are no baseline data before the accident nor is there a suitable comparison control group. The possible confounding factors, such as increased reporting as the Register was being developed, have not been elucidated. The data presented indicate that about 50 000–60 000 cases of disease were present in the 125 000 or so children and adolescents in the Register. Criteria which control entry of children into this register were not presented.

3.5.2.2. UkrSSR

Physicians at the clinic in Polesskoe indicate that there has been an increase of diseases of all types although the data were derived by looking at the total number of clinic and emergency room visits. In Ovruch, physicians reported an increase of 37% in adult diabetes when comparison was made between 1985 and 1988 and an increase of hypothyroidism of 91%. The actual data were not received.

Data on the total number of diseases in different regions of the UkrSSR were presented.[24] These data are available for the years 1985–1988 for 16 different areas. The rates generally are between 10 and 500 diseases reported per 10 000 children (probably reflecting major reporting differences in the different years even in the same region). Overall, the data show no statistically significant variation with time and they are at major variance with data in the AUDR in Obninsk.

3.5.2.3. BSSR

An increase of 23% in ulcer as well as ENT abnormalities were reported. The assistant chief physician in this region reported only a 2% increase in occasional illness.

3.5.2.4. USSR

Measures of general health can be assessed to some extent by examination of infectious disease rates, number of hospitalized persons, mean term of hospital stay, and death rates. These data were received from the USSR Ministry of Health for five contaminated regions and are summarized in Table 42.

Many Soviet investigators presented the team with a large number of poorly substantiated, inconsistent, extremely variable findings relative to general health. In most cases no baseline data were available and analyses for biases had not been performed.

Indicators from the USSR Ministry of Health suggest that there has been no general trend over time or in the contaminated regions (relative to the rest of the Republic) that could suggest a constantly increasing trend of general ill health as a result of the accident. Lack of a general increase in infectious diseases of different sorts would argue that there has been no clinically significant change in immune status as a result of the accident.

3.5.3. Results of Field Trips

Data on general health were gathered on Health team field trips to both control and contaminated settlements. These data related to past medical history and also to physical examinations.

3.5.3.1. Symptoms and Complaints

For evaluation of past medical history, adults were asked to record those complaints or symptoms which had occurred during the previous two months. Only data on adults were initially analysed since, in some instances, parents indicated their symptoms and com-

[24] Dr. E.I. Stepanova (Kiev).

TABLE 42. General Health Data for BSSR, RSFSR and UkrSSR Provided by the USSR Ministry of Health

Region	Indicator	Per number of persons	1985	1986	1987	1988
Gomel	Dysentery	100 000	236	110	102	219
Mogilev			132	78	105	163
Entire BSSR						**140**
Bryansk			431	206	236	223
Entire RSFSR						**313**
Kiev			72	94	85	78
Zhitomir			89	101	80	89
Entire UkrSSR						**97**
Gomel	Viral hepatitis	100 000	237	214	178	220
Mogilev			276	223	179	207
Entire BSSR						**232**
Bryansk			198	203	110	119
Entire RSFSR						**145**
Kiev			199	156	133	135
Zhitomir			198	166	176	243
Entire UkrSSR						**173**
Gomel	Measles	100 000	63	15	17	14
Mogilev			57	7	36	3
Entire BSSR						**8**
Bryansk			13	10	139	17
Entire RSFSR						**85**
Kiev			74	66	134	16
Zhitomir			76	171	88	20
Entire UkrSSR						**20**
Gomel	New cases of tuberculosis	100 000	51	40	39	44
Mogilev			61	46	42	39
Entire BSSR						**34**
Bryansk			41	40	39	38
Entire RSFSR						**41**
Kiev			43	41	40	34
Zhitomir			68	69	59	46
Entire UkrSSR						**36**
Gomel	Total tuberculosis	100 000	213	196	189	189
Mogilev			264	239	220	205
Entire BSSR						**169**
Bryansk			220	228	219	209
Entire RSFSR						**213**
Kiev			216	218	217	210
Zhitomir			289	304	300	273
Entire UkrSSR						**205**
Gomel	Number hospitalized	1000	28	28	28	28
Mogilev			31	31	31	30
Entire BSSR						**27**
Bryansk			25	25	25	26
Entire RSFSR						**26**
Kiev			24	24	24	24
Zhitomir			26	27	26	27
Entire UkrSSR						**28**

TABLE 42. (cont.)

Region	Indicator	Per number of persons	1985	1986	1987	1988
Gomel	Death rate from cardiovascular causes	100 000	641	583	613	614
Mogilev						
Entire BSSR						**597**
Bryansk			831	715	736	767
Entire RSFSR						**611**
Kiev			855	749	807	805
Zhitomir			759	674	673	744
Entire UkrSSR						**670**
Gomel	Death rate from accidents, trauma and poisoning	100 000	86	69	70	77
Mogilev						
Entire BSSR						**83**
Bryansk			130	93	92	100
Entire RSFSR						**111**
Kiev			101	89	86	89
Zhitomir			96	70	76	78
Entire UkrSSR						**101**
Gomel	Overall death rate	1000	10.3	9.4	9.8	10.1
Mogilev			11.3	10.0	10.4	10.4
Entire BSSR						**10.1**
Bryansk			13.2	11.3	11.8	12.4
Entire RSFSR						**10.7**
Kiev			13.3	11.9	12.5	12.4
Zhitomir			12.9	11.8	12.3	12.5
Entire UkrSSR						**11.7**

TABLE 43. Complaints Reported by 501 Examined Adults, 265 in Contaminated and 236 in Control Settlements

Complaint	Contaminated settlements				Control settlements				Total	
	Yes		No		Yes		No		Yes	No
	No.	%	No.	%	No.	%	No.	%	No.	No.
Fatigue[a]	237	89.4	28	10.6	190	81.5	46	19.5	427	74
Headache	216	81.5	49	18.5	182	77.1	54	22.9	398	103
Nosebleeds	42	15.9	223	84.1	25	10.6	211	89.4	67	434
Sore throat	105	40	160	60	89	38	147	62	194	307
Hair loss	69	26	196	74	58	25	178	75	127	374
Loss of appetite	140	53	123	47	102	43	134	57	242	257
Weight gain	51	19	214	81	32	14	204	86	83	418
Weight loss	40	15	225	85	35	15	201	85	75	426
Chest pains	141	53	124	47	102	43	134	57	243	258
Diarrhoea or constipation	71	27	193	73	60	25	176	75	131	369
Mental depression	111	42	153	59	101	43	135	57	212	288

[a] The probability factor p is, in the order of listing: 0.005, 0.225, 0.025, 0.084, 0.661, 0.707, 0.088, 0.934, 0.026, 0.709 and 0.865.

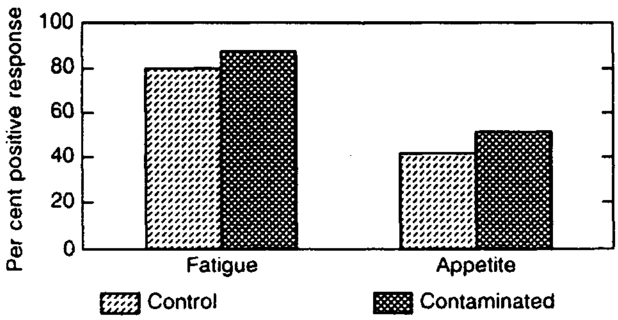


FIG. 41. Complaints of adults of fatigue and loss of appetite in control and contaminated settlements. Past two months, $p < 0.05$. (Note: the difference between control and contaminated settlements is not statistically significant unless $p < 0.05$.)

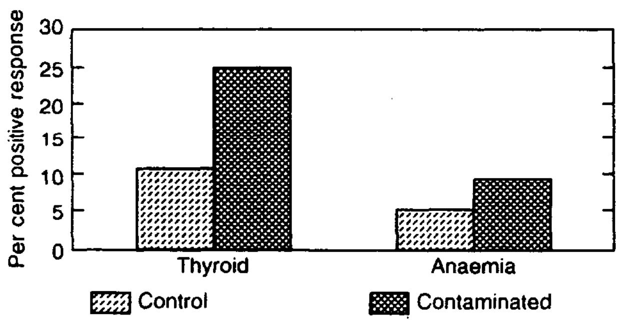


FIG. 42. Complaints of adults of thyroid abnormalities ($p = 0.000$) and anaemia ($p = 0.038$) in control and contaminated settlements.

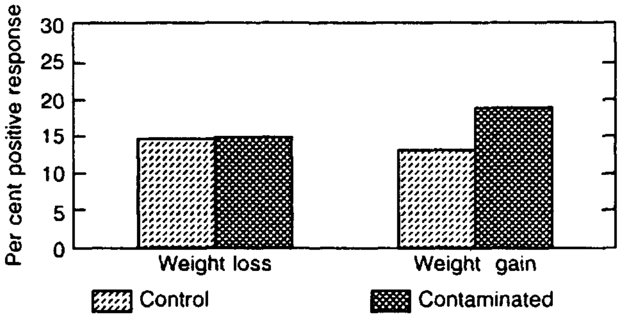


FIG. 43. Complaints of adults of weight loss ($p = 0.934$) and weight gain ($p = 0.088$) in control and contaminated settlements. Past two months.

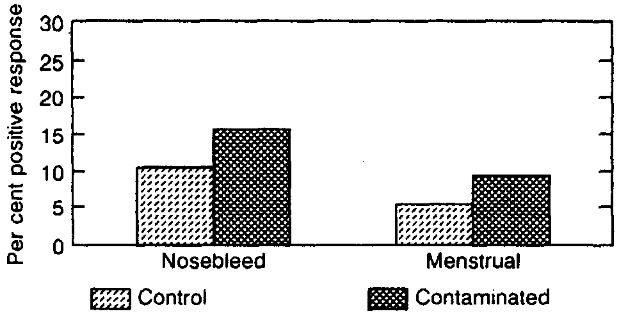


FIG. 44. Complaints of adults of nosebleeds and menstrual irregularity ($p = 0.08$–0.09) in control and contaminated settlements. Past two months.

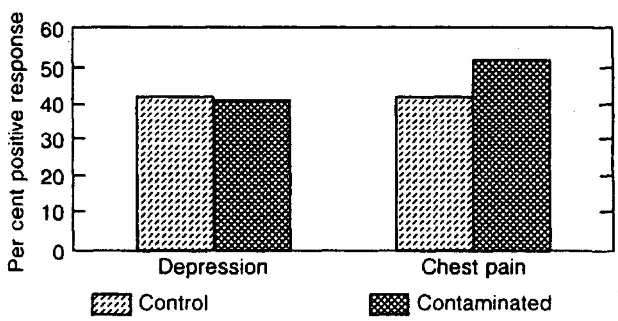


FIG. 45. Complaints of adults of mental depression ($p = 0.865$) and chest pain ($p = 0.026$) in control and contaminated settlements. Past two months.

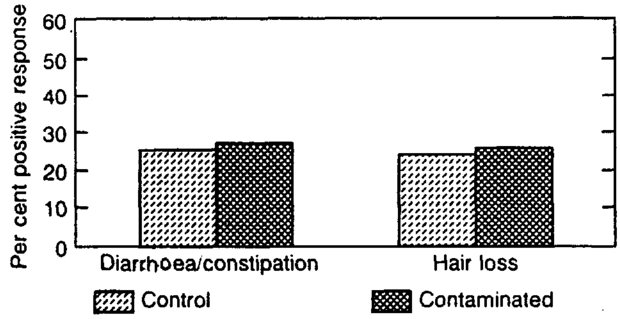


FIG. 46. Complaints of adults of diarrhoea/constipation ($p = 0.709$) and hair loss ($p = 0.707$) in control and contaminated settlements. Past two months.

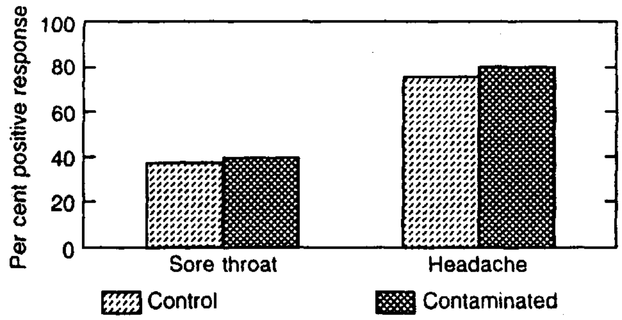


FIG. 47. Complaints of adults of sore throat (p = 0.661) and headache (p = 0.225) in control and contaminated settlements. Past two months.

plaints on a child's questionnaire. Data on complaints of anaemia and goitre were presented in the earlier sections on those topics. The complaints of the adults with regard to their health are shown in Table 43 and 58 and Figs 41–47.

3.5.3.2. Physical Examination

The physical examinations performed by the team physicians were restricted to the determination and recording of those conditions which were serious enough to require that the person was currently under the care of a local physician, or that the examiner thought should be currently under care. Thus the statistics represent what might be termed 'significant' health abnormalities.

The true incidence of abnormalities is undoubtedly greater than that expressed in the team's findings. There are two reasons for this. First, the physical examination of the team was a general one and did not include an audiometric, breast, rectal or vaginal pelvic examination. Secondly, abnormalities that could only be detected with other techniques (such as diagnostic medical radiography, etc.) would not have been detected by the team.

In the team's examination, vision abnormalities requiring corrective lenses were not recorded as abnormal. Hypertension is recorded as a separate item in the cardiovascular portion of this report.

The percentage of persons of different ages who have an abnormality based upon the team's physical examination only is shown in Fig. 50.

The percentage of children with abnormalities is shown in Table 44 and Figs 48–52.

The percentage of adults with abnormalities are shown in Table 45 and Figs 53–57.

3.5.4. Summary of General Health Issues

There are many confounding factors which plagued the collection of data with regard to general health after the Chernobyl accident. It would have been quite natural for people to seek medical advice after the accident since they were worried that radiation could be responsible for many illnesses. In addition, the physicians would be more cautious than previously in terms of evaluation of the patients. This would all lead to more effective detection and reporting of diseases. The missions have been told (and have personal experience) that many of the contaminated settlements have difficulty recruiting and retaining physicians. The transient nature of the physicians' employment would lead to differences in both reporting and methodology from year to year.

In spite of these problems, existing official data are reasonably consistent and do not support an increase of diseases of all sorts, at least through the end of 1988. The accuracy of the official data or their completeness in terms of reporting could not be evaluated.

The Project health effects field trips compared age matched persons living in contaminated and relatively clean areas since the time of the accident. On the basis of physical examination alone and excluding hypertension, the team found that approximately 3–5% of children and 10–20% of adults had a disorder that required treatment or close medical supervision. These numbers support the contention of the population that there are a large number of health problems present. In fact, the figures are undoubtedly higher since some rather basic diagnostic tests such as electrocardiographs or screening serum chemistries were not done. A statistical difference between control and contaminated settlements was not found except for abdominal problems which were more frequent in adults of contaminated settlements. Even though it was not possible to quantify the problem, one point consistently noted by the physicians was that the level of dental hygiene in all settlements was extremely poor.

3.6. Psychological Consequences of the Accident

3.6.1. Rationale

As a category of health effects, the psychological consequences may well be the most significant at the present time. The Chernobyl accident has spread contamination over a very wide area of the USSR and other countries, and has affected the lives of millions of people. Reactions have varied according to people's understanding of, and attitudes towards, nuclear energy, but dismay has been universal and anxiety widespread. In Chernobyl these reactions have combined with direct perceptions of the enhanced levels of contamination and its likely effects to produce pessimistic, depressed and fearful attitudes towards the future. Many people believe

TABLE 44. Abnormalities Observed in 860 Examined Children, 473 in Contaminated and 387 in Control Settlements

Abnormality	Contaminated settlements				Control settlements				Total	
	Abnormal		Normal		Abnormal		Normal		Abnormal	Normal
	No.	%	No.	%	No.	%	No.	%	No.	No.
Skin	9	2	462	98	6	2	381	98	15	843
Peripheral pulse			473	100			387	100		860
Eyes	1	<1	472	>99	1	<1	386	>99	2	858
Ears	2	<1	471	<99	1	<1	386	>99	3	857
Nasopharynx	11	2	462	98	3	1	384	99	14	846
Neurological	2	<1	471	>99	3	1	384	99	5	855
Cardiac	5	1	468	99	3	1	384	99	8	852
Pulmonary	4	1	469	99	0	0	387	100	4	856
Abdomen	1	<1	472	>99	1	<1	386	>99	2	858
Kidneys	3	1	470	99	2	1	385	99	5	855

TABLE 45. Abnormalities Observed in 501 Examined Adults, 265 in Contaminated and 236 in Control Settlements

Abnormality	Contaminated settlements				Control settlements				Total	
	Abnormal		Normal		Abnormal		Normal		Abnormal	Normal
	No.	%	No.	%	No.	%	No.	%	No.	No.
Skin	10	4	255	98	4	2	232	98	14	487
Peripheral pulse	1	<1	264	>99	0	0	236	100	1	500
Eyes[a]	4	2	261	98	1	1	235	99	5	496
Ears[b]	1	<1	264	>99	0	0	236	100	1	500
Neurological	3	1	262	99	3	1	233	99	6	495
Nasopharynx	4	2	261	98	0	0	236	100	4	497
Cardiac	16	6	249	94	12	5	234	95	28	473
Pulmonary	5	2	260	98	8	3	228	97	13	488
Abdomen[c]	16	6	249	94	4	2	232	98	20	481
Genitourinary	5	2	260	98	2	1	234	99	7	494
Joints	1	<1	264	>99	1	<1	235	>99	2	499

[a] Examination did not include visual acuity. Severe cataracts and blindness were recorded as an abnormality.
[b] Examination did not include auditory frequency discrimination.
[c] $p = 0.013$.

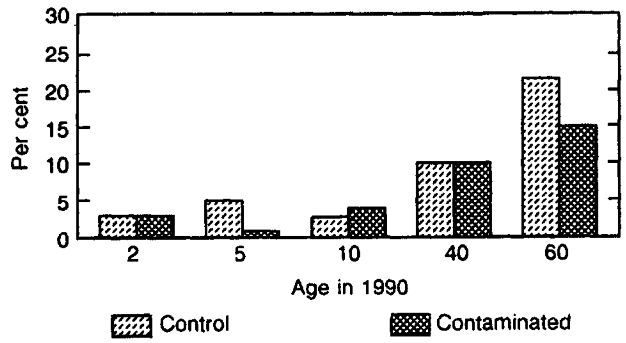


FIG. 48. **Per cent of population at different ages who require medical care on the basis of physical examination in control and contaminated settlements.** Hypertension is excluded.

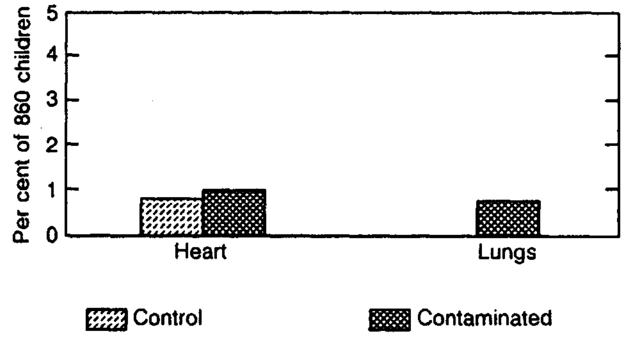


FIG. 51. **Per cent of children requiring medical care for abnormalities of heart and lungs.** p = non-significant.

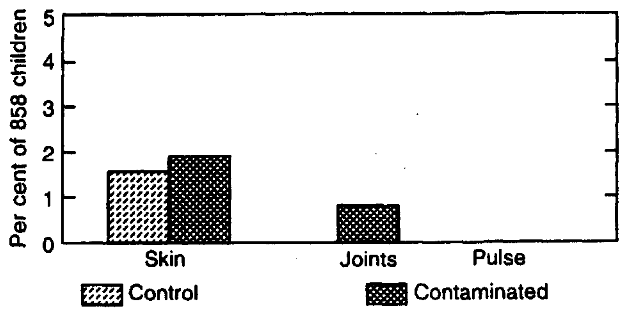


FIG. 49. **Per cent of children requiring medical care for skin and joint abnormalities.** p = non-significant.

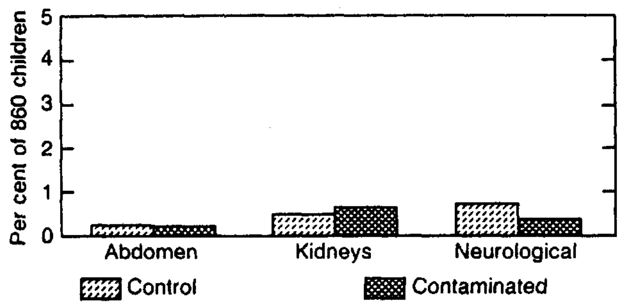


FIG. 52. **Per cent of children requiring medical care for abnormalities of abdomen and kidneys as well as neurological abnormalities.** p = non-significant.

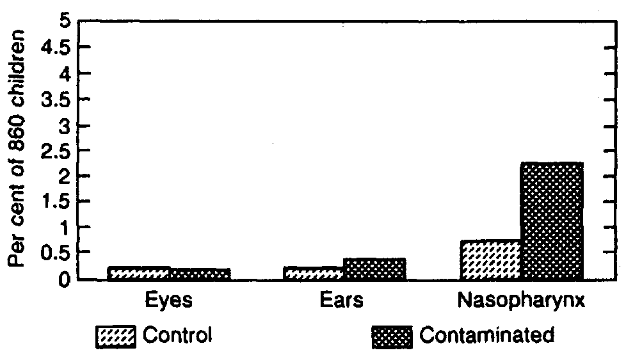


FIG. 50. **Per cent of children requiring medical care for abnormalities of eyes, ears and nasopharynx.** p = non-significant.

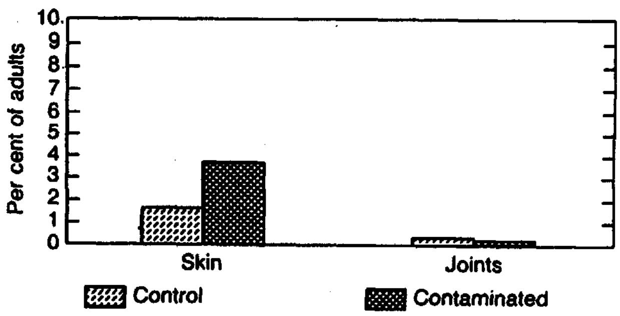


FIG. 53. **Per cent of adults needing, or being under, medical care for disorders of skin and joints in control and contaminated settlements.** p = non-significant.

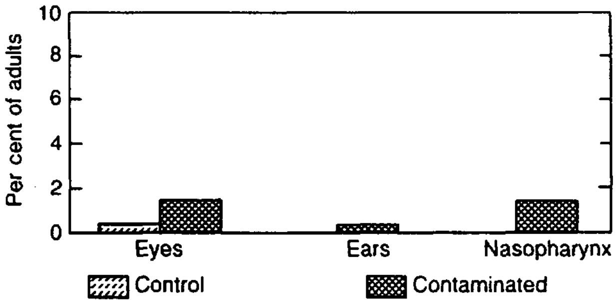


FIG. 54. Per cent of adults needing, or being under, medical care for disorders of eyes, ears and nasopharynx in control and contaminated settlements. p = non-significant.

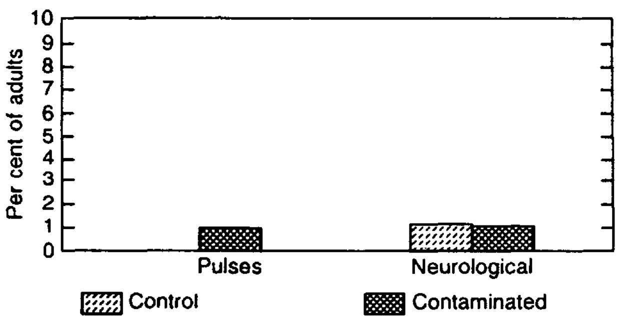


FIG. 55. Per cent of adults needing, or being under, medical care for disorders of the pulses or neurological abnormalities in control and contaminated settlements. p = non-significant.

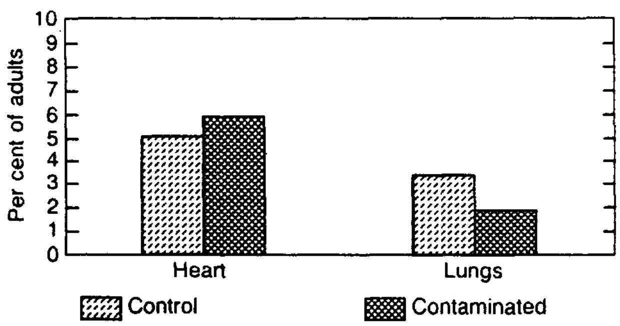


FIG. 56. Per cent of adults needing, or being under, medical care for disorders of heart and lungs in control and contaminated settlements. p = non-significant.

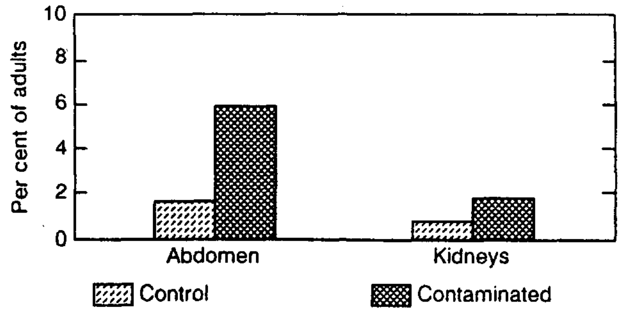


FIG. 57. Per cent of adults needing, or being under, medical care for disorders of the abdomen ($p < 0.05$) or kidneys (p = non-significant), in control and contaminated settlements).

that they are suffering illnesses directly caused by radiation. How can this be explained, in view of the largely negative findings on radiation induced health effects?

Unfortunately, despite extensive and sophisticated scientific measurement, people have been continuously afflicted with uncertainty over the objective radiological facts. This is hardly surprising in view of the physical nature of the accident, which has distributed contamination of different kinds, each with different life cycles and having different health effects, unevenly and within different environments. Further, the radiological 'facts' are complex and have been generated by different sets of 'experts', each perceived (probably unjustly) to be influenced by particular affiliations.

Psychologically, such extremes of uncertainty and ambiguity over an issue affecting the core of personal and family well-being are certain to produce disaffection and stress.

In the political long term, there is a head-on clash between two pervasive value systems, each held in high regard. These are the absolute pre-eminence of human health and well-being, on the one hand, and the respect for financial realism, on the other.

3.6.1.1. Risk Perception: The Wider Perspective

Even when factual knowledge of a hazard is well established, public perceptions have been shown to diverge widely from objective assessments. This variation is, however, by no means random. Studies of risk perception have basically compared large numbers of commonly experienced hazards in terms of their subjective 'severity'. Those that are overestimated and those that are underestimated have been identified. The next step, however, has been to elicit people's perceptions of the many other ways in which hazards differ from each other. This has led to the identification of certain qualities that appear to be consistently associated with perceived severity. Of course, this may be said to beg the main question, i.e. that anticipated adversities can only be experienced by people and these anticipations must therefore be the true reality. Notwithstanding, it is essential to compare perceived risk with known (or mathematically predicted) data because the latter should be included as one of the principal formative influences upon people's perceived judgements.

Man made radiation has been shown consistently to be among the most dreaded of contemporary hazards, although, even given the heavy toll of Chernobyl, this perception cannot be explained by the simple extrapolation of past mortality figures or by future probabilistic risk assessments. In this sense, it is similar to several high technology hazards such as chemical plants, toxic waste incinerators and waste repositories that elicit universally high levels of concern.

Most prominent among the qualities that appear to amplify these concerns is the high catastrophic potential of the risks involved, which appears to more than counterbalance their low probability. Further potent factors are the unfamiliarity and, indeed, the invisibility of the toxic agents involved, together with the close linkage to man's most dreaded common disease — cancer. These attributes are related to people's feelings of impotence — they perceive no possible means of personal control over the hazards. In the case of radioactivity, it has also to be remembered that attitudes have undergone a growth process that began with an initial awareness of the lethal capability of the atomic bomb.

The risks currently perceived in the Chernobyl affected areas have all these features in the fullest possible measure. Unlike the situation for people in other countries, the situation is not that there is simply a minuscule statistical probability of a nuclear event — the one in 10^{-6} event has actually happened and this has totally destroyed their trust in the technology and discredited their leaders.

Another relevant finding from research on risk perception is the 'availability heuristic'. This avers that direct, recent or otherwise vivid experience of a single accident results in an exaggerated assessment of the likelihood of similar accidents in the future. For most people, the experience is mediated through a press or television report and the alleged role of the media in stimulating 'availability' has been widely criticized. There is certainly a correlation between perceived risk and the extent of media coverage. However, this is unlikely to be a direct causal connection and there are clear instances (for example, with radon emissions in the home) where media attention is not reflected in public concern and is consequently diverted elsewhere. Recent research favours the theory of 'amplification' in which only 'high public concern' hazards are initially publicized dramatically; press and TV reports increase public concern, which is then reflected back to create an ascending spiral.

It is clear that some political community leaders in the USSR are motivated to express the concerns of their constituents in similarly exaggerated or dramatic form and that political debate and discussion proceed in a highly charged atmosphere, gaining increased prominence as they go back and forth from leader to follower.

3.6.1.2. Psychological Effects of Disasters: Previous Research

Research into the aftermath of disasters, worldwide, is not a recent development, but the majority of previous studies have been concerned with logistics such as communications, relief services, the consequences of relocation and the effectiveness of warning systems.

It is only in the past 15 years that serious attention has been given to the effects of major accidents on the psychological functioning and mental health of individuals. A 1981 review of 233 available publications on natural disasters [75] revealed that only two titles indicated a primary concern with psychological consequences. Prior to this, in the 1970s, there were conflicting views — with some authors claiming minimal or only transient effects (or even 'morale boosting' effects) and others providing clear evidence of negative health effects following major disasters such as the Buffalo Creek flood [76].

However, the American Psychiatric Association in the third (1980) edition of its influential "Diagnostic and Statistical Manual of Mental Disorders" formally acknowledged the potential health outcome from disasters by adding the classification of 'post-traumatic stress disorder'.

Numerous studies have now been conducted using the stress paradigm, which has almost wholly displaced the earlier search for direct 'mental illness' effects. Stress, though partially expressed through physical symptoms mediated by neuroendocrine secretions, depends crucially upon the way in which the stressor is perceived by the individual and his/her assessment of personal and external resources for controlling it. A recent development has been the provision, as part of the social or voluntary services, of therapeutic counselling for victims and their dependants following major accidents.

The sheer diversity of physical and psychological capacities of people, combined with the different 'meanings' they attribute to the wide variety of disaster events, makes it inevitable that severe or prolonged stress will have multiple consequences. Those listed by researchers include anxiety, tension, depression, psychosomatic illness, suicide ideation or attempts, marital or family discord, divorce, increased consumption of, or dependence on, alcohol, prescribed or non-prescribed drug abuse, increased susceptibility to illness, aggression, violence, domestic violence and general adjustment problems [77]. The concept of 'learned helplessness' should be included here [78]. Prolonged experience of failure to control the environment, and/or to achieve success, leads to a state of chronic apathy.

There is a growing consensus of scientific opinion around an essentially 'cognitive, transactional' model of stress which owes most to Lazarus [79].

According to Cox [80], the individual continually appraises four aspects of his transactions with the environment and strives to retain a balance between them. These are: (i) the imposed demands; (ii) the coping resources available (knowledge, attitudes, skills); (iii) the constraints under which coping proceeds; and (iv) the available support from others. We would add: (v) the appraisal of the centrality or relevance of the threat to the individual's goals or needs.

Coping strategies include direct action, information seeking, palliative activity (e.g. alcohol, smoking, drugs).

It follows that by no means all environmental adversities will have unfavourable health outcomes. Brown and Harris [81], in their careful and extensive studies of the relationship between stressful 'life events' and psychiatric symptomology, have usefully distinguished the 'exceptional' from the 'unusual' event. The 'exceptional', they argue, 'may deny to us a sense of reality'. It challenges the person's 'assumptive world', undermining fundamental beliefs about relationships of trust and the predictability of the future, forcing a complete reassessment.

This may be illustrated by a quote from a mother in Zlynka, who addressed the meeting held there for the International Advisory Committee:

"I used to read about Nagasaki and Hiroshima; it was like science fiction. Now we have been living four years with this nightmare. Often at night I look at my children and wonder how I can 'grow them' — when will this nightmare end?"

Though less cataclysmic, the accident at Three Mile Island presents us with the closest parallels to the Chernobyl disaster. Both had a severe acute phase with experiences of fear, emotional disturbance and demoralization. This gave way to a more pervasive anxiety, in the case of Three Mile Island, over the perception that the initial release could cause cancer or genetic defects and that further releases of the radioactive gas and water trapped in the plant could occur in the future. At Chernobyl there have been continuing and immeasurably deeper concerns about further releases or similar accidents in adjacent reactors of the same design. More commonly though, there is clearly considerable anxiety about the levels of caesium contamination in the environment and dark fears about the possible presence of other less publicized radionuclides, particularly plutonium and strontium. There is omnipresent uncertainty about the long term future health consequences of the high level of exposure in the early weeks. Whatever the facts (themselves equivocal) it has to be emphasized again that whatever people *believe* to be true is what shapes their potential stress responses.

In the best known study of the aftermath of Three Mile Island [82], the investigators faced the same methodological problem as at Chernobyl, i.e. a lack of pre-disaster measurements. They therefore compared Three Mile Island residents with similar people living near an undamaged nuclear plant, a conventional coal fired plant and a control area 20 miles from any power plant. Hence, they were able to control for the fact that living near an *undamaged* plant may itself be stressful. Two behavioural tests of concentration and motivation were administered, together with a health symptom checklist, the Beck Depression Inventory, and a background questionnaire.

In addition, chronic sympathetic nervous system activity was measured by biochemical assays of catecholamine levels in samples of urine.

The results on all measures indicated significant stress effects that had persisted for 17 months.

Finally, in a parallel study [83] of 'coping styles' that has close relevance to Chernobyl, it was found that, because the stress was chronic and because direct control of the source, i.e. the damaged reactor, was impossible, a coping style based on *management of the emotions*, a personal reappraisal of 'meanings', was most effective. ('Problem oriented' or 'direct control of the stressor' coping styles did not bring relief). 'Emotion management' is the form of coping that can benefit from counselling but this can rarely be available for the majority, and *social* therapy must be presented in the form of information and advice to doctors, teachers and welfare workers and directly through the media.

There is an important ethical dilemma in such an approach. In short, if the stressor is a real threat, it is dishonest to pretend otherwise or to imply that an anxious response to it is in some way abnormal.

While it may well have suffered in translation, the use of the term 'radiophobia' by scientific experts in the USSR illustrates this problem. In a spirited exchange at the IAEA Scientific Meeting in 1988 [84, 85], it was argued that the use of this diagnostic term, at any rate in western Europe and the USA, implies a fear reaction to a stimulus that is normally regarded as wholly benign. Few would place Chernobyl in this category, as is witnessed by the enhanced risk perceptions throughout the USSR and in many countries far removed from the source.

It is hoped that the main outcome of the present exercise will be an accurate assessment of the current threat and future prognosis, allowing any exaggeration in personal and community response to be clearly assessed. Only then can a campaign of therapeutic advice on stress management be effectively designed and implemented.

3.6.1.3. Methodological Problems in Post Traumatic Stress Disorder Research

Those who doubt the reality of stress effects may argue with some justice that most of the evidence for 'post-traumatic stress disorder' is derived from self-report, much of it qualitative. This raises the possibility, particularly in Chernobyl where the stakes are high, that symptoms will be exaggerated to conform with people's expectations of ill-effects or deliberately to attract sympathy or compensation in their adversity.

This argument could extend to the behavioural measures used by Baum et al. [82], though not to the biochemical assays. Fortunately, another study goes a long way to dispelling these doubts. Adams and Adams [77] examined the effects of disaster related stress following the volcanic eruption at Mount St Helen's, Washington, USA in 1980. The town of Othello (population 5000) was seriously threatened and the dread of secondary eruption and the presence of a thick ashfall continued for over a year. These investigators relied entirely on *behavioural* measures, i.e. community records, making direct comparison between the seven months following the disaster with the preceding seven months. Significant differences were found in the use of the mental health 'crisis phone line', in scheduled appointments at the mental health clinic, hospital emergency room visits, district court cases, police records of domestic violence, total number of police 'report forms' and the number of clients served by the community alcohol centre.

3.6.1.4. Technological (Chernobyl) and Natural Disasters Compared

In terms of human consequences, technological disasters differ from natural disasters in several important ways. They represent a severe loss of expected control. There is total failure, despite reassurances from politicians and experts. These consequences are markedly different from, e.g. floods, earthquakes and volcanic eruptions, where control has always been lacking and is not expected. The elements of human error and attributions of blame are absent from natural events. Paradoxically, although natural disasters are uncontrollable, they are often predictable to some extent — they do not 'come suddenly from nowhere'. They are also clearly observable to the victims and to sympathizers on whom relief may depend. Their effects are relatively easy to measure by experts and mitigation plans can be widely publicized and understood.

Even more important, though, most natural disasters have an aftermath in which, however low the low point may have been, there is steady and often rapid improvement. The worst feature of Chernobyl, showed to a much smaller extent by Three Mile Island and Love Canal, is the ever present invisible threat and the continuing fear that the future is blighted by irreversible cancer or genetic effects. This may even have increased over the five years — certainly it shows little sign of abating.

3.6.2. Review of Official Data

3.6.2.1. BSSR

No information was available.

3.6.2.2. UkrSSR

In Bragin physicians judge that there has been an increase in strokes and in stress, but no increase in suicide.

Dr. Nyagov of the Neuropsychology Department of the AUSCRM in Kiev has been studying stress in three groups. Her data are based on questionnaires filled out by about 5000 patients who have come to AUSCRM (mainly for other purposes). Thus, it cannot be considered a representative sample. She reported 'psycho-vegetative deficiency' and 'vegetative dystonia' in 30% of the emergency accident workers as well as neuroticism and decreased libido in about the same percentage.

The psychoneurologists in the Kiev group indicated that anxiety is present in 80% of the people examined but that a normal level of anxiety in unexposed populations is between 40 and 50%. They indicated that the disorders are also expressed in terms of behavioural deviations such as aggressiveness, increased smoking and alcoholism. They feel that many mothers with children in areas of contamination have become neurotic and that there are psychophysical reactions with one third of patients demonstrating 'vegetative dystonia'.

The team contacted two physicians who had attended the WHO conference on Psychological Effects of Chernobyl in late May 1990 in Kiev. The group attending the conference visited Korosten as a place where 'radiophobia' was supposed to be prevalent. The general consensus was that the people contacted on the street in Korosten were concerned about radiation but that they did not demonstrate phobic behaviour. Apparently, a large number of people had left the town, even though the contamination levels in the town are at the relatively low level of 1-5 Ci/km^2 (37-185 kBq/m^2) of ^{137}Cs.

3.6.2.3. RSFSR

In Korma the local doctors assessed a 39% increase in psychiatric disorders. In Novozybkov there was concern by the parents for their children's long term

TABLE 46. Alcoholism and Alcohol Psychosis in BSSR, FSFSR and UkrSSR per 100 000 Population

Region	1985		1986		1987		1988	
	Newly detected	Total incidence	Newly detected	Total incidence	Newly detected	Total incidence	Newly detected	Total incidence
Gomel	256	1857	224	1947	236	2031	182	1935
Mogilev	374	2163	311	2254	212	2241	157	2107
Entire BSSR							**142**	**1756**
Bryansk	227	1505	345	1712	311	1828	244	1906
Entire RSFSR							**198**	**1998**
Kiev	195	2108	202	1917	190	1835	165	1606
Zhitomir	254	1816	262	1828	213	1797	169	1699
Entire UkrSSR							**147**	**1609**

safety. They also expressed distrust for Soviet scientists and officials at all levels. In Zlynka many of the women indicated they were suffering emotionally, worrying not about themselves but about the future of their children and because the information that they read in the media ranges from indications that there is no significant problem to comparisons with Hiroshima and Nagasaki. They find this conflicting information seriously disturbing, especially when combined with distrust in the local and centralized government.

Some indication of the degree of stress may be seen from official data on alcoholism and alcohol psychosis (Table 46). Such data are available from the Ministry of Health for the years 1985–1988 in five contaminated regions. These data are presented here with the recognition that individual reporting and official recording of such data are usually imperfect. However, trends may be recognized if the reporting methodology has not changed over the time period.

3.6.3. Results of Field Trips

3.6.3.1. Qualitative Impressions from the Field Trips

As a result of the magnitude and uniqueness of the Chernobyl accident, it was important to assess the attitudes of different segments of the population to radiation, the methods employed for coping with the threat and any measurements of stress that could be obtained. Task 4 Missions were designed to address some of these issues although in the final analysis it was clear that psychological effects extend geographically well beyond the regions that Missions 8–10 were able to visit.

Unfortunately, in the USSR, these areas in medicine, psychiatric and neurological disorders, are treated and classified somewhat differently from medical practice in Japan, western Europe and the Americas. This makes comparison of past records and new measurements difficult. For example, the terms 'vegetative dystonia' and 'vasovegetative disorder' are rarely used in other countries. As related to the team, disorders of the autonomic nervous system or vegetative disorders are manifest by the symptoms of anxiety, nervousness, sweating, headaches, chest pain, disturbances of sleep, tenderness in hands and legs and abnormalities of blood pressure. In short, the medical tradition in the USSR has, since Pavlov, tended to classify all psychopathology in terms of the originating physiological or neurological structures, whereas the practice in other countries has been to categorize symptoms on an empirical/pragmatic basis.

The Project Mission provided an opportunity to examine a significant number of rural children and adults who have been exposed to varying levels of radioactive contamination. A great deal of the personal distress and community disarray that we observed was a secondary effect of the accident. Migration between established settlements or to newly constructed settlements, or even to 'foreign' Republics within the USSR, all contribute to the malaise. Research has shown that relocation is a highly stressful experience in itself, particularly for the elderly, infirm and 'long settled'. Relationships are split up and social networks destroyed; there is often 'grieving for a lost home' [86].

The ever present threat of personal change is particularly difficult for those who have not previously had to make personal decisions about where the family should reside or what types of work they should do. Where agriculture is the primary occupation, its seasonal and daily routines set the pattern for family and community living. If agriculture is suddenly forbidden these patterns lose their meaning. The organizational fabric of the community is also being stretched and torn by outside influences from higher levels of government. Decreased food and dry goods supplies, due to political decisions made many hundreds or thousands of kilometres away, are having an impact. The lack of these items is a stressor in its own right. The affected settlements believe that their plight has been ignored or denied by the central government and, in view of this, their high level of anxiety and depression is not surprising.

The deep disaffection that we observed was not always related to the effects of the accident. There was great concern about the economic well-being of each settlement in the context of the significant political changes in the Republics and in the USSR itself. These often seemed to be of such a magnitude as to equal or even transcend the effects of the Chernobyl accident itself.

Furthermore, it became plainly evident in the course of the many meetings set up in the settlements by the International Advisory Committee that the impact of the accident and the current political disturbances are synergistic. A number of politicians and aspiring politicians perceive the accident as a potent issue around which an otherwise diffuse public opinion and protest can be rallied. In particular, any leader who gives promise of effective representation to the remote bureaucracy with the aim of improving food supplies, medical services, compensation or resettlement, is likely to gain a local following. This may not be without an honest belief that media reports of extensive health effects are realistic.

The clothes of most people the team met were neat, clean and utilitarian. Most people the team visited appeared to have made an effort to dress exceptionally well when they interacted with the team. Most were polite but initially suspicious of foreigners. They rapidly became friendly and very helpful when they learned that the team consisted of health professionals. Most of the settlements had received very few outside visitors prior to Chernobyl and many of the control settlements were still in this relative isolation until the team arrived.

Decisions relating to relocation possibilities clearly were a major cause of stress in contaminated settlements. There was a definite desire on the part of parents to improve themselves and provide their children with social and educational opportunities that are not available to them in their settlements. Most parents in contaminated settlements had limited data upon which to make decisions about relocation. The decision was often made more difficult by the wishes of the older members of the extended families to stay where they were, in familiar surroundings. It is of interest that even some persons in control settlements wanted to relocate. For some, the reason was that they suspected their own settlement was contaminated; for others who knew that the settlement was essentially clean, there were concerns about the possibility of another accident at Chernobyl.

Parents were more concerned about the well-being of their children than about their own well-being. The parents were concerned about the lack of definitive information relative to past, present and future projected radiation doses. Most did not understand that there were different radionuclides with different levels of risk. 'Summer detoxification' programmes in which children are sent to other areas were confusing to the parents. They did not understand why children should be returned to a contaminated area after they had been sent away so that they might eliminate ^{137}Cs from their bodies.

Children were remarkably well behaved, well nourished and not particularly afraid of medical examiners. They did cry, appropriately, when blood was drawn. The older children consistently showed fewer symptoms than their parents claimed. The parents were generally helpful and co-operative and were glad to have any immediate results that we could provide. In some cases they did have difficulty in accepting negative results but, if presented with these, they seemed initially surprised, even disappointed, but then subsequently relieved.

In the clinics the children were open and talkative. Crayons and paper were provided so that the children had something to do between examinations. Over 100 of the drawings they produced were reviewed. None were morbid in design, content or colour; there was no preoccupation with death, black skies, black rain or monsters. In most pictures the sun was shining, houses had open doors and windows; the fields had small animals and children playing. No animals or people were drawn deliberately misfigured.

3.6.3.2. *Attitudinal and Stress Related Items in the Health Questionnaire*

The team's questionnaire had a number of questions related to attitudes and other parameters that might indicate secondary effects of the disaster or post-traumatic stress disorder. Many of the questions were filled out by mothers or fathers of children, and in some cases there was ambiguity as to whether the answers reflected the child's attitudes or those of the parents. For this reason, analysis was restricted to the questionnaires filled out by adults for themselves prior to their examination (i.e. only on Groups 4 and 5 born in 1950 and 1930, respectively). The survey, therefore, is limited in that it reflects the attitudes of a population that is represented

TABLE 47. Years of Schooling

Years of schooling	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
2–4	34	13	36	15	70
5–9	80	31	75	32	155
10	129	49	101	43	230
>11	19	7	22	9	41
Total	262	100	234	100	496

p = 0.518.

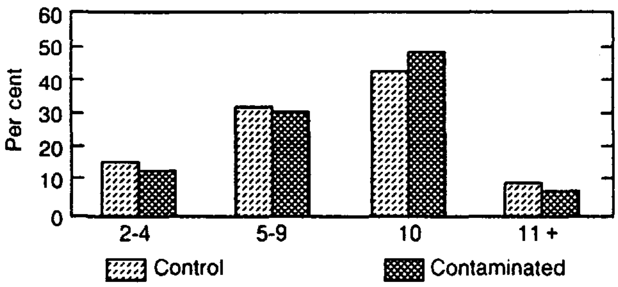


FIG. 58. Number of years of schooling of adults in control (n = 234) and contaminated (n = 262) settlements. p = 0.518.

by a sample comprised about equally of these two groups.

It was important to characterize the groups who answered the attitudinal and psychological questions to make sure there were no major differences that would confound the analysis. Educational level was one such parameter. The results from comparing contaminated with non-contaminated samples are shown in Table 47 and Fig. 58.

Another parameter that was examined was the number of persons living in the household with the individual respondent. This was obtained for nutritional information but also gives an estimate of the size of households in the areas regarded as potentially hazardous and non-hazardous.

It will be seen from Table 48 and Fig. 59 that there are somewhat more small families and fewer large ones in the contaminated areas. It may be speculated whether this is due to selective migration or evacuation, but in any case the trend is not significant and would be unlikely to confound comparisons on other variables.

Other parameters that allowed useful comparison were whether people had lived in that settlement immediately after and since the accident. The results for the former (Table 49) show that the two samples are closely similar. The results for the latter (see Table 50) show that there has been almost no inward immigration into either set of settlements in the four years since the

TABLE 48. Reply to Questionnaire: How Many Persons Live With You?

Number of persons	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
1	24	9	16	7	40
2	93	36	75	32	168
3	56	21	47	20	103
4	61	23	56	24	117
5–8	28	11	41	17	69
Total	262	100	235	100	497

p = 0.237.

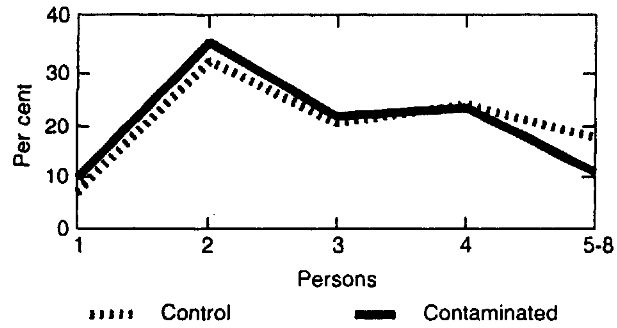


FIG. 59. Number of persons living in a household in control (n = 235) and contaminated (n = 262) settlements. p = 0.237.

accident. Unfortunately, there is no way of estimating outward migration. The nature of these communities is that they are isolated, remote from urban influence, resistant to change and conservative in values.

To these comparisons should be added the fact that age (and probably gender) were exactly matched because of the method of sample selection.

Overall, there were no detectable differences between the two samples, except, of course, the one under consideration — level of contamination.

3.6.3.3. Data on Evacuation Desires

There were two questions relating to relocation from existing settlements to another. The first asked whether the respondent wanted to be evacuated to another settlement. The results are shown in Table 51. The second question asked whether the government should relocate 'all persons' living in the settlement. The results are given in Table 52.

As might be expected, there were major and significant differences in the desire of persons to be relocated based upon whether they lived in a control or a clearly contaminated settlement. Interestingly, about 20% of persons living in a contaminated settlement wanted to remain in their 'contaminated settlements' or considered them 'clean'. The desire to have the government relocate all persons was higher than the desire of single individuals to move. Indeed, if the 'not sures' are added to the 'agrees' the wish could be regarded as virtually unanimous (96%). Those who do not themselves wish to move are, nonetheless, it seems, supportive of the principle.

Another interesting finding was that a few persons (8%) in control settlements wanted to relocate. Also, a full 20% of this sample were in favour of the principle of government sponsored relocation. At the time of the

TABLE 49. Reply to Questionnaire: Were You in the Settlement for the First Month after the Accident?

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Yes	254	96	230	98	484
No	10	4	5	2	15
Total	264	100	235	100	499

p = 0.411.

TABLE 50. Reply to Questionnaire: Have You Lived in the Settlement since the Accident?

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Yes	262	>99	234	98	496
No	1	<1	2	2	3
Total	263	100	236	100	499

p = 0.605.

medical examination this item was discussed in more detail. They generally explained that they simply did not believe expert assurances that their settlement was 'clean' or they were worried about a possible future accident. These attitudes are expressed graphically in Figs 60–62.

Doubtless there is a proportion of the population that would seek to turn the crisis situation to advantage by migrating to what they perceive as better housing and living conditions.

It may be inferred from a comparison of Tables 51 and 52 that people would choose collective relocation, if it is to occur at all. Many have lived in the same communities since birth and this preference reflects their solidarity in adversity. Social relationships between individuals have been shown to be critical not only to

TABLE 51. Reply to Questionnaire: Do You Want to Move from the Settlement?

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Yes	188	72	18	8	206
No	52	20	195	83	247
Uncertain	22	8	21	9	43
Total	262	100	234	100	496

$p = 0.000$.

TABLE 52. Reply to Questionnaire: The Government Should Relocate All Persons Living Here

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Agree	220	83	48	20	268
Not sure	34	13	113	48	147
Disagree	10	4	75	32	85
Total	264	100	236	100	500

$p = 0.000$.

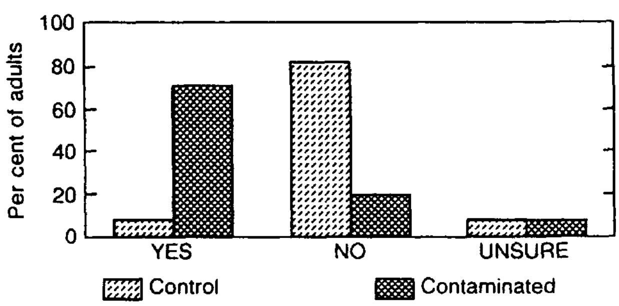


FIG. 60. Opinions of adults concerning their individual desire to leave control or contaminated settlements ($n = 496$, $p < 0.05$). The question asked was: "Do you want to move from this settlement?"

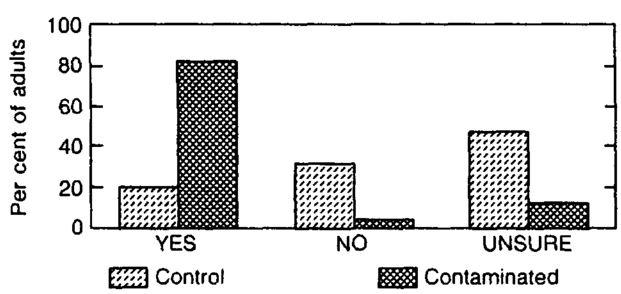


FIG. 61. Opinions of adults on whether the government should relocate them ($n = 500$, $p = 0.001$). The question asked was: "Should the government relocate all persons living here?"

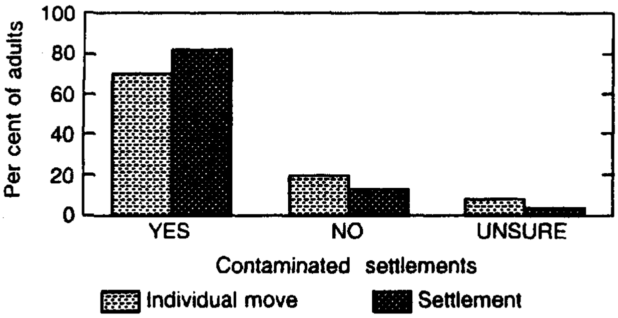


FIG. 62. Comparison of desires to relocate people individually or collectively.

e.g. chronic occupational stress, but also to the patterns of attempted escape behaviour in major fire and other disasters. The availability of social support was shown to have ameliorated personal distress following Three Mile Island [82].

Harshbarger [87] reports that some of the stress experienced by relocated victims of the Buffalo Creek flood could have been substantially reduced if attempts had been made to keep neighbourhoods together.

On the other hand, there is much evidence from previous research [86] that relocation under any circumstances can be stressful, particularly for the elderly. It could only be justified by a net health benefit.

3.6.3.4. Sleep, Smoking and Alcohol Consumption

These items were questioned on the assumption that different levels of psychological stress may be identified through behavioural measures. These give an indication of the mechanisms used to cope with stress. It was recognized that the amount of alcohol consumed might not be accurately reported in terms of volume; however, the biases are likely to have been the same in both control and contaminated settlements. The data should be thought of as applying only to a rural population of 40 and 60 years olds. Sex may play an important role in the habits and these data will need to be looked at in more detail in the future, as will the relationship between stress measures and the desire to relocate.

The number of hours slept per night and indications of extreme fatigue/depression in each group are shown in Tables 53 and 54 and Figs 63 and 64. It will be seen that there is no significant difference. The particular importance of this parameter is that respondents would not know what answer to give in the event of a conscious or unconscious motive to claim an enduring health effect from the accident.

Data on alcohol consumption and smoking are shown in Tables 55–57.

Data on liquor consumption and smoking habits are presented graphically in Figs 65–67.

TABLE 53. Reply to Questionnaire: On Average, How Many Hours Do You Sleep?

Number of hours	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
2–5	38	14	31	13	69
6–8	212	80	198	84	410
9–12	14	6	7	3	21
Total	264	100	236	100	500

$p = 0.375$.

TABLE 54. Reply to Questionnaire: Do You sometimes Feel so Tired that You Do not Get up in the Morning?

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Yes	173	66	122	52	295
No	89	34	113	48	202
Total	262	100	235	100	497

$p = 0.001$.

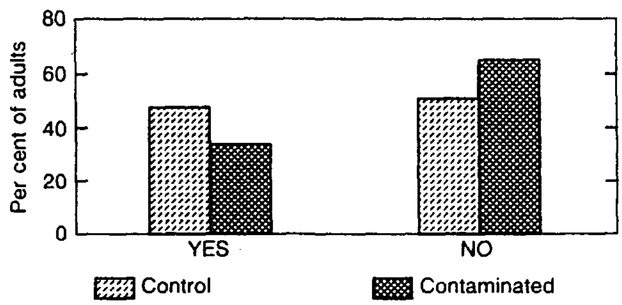


FIG. 63. Comments of adults relative to severe tiredness in control (n = 235) and contaminated (n = 262) settlements (p = 0.01). The question asked was: "Do you feel too tired to get up in the morning?"

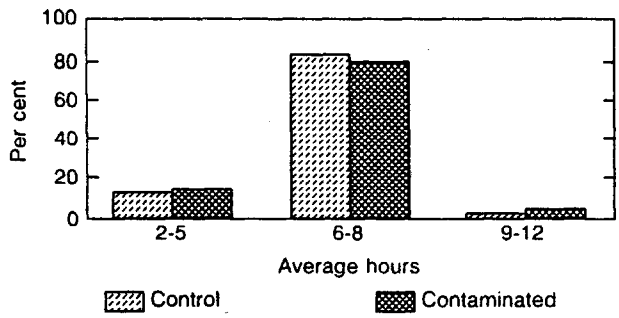


FIG. 64. Average hours of sleep by adults in control and contaminated settlements. n = 500, p = 0.375.

TABLE 55. Reply to Questionnaire: Do You Drink Hard Liquor?

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Never	59	22	72	31	131
Rarely	94	36	98	41	192
Sometimes	102	39	58	24	160
Frequently	8	3	8	4	16
Total	263	100	236	100	499

p = 0.007.

TABLE 56. Reply to Questionnaire: Have You Ever Smoked?

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Yes	89	34	75	32	164
No	173	66	160	68	333
Total	262	100	235	100	497

p = 0.627.

Consumption of alcohol shows the same pattern but, again, it is not possible to be sure whether the difference reflects actual consumption or differences in perceived recourse to this palliative as a way of relieving stress.

In view of the results for early morning fatigue and alcohol consumption, it is unexpected to find no significant difference with respect to smoking. The proportion 'smoking now' is also surprisingly low and these data would benefit from comparison with other samples.

It seems unlikely, though possible, that the respondents are unaware of the connection between smoking and stress.

In one section of the health questionnaire, we elicited medical history data on a wide range of symptoms, using the following guidance to interviewers:

"Put a check in the box if the person being examined today has had any of the following complaints during the last two months."

TABLE 57. Reply to Questionnaire: Do You Smoke Now?

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Yes	61	23	50	21	111
No	199	77	184	79	383
Total	260	100	234	100	494

p = 0.578.

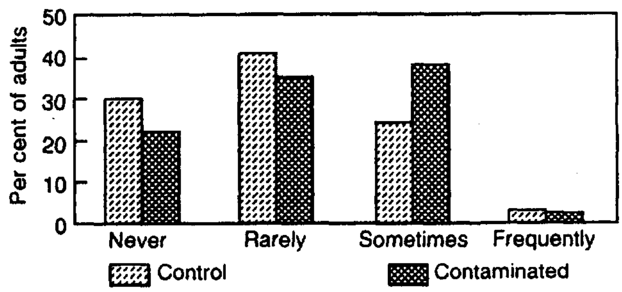


FIG. 65. Frequency of alcohol consumption by adults in control and contaminated settlements. p = 0.007.

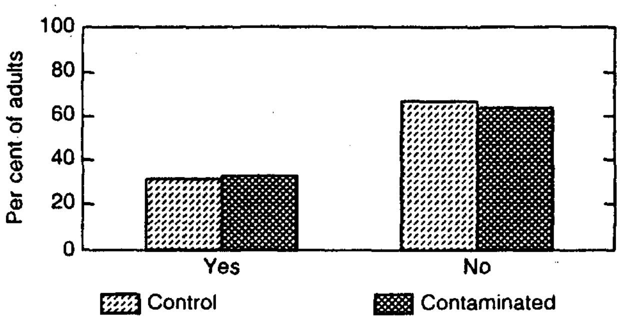


FIG. 66. Smoking history of adults (n = 497, p = 0.627). The question asked was: "Have you ever smoked?"

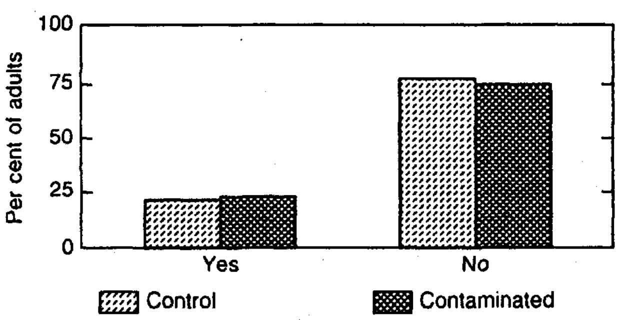


FIG. 67. Per cent of adults who currently smoke cigarettes in control and contaminated settlements. n = 494, p = 0.578.

The results for 14 of these symptoms are shown in Table 58. The percent saying 'yes' in column 1 is an aggregate for both contaminated and non-contaminated samples and gives some indication of the overall incidence. For a measure strictly applied over a two month period they are disturbingly high, but it is commonly found that respondents interpret the time period in an extended way.

The symptoms are divided between those which show significant differences between contamination and control settlements and those which do not.

By far the most significant differences are in fatigue, loss of appetite and chest pains, which are classic stress symptoms. Turning to the counter indications, the evidence for a stress model is weakened by the lack of difference in the incidence of headaches and depression.

The two *physical* symptoms that are most likely thought by the public to be radiation linked, i.e. thyroid/goitre and anaemia, are also significant. Health examinations data would suggest that these responses may be enhanced perceptions, as distinct from physically mediated disorders. It is interesting that nosebleeds, about which the same argument may be offered, come near to being significantly different also. This evidence is reflected in Table 59, which gives responses to a separate question on the perceived cause of illnesses.

A high proportion of the population think they have an illness due to radiation. This is a depressing statistic and one that does not appear to reflect the objective position. Furthermore, although Table 59 reveals significant differences between the contaminated and control settlements, a surprising 30% of the people in uncontaminated settlements think they have a radiation induced illness and 44% are 'not sure'.

The overall evidence provides strong support for a stress model.

We asked questions about the perceptions of the population with respect to radiation and their feelings about the future. All, except the latter, demonstrate significant differences between persons living in control and contaminated settlements. They also demonstrate

TABLE 58. Perception of Illness in Contaminated Compared to Control Settlements

Illness perception regarded as significant (<0.05)	Percentage who replied 'yes' Contaminated settlements	Control settlements	All settlements	p
Fatigue	89	81	85	0.005
Loss of appetite	53	42	48	0.025
Chest pains	53	43	49	0.026
Thyroid/goitre	25	11	18	0.000
Anaemia	8	5	7	0.035
Illness perception regarded as non-significant				
Headache	81	77	79	0.225
Depression	42	42	42	0.865
Sore throat	40	35	39	0.661
Hair loss	26	25	25	0.707
Diarrhoea or constipation	27	25	26	0.709
Weight gain	19	14	17	0.083
Weight loss	15	15	15	0.934
Menstrual irregularity	9	6	8	0.093
Nosebleeds	16	11	13	0.084

TABLE 59. Reply to Questionnaire: I Think I Have an Illness Due to Radiation

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Agree	117	45	70	30	187
Not sure	122	46	104	44	226
Disagree	24	9	62	26	86
Total	263	100	236	100	499

p = 0.000.

that about half of the population is not well enough informed about the facts (or does not believe them) to feel comfortable in forming a definite opinion.

Some of these tables are presented in graphic form in Figs 68–71.

It will be seen from Tables 59–62 that general morale and confidence in the future are very low. Very few believe that the level of radiation is decreasing (Table 60) and few have accepted the notion that a small amount of radiation is safe (Table 61). It is upon this latter premise that the '35 rem (350 mSv) concept' depends. In both cases, these perceptions run counter to 'expert' opinion and the fact that, in addition to those who have made up their minds, roughly half the population are 'not sure' is a further indication of the prevalence of uncertainties that give rise to stress.

The expectations that the problems of Chernobyl will mainly be solved within the next ten years is not shared

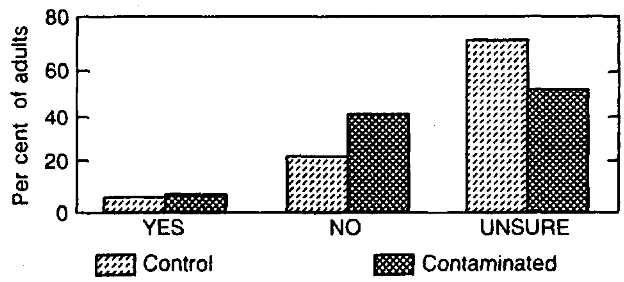


FIG. 68. Per cent of adults in control or contaminated settlements who were asked: "Is the level of radiation decreasing?" n = 501, p = 0.0000.

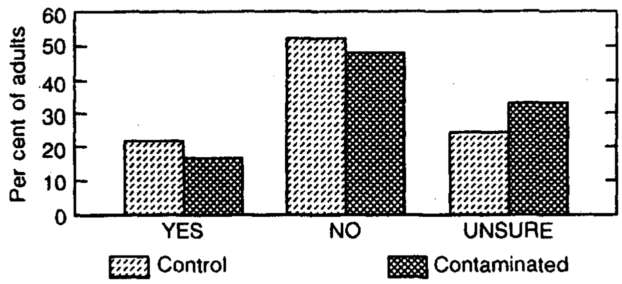


FIG. 69. Per cent of adults in control or contaminated settlements who were asked: "Is a small amount of radiation safe?"

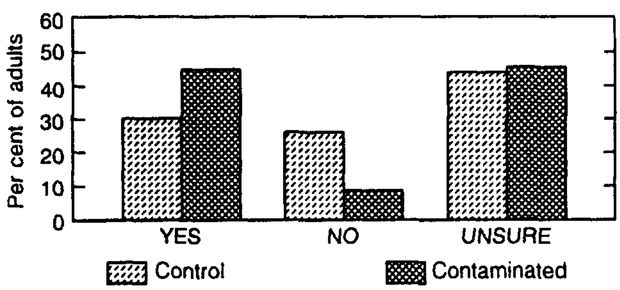


FIG. 70. Per cent of adults who feel that they have an illness due to radiation from the Chernobyl accident. p = 0.001.

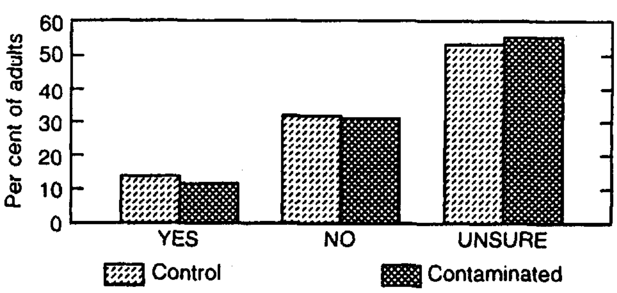


FIG. 71. Per cent of adults in control or contaminated settlements who think that the problems related to Chernobyl will be mostly solved by the year 2000. n = 501, p = 0.85.

at all by a third of the population and more than half are 'not sure'; again, there is widespread uncertainty. This pessimism applies equally to contaminated and non-contaminated settlements (Table 62).

3.6.4. Summary of Psychological Issues

The psychological problems related to Chernobyl are major. The fear, uncertainty and feelings of helplessness clearly extend well beyond any measurable significant radioactive contamination.

There appear to be several major points relative to the psychological effects. The first is that the Chernobyl accident cannot be taken out of the context of social and economic changes that are occurring independently of the accident. Glasnost, perestroika, food shortages, ethnic unrest and nationalism are all inextricably meshed with the impact of Chernobyl.

Lack of information and lack of trust are major problems that were identified. The population does not know or believe whether their food and houses are contaminated, what the effects of radiation are, or whether they should seek relocation. Some of the problems relating to lack of information are associated with the fact that most of the data about the accident were not available for at least two years after the event. Another problem faced by the population is the conflicting information not only in the media but from different groups of Soviet scientists.

Most of the people have genuine concerns and are not acting in an irrational fashion, given their circumstances. As a result, we would not use the term 'radiophobia' for the psychological effects that are present. The magnitude of the population that had significant concerns is large and is an indication of the diffuse nature of the problem. It is of interest that, while the population clearly suffers from stress, we were unable at this point to ascertain whether the stress is being translated into other physically identifiable abnormalities such as hypertension or nutritional deficiencies that are different in contaminated versus control settlements or, for that matter, from the Soviet population as a whole. There may be an increased incidence of some abnormalities (such as gastric ulcer) that are present but which we did not test for.

It should be pointed out that not all psychological problems will be solved by relocating persons living in highly contaminated settlements. In instances where relocation has occurred, there have often been profound social disruption and other stresses created by the breakup of extended families. It also gives an indication of the very significant stress that would be created by relocation.

Psychological problems exist and will continue in settlements that have very little radioactive contamination. This is due to the fact that many of these settle-

TABLE 60. Reply to Questionnaire: The Level of Radiation is Going Down

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Agree	18	7	14	6	32
Not sure	137	52	169	72	306
Disagree	110	41	53	22	163
Total	265	100	236	100	501

$p = 0.000$.

TABLE 61. Reply to Questionnaire: A Small Amount of Radiation is Safe

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Agree	44	17	52	22	96
Not sure	129	49	126	53	255
Disagree	91	34	58	25	149
Total	264	100	236	100	500

$p = 0.039$.

TABLE 62. Reply to Questionnaire: The Problems Related to Chernobyl will be Solved Within the Next 10 Years

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Agree	33	12	33	14	66
Not sure	148	56	127	54	275
Disagree	84	32	76	32	160
Total	265	100	236	100	501

$p = 0.85$.

ments share the same feelings of uncertainty and have not been specifically visited by authorities to document and confirm that there is, in fact, little or no contamination present. Even if this happens, the population continues to have fears about the potential of another similar accident but with a different fallout pattern.

Health problems, whether related to radiation or not, will continue to occur and to pose long term psychological problems. Whenever a cancer occurs there will be an immediate tendency to blame it on the Chernobyl accident. This is understandable for, although the accident will only very slightly increase the statistical incidence of cancer, it provides a ready and easy 'causal attribution'. Moreover, it is an explanation that displaces all responsibility on to an external, simplified, causal agent. Such problems and issues can be expected to take decades to resolve. There are, however, a number of actions that can be taken to speed up the process.

3.7. Nutrition

3.7.1. Rationale

Issues related to nutrition are important because poor nutrition can be responsible for a myriad of health problems. One of the greatest of these concerns is the possibility that Chernobyl fallout could cause an increase in the incidence of cancer. In this context one should note that cancer is a relatively common disease (about 20% of all causes of death) in developed countries, including the USSR; further, about 80% of cancers are thought to have environmental causes (NOT associated with radiation), including 35% that are influenced by the diet [88].

There is little evidence for significant potentiation or protection of radiation by dietary variations. On the other hand, many of the health concerns that were expressed to the team could be secondary to poor nutrition. These problems include goitre (related to iodine deficiency), hypertension (related to obesity and salt intake), anaemia (possibly related to protein, iron and/or vitamin deficiencies, or to lead toxicity) and rickets (related to calcium and/or vitamin deficiencies).

Excessive dietary intakes of toxic microcontaminants are potentially another cause for concern. The attention of the International Advisory Committee was drawn to the fact that large quantities of lead and boron were dumped on the Chernobyl reactor core between 27 April and 10 May (see Section 2.6) during which period the wind direction was predominantly towards the northeast. Concern was expressed that some of these toxic components may have been widely distributed in the environment and may, therefore, be causing contamination of food supplies. This concern was repeated in many settlements by local citizens and physicians.

Another potential dietary factor that could lead to increased incidence of illnesses within the contaminated as compared with the control or non-contaminated areas is the fact that the diet may have changed substantially in recent years, partly as a result of the control measures introduced to prevent the consumption of contaminated foods.

For all these reasons it was felt that a nutritional assessment of persons living in some of the affected regions would be useful.

3.7.2. Review of Official Data

3.7.2.1. General Nutrition

Soviet scientists appear to have undertaken extensive research on the nutrition of persons living in the areas affected by Chernobyl. However, for the most part, the information on this topic provided to the Project's teams was only anecdotal in character; very little of it has yet been documented in an accessible form.

It was mentioned[25] that the following confounding factors may lead to an increased incidence of illnesses within the contaminated as compared with the control or non-contaminated areas. These are:

(1) The diet was changed substantially in recent years. As an example, it was mentioned that rickets was discovered in some of the settlements in 1988, presumably secondary to milk deprivation. The incidence of rickets in some small settlements was 10–20% of one to three year old children.[26] However, hard data were not available.
(2) The children were subjected to long periods of indoor confinement by parents, teachers, etc., so that their exposure to radionuclides would be limited.

One of the most pertinent statements (originating from the Institute of Nutrition in Kiev) concerning the period shortly after the accident was that: "Beginning in May 1986 there was a decrease in the major food components of the diet, providing 30% less joules, 25% less protein and 30% less carbohydrates; there was also 84% less fresh fruit."

The general truth of this statement (at least qualitatively, if not quantitatively) was confirmed independently by nutritionists in Kiev, Gomel, Minsk and Moscow. However, it appears that the problem was a short term one, mainly in the year immediately following the accident. Since then the situation has more or less normalized.

According to the Moscow Institute of Nutrition, three Soviet institutes have conducted collaborative research in some of the areas affected by Chernobyl, including field trips conducted in 1987 and 1989. It was established that people in the affected areas had particularly low intakes of protein (especially animal protein), of plant fats and of vitamins. With respect to the latter it was established that there was a very high occurrence of low intake of vitamin C, carotene, vitamins B_1, B_2 and E. These deficiencies were observed in both years but were not as serious in 1989 as in 1987. The main reasons mentioned for these deficiencies include non-availability of suitable food products, poor eating habits by the persons concerned, and the use of overrefined products. These deficiencies are now being overcome by the use of vitamin supplements.

UkrSSR

AUSCRM scientists[27] indicated that rickets was found in about 30% of young children both before and

[25] Dr. L.A. Il'in (Moscow).
[26] Dr. A.K. Gus'kova (Moscow).
[27] Dr. E.I. Stepanova.

after the accident. This is based upon clinical diagnosis only. Most were felt to be Grade 1 and 2 with no cases of Grade 3 rickets.

Another scientist[28] has examined the diet of both adults and children in Narodichi and Polesskoe. The diet was divided into six groups: 0-3, 3-6, 7-10, 11-13, 14-17 years of age and adults. The previous estimates of those who are not following dietary restrictions were confirmed.

Dietary matters have been studied by two methods: (1) questionnaire, and (2) measurement of the weight of meals. Seventeen major components (e.g. amino acids, vitamins, protein, fat, carbohydrates, etc.) were analysed for ten settlements in the Polesskoe and eight settlements in the Narodichi district. This study included all seasons and was conducted from 1986-1989. The results were divided into the three categories of contaminated areas: 10-15 Ci $^{137}Cs/km^2$ (370-555 kBq $^{137}Cs/m^2$), 15-40 Ci $^{137}Cs/km^2$ (555 kBq $^{137}Cs/m^2$ -1.48 MBq $^{137}Cs/m^2$) and >40 Ci $^{137}Cs/km^2$ (>1.48 MBq $^{137}Cs/m^2$). At the present time it appears that there remain major shortages in food supply from clean zones such as milk, meat, vegetables and juices.

Children over the age of 7 have three meals a day at school which are clean but their large evening meal at home probably is not clean. There are 2000 older persons still living within the contaminated 30 km zone who are eating locally produced foodstuffs, and there are some 60-80 children who are coming to visit or live with their grandparents in this area.

BSSR

In Bragin, Mission 1 was told that the diet was of concern in this region. The feeling of the physicians was that less milk is being consumed than in the past. A study on children was apparently done by the Food Centre of the USSR, but the team was unable to obtain a copy.

RSFSR

In Zlynka, Mission 1 was told that milk comes from elsewhere, but local vegetables were grown and eaten. It should be noted that both in this town and many others, although the milk supposedly comes from elsewhere, it only comes at intervals of three or four days and that most of the population does not have any means of refrigeration.

3.7.2.2. Anthropometry

An overall impression of the nutritional status of a population group may be gained from anthropometry, i.e. from an evaluation of heights and weights in comparison with standard charts.

The team was given data relative to height and weight parameters for both Moscow and Leningrad. Only the Moscow data are presented here since there was little difference from Leningrad. The data are useful as baseline comparative data for the team's health effects field trips (Table 63).

3.7.2.3. Lead

UkrSSR

An AUSCRM scientist[29] indicated that the lead level was investigated by urine analysis in 1987 in the children who were in Pripyat and found to be higher than normal but not high enough to be the main cause of the anaemia. Actual data were not available at his institute. No analysis of lead had been done in the UkrSSR for areas outside the 30 km zone.

BSSR

Health authorities in Gomel indicated that 47 children had been tested for lead in Krasna and Gomel, but where these data had been obtained was not certain. It was indicated that they had done some limited sampling for lead analysis in blood and urine.[30] These were done by atomic absorption on a machine at the Academy of Sciences. It was indicated that some blood samples gave elevated results indicative of lead contamination.

3.7.2.4. Iodine

Iodine is an important factor in relation to thyroid disease, particularly goitre (see Section 3.3.1), since it is a component of several thyroid hormones. Various Soviet sources indicated that the places visited by the Project's teams are in an endemic goitre area, implying that there is a nutritional deficiency of iodine there.

Soviet data with respect to thyroid function are discussed in Section 3.3.1.2. As regards inorganic iodine, two additional factors are worth noting:

(1) The Soviet authorities are sufficiently concerned about iodine deficiency for there to be a programme of salt iodization. However, Soviet sources have provided evidence that this programme is not working effectively and that much of the salt that is available either is not iodized or is failing to meet the required quality control standards. (A few spot measurements on salt samples collected by the

[28] Dr. Salyi (Kiev).

[29] Dr. V.G. Bebeshko (Kiev).

[30] Dr. S.V. Petrenko (Minsk).

TABLE 63. Published Height and Weight of Individuals Living in Moscow

Age group	Sex	Percentile							
		Mean	5	10	25	50	75	90	95
				Weight (kg)					
20–29	Males	74.5	60	62	66	74	82	89	93
30–39		75.9	59	61	67	75	83	92	97
40–49		77.6	59	62	68	75	86	95	104
50–59		77.5	57	63	69	76	85	94	101
60–69		77.3	58	62	69	77	86	93	100
20–29	Females	63.5	49	52	55	61	69	80	84
30–39		66.3	50	52	58	65	72	83	88
40–49		72.4	53	57	63	72	81	90	96
50–59		75.2	54	60	67	75	84	91	98
60–69		74.1	52	58	66	74	82	90	94
				Height (cm)					
20–29	Males	176.9	166	168	173	177	181	185	187
30–39		174.9	163	167	171	174	179	183	186
40–49		173.0	162	165	168	172	177	181	184
50–59		171.3	161	163	167	171	176	180	182
60–69		169.4	159	161	165	170	175	178	180
20–29	Females	163.6	153	156	159	164	168	171	174
30–39		161.7	152	155	158	161	165	169	171
40–49		159.9	152	153	156	160	164	166	168
50–59		158.8	149	152	155	159	163	165	167
60–69		156.8	147	149	153	157	161	163	166

Project's nutritional team confirmed that three out of five randomly collected specimens did not contain any supplementary iodine and that one of the supplemented samples contained iodine at only about 10% of the required level.)

(2) A survey on iodine in soil carried out several years ago revealed widely varying levels from one district to another within the region (implying that it would be possible for neighbouring settlements to be completely different in respect of sufficiency of iodine).

3.7.3. Results of Field Trips

3.7.3.1. Purpose and Scope

Several of the Task 4 missions collected data and samples relevant to the evaluation of the nutritional status. Mission 5A, in particular, was organized to collect individual samples of foodstuffs and diets. However, for a variety of reasons, including constraints (due to lack of time and logistic support) on the number of places that could be visited and the numbers of samples that could be collected and analysed, the scope of Mission 5A was necessarily limited. Accordingly, the main purpose of this mission was to obtain samples and information that would be *indicative* of various parameters of nutritional interest; it also was intended that these studies should be undertaken in regions affected *differently* by the accident. Because of the above mentioned constraints, however, there was no possibility of conducting these studies in a way that could be regarded, in the statistical sense, as being completely representative of the regions visited.

The main purpose of the mission was to obtain samples of food, blood, urine, etc. for analysis of various components of nutritional interest not directly related to radioactivity. In addition, some environmental samples, particularly lichen, were collected to be used as bioindicators of environmental contamination, particularly with respect to the toxic heavy metals, lead and cadmium.

Specific objectives were:

To obtain information from Soviet sources on the composition of diets and to verify the reasonableness of this information by actual observation of local eating habits.

To obtain information on whether the diet has changed since the Chernobyl accident, whether or not there are significant seasonal variations, and whether children's diets differ from those of adults.

To obtain information on the local occurrence of trace element deficiencies (iodine, iron, zinc, selenium, etc.) and the existence of supplementation programmes (if any) before and since the accident.

To collect duplicate portion dietary samples from well defined selected individuals in contaminated and non-contaminated areas.

To assess whether there is contamination from toxic metals such as lead, cadmium and mercury in the diet and blood.

To collect staple food items including salt, cabbage and potatoes for the analysis of essential trace elements.

To collect blood, urine, hair and milk (breast and cow) samples from the above individuals and others for the assessment of essential toxic trace elements and other relevant biochemical parameters.

The regions visited were selected by the team's Soviet counterparts and are described below. The selection of sampling sites within these regions was made by the Project team.

Novozybkov Region (RSFSR)

This is a region with a population of about 62 000, of which 44 000 live in the town of Novozybkov and 18 000 in the surrounding settlements. The region is one with relatively high levels of environmental radioactivity, but with relatively low transfer factors to food. The places from which samples were collected included: Gatka, Novozybkov, Svyatsk, Staryj Bobovichi and Staryj Vyshkov.

Ovruch Region (UkrSSR)

This is a region with a population of about 86 000, of which 14 000 live in the town of Ovruch and the remainder in the surrounding towns and settlements. The region is one with relatively low levels of environmental radioactivity, but with relatively high transfer factors to food. The places from which samples were collected included: Daleta, Kortsevka, Michul'nya, Ovruch, Rakitnoe and Slovechno.

Bragin Region (BSSR)

This is a region with a population of about 23 000, of which 6000 live in the town of Bragin and the remainder in the surrounding towns and settlements. Although it contains some evacuated zones, persons living in the occupied parts have relatively low body contents of ^{137}Cs (see Fig. 5 of Part E). The places from which samples were collected included: Bragin, Gden, Komarin, Malozhin, Mikulichi and Savichi.

3.7.3.2. Sample Collections

Duplicate diet portions representing as accurately as possible both foods and fluids consumed during a twenty-four hour interval were collected from 34 volunteer subjects (the maximum number possible in the limited time available) chosen to represent different social groups. Participants collected equal amounts of food and fluids (based on visual perception) as these materials were consumed. The purpose of the investigation was explained to each participating subject by the team's translator. Subjects were cautioned not to deviate from normal dietary patterns. Participants were also asked to provide morning urine specimens for the measuurement of electrolytes, iodine and some trace elements. Pooled urine samples also were collected for the measurement of plutonium. Blood and hair samples for analysis of trace elements and other biochemical parameters were also collected from those providing duplicate diets. Heights and weights of the test subjects who provided duplicate diets also were recorded for later anthropo-metric evaluation.

A few grams of mixed hair were obtained from local hairdressers for study of certain trace elements. Within twenty-four hours of drawing blood, plasma or serum were separated and frozen in special plastic tubes in preparation for later transport to Vienna. Whole blood samples and blood cells which remained after the separation were also kept frozen for transportation. During the last day of the team's stay in each of the three areas of investigation, food samples were blended and

TABLE 64. Overview of Samples Collected and Analysed

Matrix		Analyte(s)	Number of samples
Blood	— whole	Cadmium, lead,	27
		mercury, selenium	40
	— serum	Iron	39
	— plasma	Zinc	32
Diets		Trace elements	34
Foodstuffs		Cadmium, lead	36
Human milk		Pesticide residues	12
Hair		Trace elements	31
Urine		Iodine	76
Lichens		Cadmium, lead	105
Water		Cadmium, lead	41

homogenized and aliquots were kept sealed and frozen in clean plastic bags to facilitate transport. A limited number of milk samples were collected from local households and collective farms for radioactivity measurements and for the determination of a few essential trace elements. A few samples of breast milk also were collected from local maternity clinics in the different areas visited for determination of trace elements and other constituents.

Lichen samples (species *Parmelia sulcata*) were collected for use as a bioindicator of pollution because of its known suitability for air pollution monitoring and its common occurrence. Samples were taken, together with the substrate bark (mostly poplars, but in some cases willows), from approximately 1.5 m above ground, and stored in paper bags. Other environmental samples for trace element studies included a few tree cores and some grass and soil specimens.

Special precautions were taken to ensure that the samples would be uncontaminated and suitable for eventual analysis. Food samples were blended in a machine specially developed for trace element studies (i.e. with a plastic bowl and titanium knives). Storage containers were pre-cleaned before use. Blood samples were collected using different kinds of 'vacutainers' chosen for their suitability for whole blood, blood serum or trace element studies. All samples subject to the risk of spoilage were kept frozen until analysed.

An overview of the samples collected and analysed is given in Table 64.

3.7.3.3. Arrangements for the Analysis of Food and Other Samples Collected in the USSR

All samples collected in the USSR by Mission 5A were first shipped to the IAEA Laboratory at Seibersdorf. Subsequent analyses were carried out, partly in Seibersdorf itself, partly by members of the Project mission team and partly by a network of analytical laboratories in various countries. All of the latter were laboratories with which the IAEA had previous contracts through its various programmes, such as the Analytical Quality Control Services Programme [89] and the Co-ordinated Research Programme on Human Daily Dietary Intakes of Nutritionally Important Trace Elements as Measured by Nuclear and Other Techniques [90]. A list of participating laboratories is given in the Annex, with some information on the analytical methods employed.

All these laboratories were requested to pay special attention to analytical quality control. For trace element analyses, several certified reference materials were provided (IAEA-H-9 human diet, IAEA-A-11 milk, IAEA-155 whey, Bowen's kale, ARC/CL-TD total diet) [91]. Several laboratories also used certified reference materials from other sources, e.g. NIST. The laboratories were requested to validate their techniques using these materials *before* the analysis of 'real' samples, and to report their results. In addition, for some analyses, results were available from more than one laboratory, thereby providing additional corroboration of the analyses.

3.7.3.4. Food and Energy Intakes

The Task 4 teams did not specifically seek independent data on food and energy intakes. However, some of the data that they collected do provide indirect evidence, if such should be needed, that current levels of food consumption are entirely adequate; in fact, if there is a problem at all, then it is more one of overnutrition (with some major nutrients) rather than of undernutrition.

TABLE 65. Reply to Questionnaire: At How Many Meals per Week Do You Eat Green Vegetables in Summer?

Number of meals per week	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
1–3	51	20	33	14	84
4–6	61	24	47	20	108
7	142	55	153	66	295
8–9	2	1	0	0	2
Total	256	100	233	100	489

$p = 0.071$.

TABLE 66. Reply to Questionnaire: At How Many Meals per Week Do You Eat Meat?

Number of meals per week	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
1–3	40	16	55	24	95
4–6	73	29	84	36	157
7	139	54	91	40	230
10–17	3	1	0	0	3
Total	255	100	230	100	485

$p = 0.002$.

TABLE 67. Reported Average Bread and Potato Intake per Person per Week

	Contaminated areas		Control areas	
Foodstuff	Intake (kg)	SD	Intake (kg)	SD
Bread	1.63	0.90	1.70	0.88
Potatoes	2.70	1.79	2.60	1.46

Data from the Mission 8–10 questionnaires for weekly consumption of vegetables, meat, bread and potatoes are given in Tables 65–67.

Differences between contaminated and uncontaminated group means are not significant for either variable.

These tables are shown in graphic form in Figs 72–75.

Energy intakes of the test persons who provided duplicate daily diet samples can be estimated approximately from the dry weights of diet provided. The results of such calculations, assuming 5.5 kcal/g, are shown in Table 68.

Estimated energy intakes in Bragin and Novozybkov fall somewhat below the expected energy expenditures [92]. This sort of discrepancy is not uncommon in duplicate diet studies, and may be caused by the test subjects forgetting to include some items (e.g. snacks and alcohol) in their duplicate diet records. Another possibility is that the assumption of 5.5 kcal/g may be too low. This would be so if the diets were exceptionally fatty (for

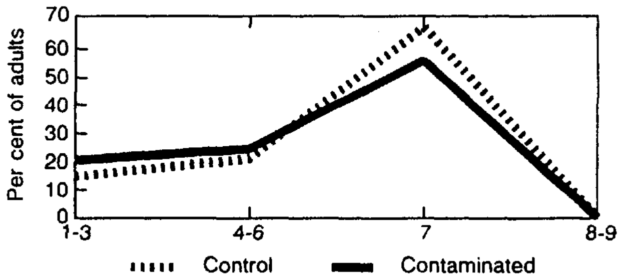


FIG. 72. Number of meals per week at which the adult person eats green vegetables in the summertime. n = 489, p = 0.071.

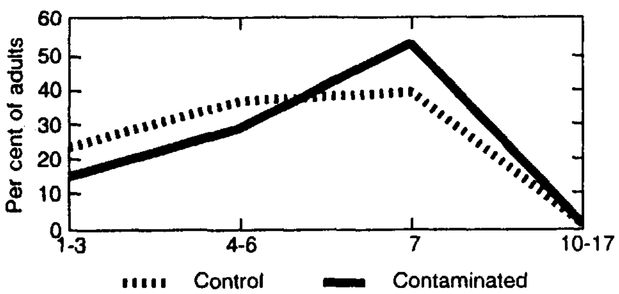


FIG. 73. Number of meals per week at which the adult person eats meat. n = 485, p = 0.002.

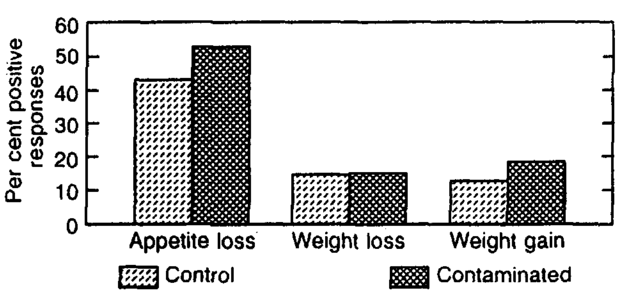


FIG. 74. Nutrition related complaints of adults living in control and contaminated settlements. Appetite loss: p = 0.025; weight loss: p = 0.934; weight gain: p = 0.088.

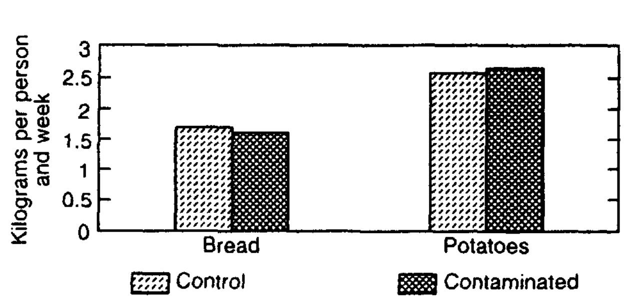


FIG. 75. Average weekly consumption of bread and potatoes by person living in control or contaminated settlements. p = non-significant.

which there is indeed visual evidence). The issue is expected to be clarified later when data become available on energy contents as determined by 'bomb' calorimetry. In any case, one would be mistaken to conclude that the test subjects were suffering from undernutrition, as demonstrated by the following anthropometric data.

3.7.3.5. Anthropometry

An overall impression of the nutritional status of a population is provided by anthropometric analysis, i.e. from heights and weights. For adults this may be done by calculation of the body mass index (BMI) (body mass divided by the square of the height in metres). For children it is done by comparison with standard growth curves (data for US children taken from the National Center for Health Statistics (1979) have been used here).

Anthropometric data were collected by the medical team in control and contaminated settlements. Test subjects were chosen whose birth years were 1988, 1985, 1980, 1950 and 1930 (identified in the Tables as Groups 1-5, respectively). A summary of the data for children and adults relative to height, weight and body mass index is shown in Tables 69 and 70 and Figs 76-88. For comparison, the group of 34 test subjects chosen for the duplicate diet study had the following parameters:

Age:	35.7 ± 12.7 years
Weight:	71.8 ± 14.4 kg
Height:	166.4 ± 7.1 cm
BMI:	25.9 ± 4.9

The main conclusions that can be drawn from these studies are that (1) there are no significant differences between the control and contaminated regions, (2) the Soviet children for whom data were collected have heights and weights that are almost identical to those of US children of comparable ages and (3) a large fraction of the Soviet adults included in the study have body mass index values corresponding to the categories 'overweight' or 'obese' (Table 71).

Observation by team members in the regions that were visited provided the general impression of a diet that, in comparison with other developed countries, is relatively low in protein, high in animal fat, and (except in the summer and early autumn) low in fresh fruits and vegetables. All but one of the families studied in the Project were consuming foods produced in their own gardens — which may be typical for rural, but not for urban populations.

3.7.3.6. Iodine Nutrition

The rationale for wishing to study iodine nutrition was already referred to.

TABLE 68. Energy Intakes of Test Persons who Provided Duplicate Daily Diet Samples

Settlement	Dietary intake (kcal/d)			
	Expected	Estimated		
		Mean	SD	Number
Bragin	2440	1944	794	12
Novozybkov	2480	1984	723	13
Ovruch	2480	2547	661	8
Total	2465	2106	757	33

TABLE 69. Height and Weight Observed in the Children of Examined Groups

Group	Contaminated areas					Control areas				
	No.	Height (cm)		Weight (kg)		No.	Height (cm)		Weight (kg)	
		Mean	SD	Mean	SD		Mean	SD	Mean	SD
Group 1	148	90.9	4.7	13.6	1.9	100	89.9	10.2	13.8	2.5
Group 2	165	112.1	6.6	19.8	3.5	107	110.6	12.3	19.8	2.7
Group 3	161	141.5	7.0	35.6	8.4	109	139.0	7.3	33.9	7.2

TABLE 70. Height and Weight Observed in Adults of Examined Groups

Group	Contaminated areas							Control areas						
	No.	Height (cm)		Weight (kg)		Body mass index (kg/m^2)		No.	Height (cm)		Weight (kg)		Body mass index (kg/m^2)	
		Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD
4	133	165.1	8.2	78.5	13.9	28.8	5.0	97	164.2	8.4	76.7	13.3	28.6	5.3
5	125	163.5	9.1	77.2	14.3	28.9	5.6	95	161.6	7.2	74.9	12.8	28.8	5.0

Iodine deficiency disorders — of which goitre is only the most visible symptom — are now recognized as a major public health problem in many regions of the world [93]. In childhood, iodine deficiency can cause mental retardation, delayed motor development, growth failure or stunting, lack of energy, tiredness and reduced productivity. In pregnancy, iodine deficiency causes spontaneous abortions, stillbirths and infant deaths, and interferes with brain development of the foetus. The 43rd World Health Assembly, meeting in Geneva in May 1990, recognized that nearly 1000 million people still live in iodine deficient areas, and called for a global health initiative to eliminate such disorders by the year 2000.

Two kinds of information were obtained from the team's programme that relate to *nutritional* aspects of iodine metabolism, namely from the determination of iodine in duplicate diets and in urine. The results are summarized in Table 72.

Nutritional requirements for iodine have been considered recently by various expert bodies, most recently by WHO [94]. For adults, daily dietary intakes in the range

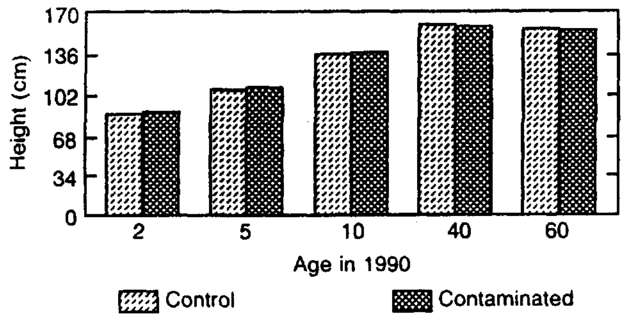


FIG. 76. Height of persons by age group in control and contaminated settelements.

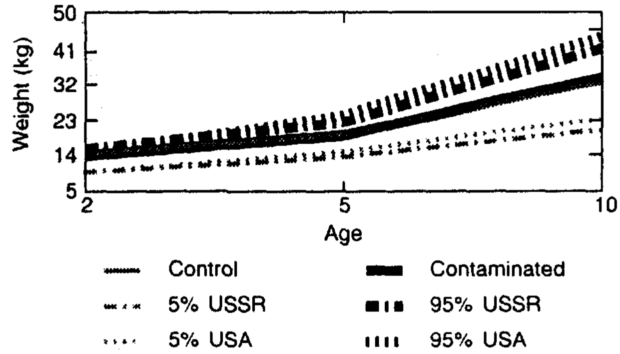


FIG. 79. Weight of children of both sexes and different ages in control and contaminated settlements compared to published norms for the USSR and USA. (Note: symbols for control and contaminated cases overlap graphically).

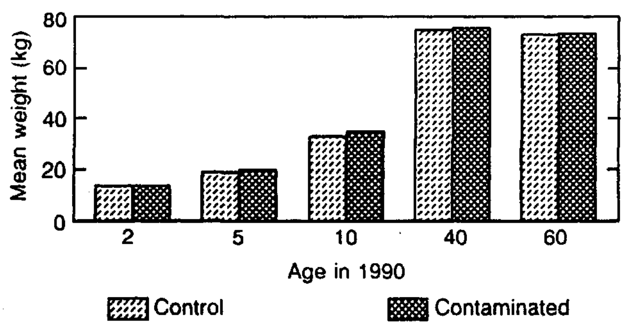


FIG. 77. Weight of persons by age group in control and contaminated settlements.

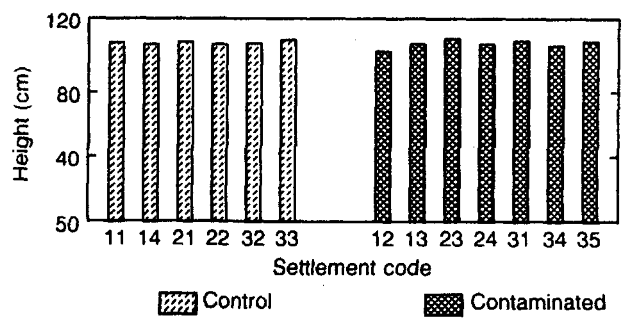


FIG. 80. Height of children of age 5 in individual control and contaminated settlements. Adjusted for sex 50:50; SD: ±2 cm.

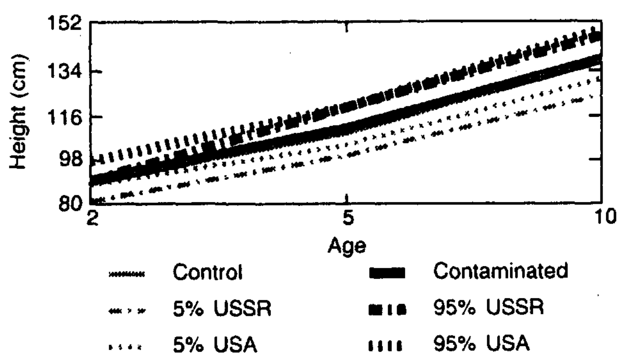


FIG. 78. Height of children of both sexes in control and contaminated settlements compared to published norms for the USSR and USA. (Note: symbols for control and contaminated cases overlap graphically).

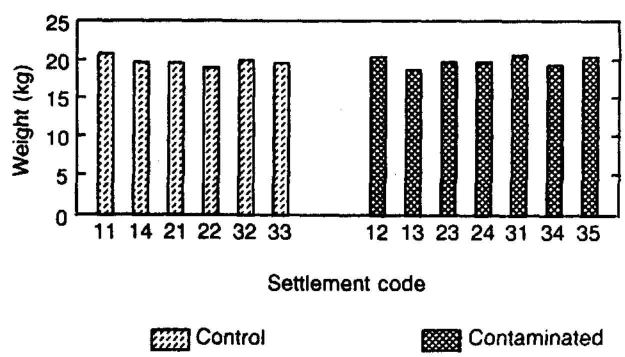


FIG. 81. Weight of children of age 5 in individual control and contaminated settlement. Adjusted for sex 50:50; SD: ±1 kg.

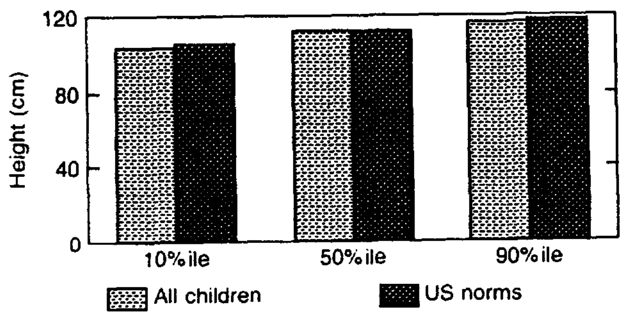


FIG. 82. Height distribution of children of age 5 compared to US norms.

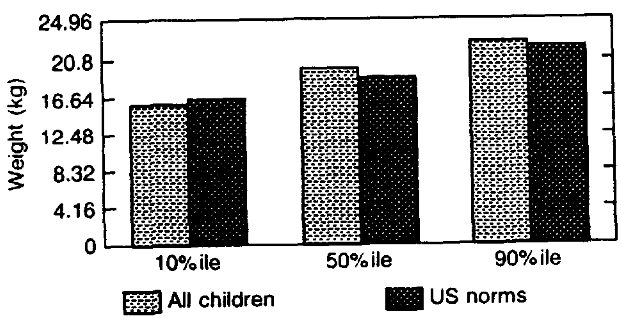


FIG. 83. Weight distribution of children of age 5 compared to US norms.

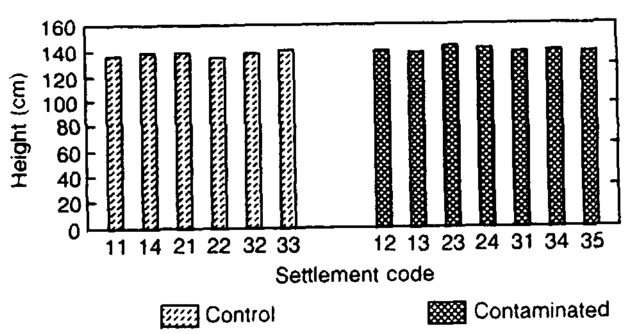


FIG. 84. Height of children of age 10 in individual control and contaminated settlements. Adjusted for sex 50:50; SD: ±2 cm.

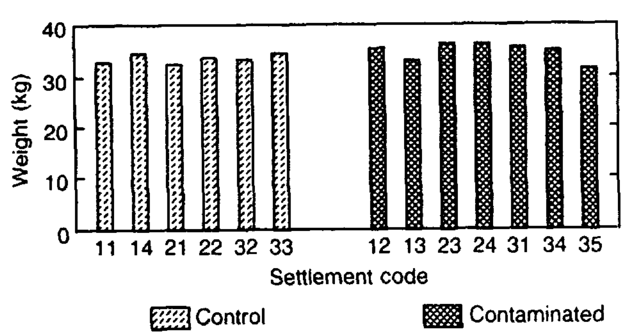


FIG. 85. Weight of children of age 10 in individual control and contaminated settlements. Adjusted for sex 50:50; SD: ±2 kg.

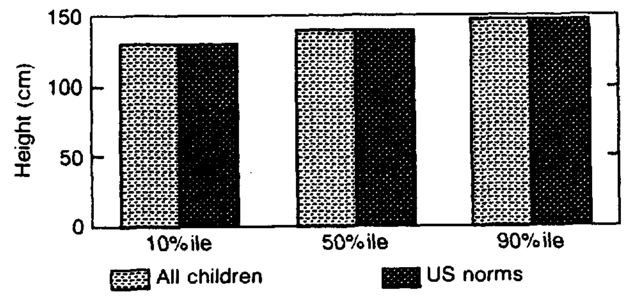


FIG. 86. Height distribution of children of age 10 compared to US norms.

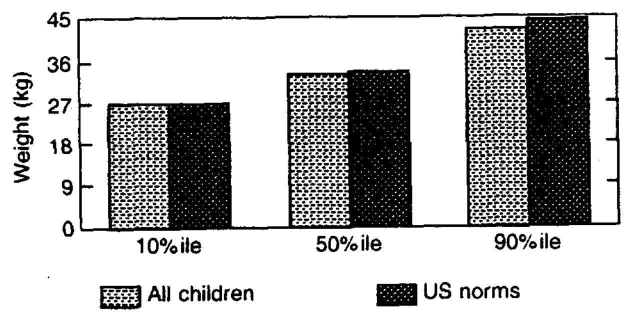


FIG. 87. Weight distribution of children of age 10 compared to US norms.

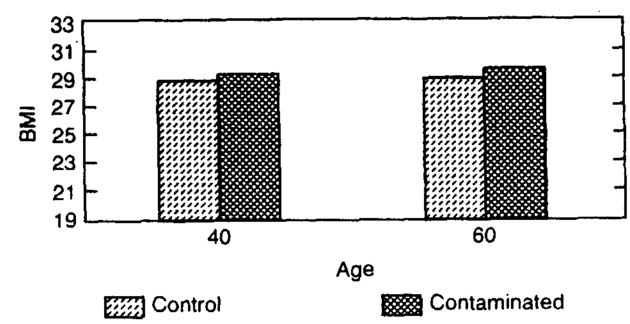


FIG. 88. Mean body mass index (BMI) of adults (ages 40 and 60) in control and contaminated settlements. WHO: normal 19–25, obese >30.

of 120–150 μg are recommended. Soviet intakes are apparently only around *half* this level, which might be taken to imply a significant nutritional deficiency. Urinary excretion, on the other hand, at mean levels around 11 μg/dL, is *above* the range of values proposed by the International Council for the Control of Iodine Deficiency Disorders (ICCIDD [93]), corresponding to a mild degree of iodine deficiency. (The mean urinary excretion of iodine in these subjects was 75 μg/day, which confirms the results of the diet analysis.) It should also be noted that the findings of the medical team in relation to thyroid hormones and thyroid size — namely a lack of any significant abnormalities — suggests that

TABLE 71. Descriptive Terms for Weight of Persons

Description	Body mass index for men (kg/m^2)	Body mass index for women (kg/m^2)
Underweight	≤19	≤18
Acceptable	20–25	19–24
Overweight	26–30	25–30
Obese	>30	>30

TABLE 72. Iodine in Duplicate Diets and in Urine

Matrix	Settlement	Number of samples	Unit	Analysis of iodine samples		Comparator values	Analyst
				Mean	SD		
Diet	Bragin	12	μg/d	83	36	120–150[a]	YUG-1
	Novozybkov	13		40	24		
	Ovruch	9		137	104		
	All	34		81	69		
Urine	Bragin	46	μg/dL	12	7	3.5–5.0[b]	GER-1
	Novozybkov	13		11	8		
	Ovruch	17		11	7		
	All	76		11	7		

[a] Proposed population **minimum** mean daily intake sufficient to meet normative adult requirements [94].

[b] Median urinary iodine excretion corresponding to mild iodine deficiency [93].

there is *no* significant iodine deficiency in these study groups.

In conclusion, it would appear that dietary intakes of iodine are generally low, but not so low as to cause discernible symptoms of iodine deficiency. However, this conclusion is complicated by the fact that there may be great variability in iodine intake caused (1) by differing levels of iodine in the soil (and therefore in the food) from one district to another, and (2) by variable effectiveness of the present salt iodization programme.

Further research appears to be called for to clarify whether there would be any expected benefits from increasing the effectiveness of the present salt iodization programme, particularly for the groups most at risk (pregnant women and children), or whether this programme could safely be discontinued.

3.7.3.7. Lead and Other Toxic Elements

The rationale for wishing to study lead was only briefly referred to in Section 3.7.1.

High levels of lead in the blood can result in anaemia [95]. Anaemia, however, is not seen unless blood lead levels exceed 40 μg/dL. Recent work has shown that lower levels can reduce intelligence. Blood lead levels in the range of 10–20 μg/dL may cause a reduction in intelligence quotient (IQ) of about 4 points compared to that of populations with lower blood lead levels [95, 96].

Screening for significant lead poisoning is sometimes accomplished by measurement of free erythrocyte protoporphyrin (FEPP). This method was not used because it is an indirect measurement, is not as sensitive as blood lead measurement, and finally because there may be some elevation in FEPP in cases of thalassemia and iron deficiency anaemia.

Another measurement that is sometimes made is that of urinary lead. This method was not used because of the difficulties in collecting urine samples from children, in keeping the samples free of contamination and the significant logistical difficulties in the transport of large volumes of samples to the analysing laboratory.

The Task 2 and Task 5 teams collected various kinds of samples to test for the possibility that lead and other

TABLE 73. Analysis of Lead in Blood Samples from Children of Ages 2 and 5

Republic	Settlement	Number of samples	Analysis of lead samples (μg/dL)	
			Mean	Range
BSSR	Bragin	11	8.8	6–12
	Kirovsk	21	7.0	5–14
	Khodosy	18	7.3	5–11
	Veprin	11	7.4	5–12
	Korma	24	7.7	4–11
RSFSR	Unecha	15	6.6	4–11
	Surazh	15	7.3	5–11
	Novozybkov	22	7.2	4–21
	Zlynka	25	8.9	5–15
UkrSSR	Trokovichi	5	7.6	4–13
	Krasilovka, Chemer	5	8.4	7–10
	Narodichi	8	7.0	5–11
	Polesskoe	5	6.4	5–8

TABLE 74. Lead in Foodstuffs

Matrix	Settlement	Number of samples	Typical values[a] (outliers in parentheses) (ng/g dry matter)
Milk	Bragin	4	5–25
	Ovruch	7	10–30
Potatoes and bread	Bragin	4	~20
	Novozybkov	2	~50
	Ovruch	4	~40
Fruit and vegetables	Bragin	6	80–250 (600)
	Novozybkov	4	100–260 (530)
	Ovruch	7	40–240
Mushrooms	Bragin	1	~1300
	Novozybkov	1	~500

[a] Because of the small number of samples analysed, these values are *indicative* of the general levels of lead present, but may not be statistically representative. Analysts: AUS-1, AUS-2.

TABLE 75. Results of the Analysis of Lead, Cadmium, Mercury and Boron in Different Matrices

Matrix	Settlement	Number of samples	Unit	Analysis of lead samples		Comparator values	Analyst(s)
				Mean	SD		
Diet	Bragin	12	μg/d	25	13	3–510[a]	AUS-1/2, FIN-1, IAEA-2, ITA-2
	Novozybkov	13		49	66		
	Ovruch	9		82	128		
	All	34		49	78		
Blood	All	27	μg/dL	8.9	4.0	0.8–27[b]	SWE-1
Water	All	41	μg/L	2.6	2.6	<50[c]	IAEA-2
Hair	Bragin	10	μg/g	3.9	2.9	0.5–2.8[d]	UK-1
	Novozybkov	14		6.5	4.0		
	Ovruch	7		6.3	4.9		
	All	31		5.6	4.0		
Lichen	Bragin	39	mg/kg	14.6	4.2	3–370[e]	NET-1
	Novozybkov	31		12.6	5.2		
	Ovruch	35		21.2	6.4		
Matrix	**Settlement**	**Number of samples**	**Unit**	**Analysis of cadmium samples**		**Comparator values**	**Analyst(s)**
				Mean	**SD**		
Diet	All	34	μg/d	8.4	8.0	8–200[a]	AUS-1, FIN-1, IAEA-1/2
Blood	All	27	μg/L	1.1	0.9	0.3–7[b]	SWE-1
Hair	All	31	μg/g	0.4	0.3	0.2–6.5[d]	UK-1
Lichen	All	32	mg/kg	0.7	0.4	0.6–21[e]	NET-1
Water	All	40	μg/L	0.20	0.22	<5[c]	IAEA-2
Matrix	**Settlement**	**Number of samples**	**Unit**	**Analysis of mercury samples**		**Comparator values**	**Analyst(s)**
				Mean	**SD**		
Diet	All	32	μg/d	3.4	2.7	0.7–60[a]	IAEA-1, ITA-1
Blood	All	40	μg/L	2.2	1.5	0.6–59[b]	YUG-1
Matrix	**Settlement**	**Number of samples**	**Unit**	**Analysis of boron samples**		**Comparator values**	**Analyst(s)**
				Mean	**SD**		
Diet	All	32	mg/d	2.0	1.4	1.6[a]	FIN-1
Hair	All	31	μg/g	4.2	2.7	0.8–10[d]	UK-1

[a] Ref. [100].
[b] Ref. [101].
[c] Maximum permissible concentration in drinking water.
[d] Analyst's normal range for UK subjects.
[e] Analysts's own range for samples collected in the Netherlands.

toxic elements might be contaminating the food supplies. They included blood samples from children, duplicate diets (together with blood and hair samples from the same test subject), and a small number of individual foodstuffs. In addition, lichen samples were used as bio-indicators of environmental contamination.

The children's blood samples were obtained on two and five year old children (see also Section 2.6.8) since young children are the segment of the population that most often demonstrate the highest blood lead levels when lead is present in the environment. This is usually because lead is absorbed like, or in lieu of, iron and follows a similar absorptive pathway. In addition, young children spend a lot of time crawling in dirt and putting their hands in their mouths, which also increases the intake of environmental lead above that which might be found in adults. Confounding factors that are sometimes a problem in environmental lead studies are the presence of lead in solder used for canned foods, the presence of leaded paint in houses, local industrial factories emitting lead and exposure to combustion of leaded gasoline.

Missions 8–10 collected blood samples from children for blood lead analysis. While acid washed heparin tubes can be used for lead analysis, the heparin can break down if the samples are not kept refrigerated and this will invalidate the results. For this reason EDTA tubes were utilized. With the use of such tubes samples can be kept unrefrigerated for a week, although it is necessary to check the tube lot in order to determine whether there is significant leaching of lead from the glass of the tubes.

The results of the 185 analyses are shown in Table 73.

The blood lead levels were in the low normal range in the villages the team studied. There was no significant difference between settlements that were near Chernobyl and those far away. The relatively low blood lead levels were probably the result of the settlements being quite rural. In such circumstances the children were not exposed either to industrial sources or to leaded gasoline fumes. Blood lead levels in cities such as Gomel may be higher than those that we found in rural areas.

Elevated blood lead levels were not found, and therefore lead does not appear to be a factor in the health of the people.

All samples were from venopuncture and obtained on 2 and 5 year old, randomly selected children. Normal values for the test are <29 μg/dL. Not one of the 185 blood samples showed an elevated lead level.

Some results for lead and other toxic elements in foodstuffs, total diet and various other specimens are summarized in Tables 74 and 75.

Observed dietary intakes of lead were somewhat variable, but sufficiently low to be of no concern. WHO has defined a provisional daily tolerable intake of lead equal to 7 μg/kg body weight [97]. For an 80 kg adult this corresponds to 560 μg/day. It is apparent that all of the dietary intakes are well below this figure. Therefore,

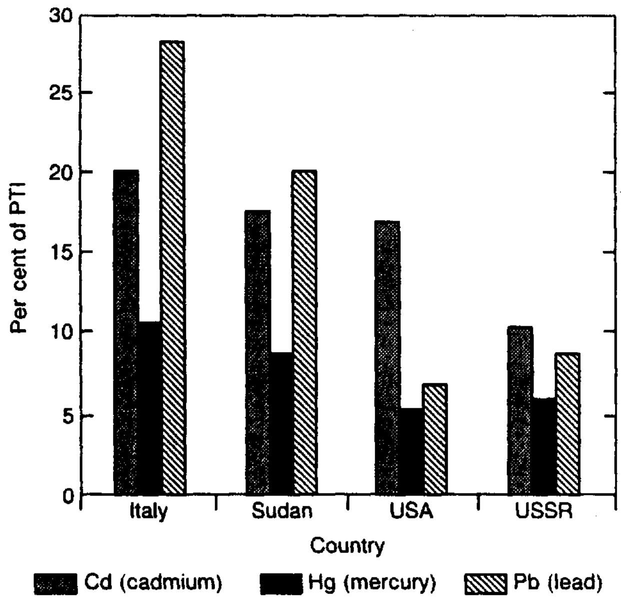


FIG. 89. Dietary intakes of toxic elements in the USSR compared with some other countries. All values are expressed as percentages of the relevant Provisional Tolerable Intake (PTI) defined by WHO and FAO (calculated for 80 kg body weight); USSR data from this study; data for other countries from an IAEA co-ordinated research programme.

lead contamination does *not* appear to be a problem. This conclusion is confirmed by the similarly low values for lead in blood, hair and lichen.

Values for lead in individual foodstuffs (Table 74) are highly variable, but again there was no indication of any cause for concern. (It should be noted that all of the values in this table are on a dry weight basis. For comparison, the provisional tolerable intake, calculated for an 80 kg adult consuming 400 g of dry matter per day, would correspond to a *mean* concentration of lead in food equal to 1400 ng/g dry matter.)

Levels of lead in hair (Table 75) are somewhat higher than in the comparator country (UK) but are fully compatible with what would be expected in a region where leaded petroleum products are in common use.

On the days when lead was dropped onto the Chernobyl reactor, the wind was allegedly blowing predominantly in a northeasterly direction, which would have been in the direction of Bragin. It is therefore interesting to note that the lead values for Bragin do *not* indicate any problem of lead contamination.

Results for some other toxic elements of possible interest, and for lead and cadmium in various kinds of water samples (drinking water and surface water) collected by another team, also are included in Table 75; they are all within normal limits.

Overall, dietary intake of toxic elements (lead, cadmium, mercury) was low in comparison with those reported in many other countries; it was also well below the maximum tolerable intakes specified by international organizations (Fig. 89).

TABLE 76. Results of Iron Analyses

Matrix	Settlement	Number of samples	Unit	Analysis of iron samples		Comparator values	Analyst(s)
				Mean	SD		
Diet	Bragin	12	mg/d	13.9	10.1	5.1–47[a]	IAEA-1,
	Novozybkov	13		12.7	6.2		FIN-1,
	Ovruch	9		21.3	8.9		ITA-1
	All	34		15.4	9.0		
Serum	Bragin	16	mg/L	0.88	0.26	0.75–1.5[b]	SWE-1
	Novozybkov	13		0.81	0.30		
	Ovruch	10		0.93	0.25		
	All	39		0.87	0.27		

[a] Ref. [100].
[b] Ref. [101].

3.7.3.8. Iron Nutrition

The rationale for wishing to study iron nutrition was only briefly referred to in Section 3.7.1. The main focus of interest is in connection with iron deficiency anaemia.

Iron deficiency anaemia is one of the most common deficiency diseases in the world today. FAO/WHO [98] sources suggest that there are as many as 1300 million people who are suffering from anaemia, and that about half these cases are due to iron deficiency. Other effects include reduced work capacity, increased maternal deaths (an associated cause in 50% of such deaths and the main cause in 20% of such deaths in some developing countries), intrauterine growth retardation, low birth weight and increased perinatal mortality, loss of cognitive ability in children, and impaired ability to resist disease.

There are two kinds of information obtained by the Project's nutritional assessment team that relate to this problem — dietary intakes and serum iron concentrations (blood samples had been collected from the same subjects who provided duplicate diet specimens). A summary of the results obtained is presented in Table 76.

The observed dietary intakes of iron are comparable to those reported in other countries. However, this does not necessarily imply that they are adequate. The bioavailability of iron varies widely according to the nature of the diets consumed and is generally lower in diets that are poor in animal protein. Menstruating women are the group at greatest risk of iron deficiency. For this group, median basal requirements are estimated by FAO and WHO to be between 8 and 25 mg/day, depending on bioavailability [99]. Obviously, if the higher figure is applicable in this case, then these Soviet diets are deficient in iron. Unfortunately, nothing is known about the bioavailability of iron in typical Soviet diets. However, in general it may be expected to be low because of the relatively low consumption of animal protein and, possibly, also because of the high frequency of consumption of substances that inhibit iron absorption such as phytate (in brown bread) and tannin (in tea).

The results for serum iron throw more light on this issue. The overall mean is very low in comparison with literature data, and many (roughly, one third) of the individual values fall in the range that would call for further clinical investigation of these subjects.

These data are therefore highly suggestive of at least marginal iron deficiency. However, since they are based on only a very small number of analyses, it would be imprudent to draw firm conclusions. Further studies would appear to be warranted, including the application of more definitive diagnostic tests (e.g. serum iron binding capacity and ferritin).

3.7.3.9. Zinc Nutrition

Zinc nutrition was not originally identified as a potential problem when this project was planned. However, it is of interest in view of the growing recognition, also shared by some Soviet nutritionists, of the fact that marginal zinc deficiency may be much more widespread than was formerly believed [100–102]. Some of the effects of marginal to mild zinc deficiency include growth retardation, mental lethargy, cell mediated immune dysfunction, rough skin and neurosensory changes. The functions of this element are many and diverse, as evidenced by the fact that over 200 enzymes have been identified that require zinc for their activity.

TABLE 77. Results of Zinc Analyses

Matrix	Region	Number of samples	Unit	Analysis of zinc samples		Comparator values	Analyst(s)
				Mean	SD		
Diet	All	34	mg/d	9.9	4.8	4.2–17.3[a]	FIN-1, IAEA-1/2/3 ITA-1
Plasma	All	32	mg/L	0.83	0.16	0.7–1.2[b]	SWE-1
Hair	All	31	μg/g	160	44	140–235[c]	UK-1

[a] Ref. [100].
[b] Ref. [101].
[c] Analyst's normal range for UK subjects.

Zinc may also function as a promotor of free radical scavenging, which may be significant in connection with resistance to radiation damage.

Some relevant zinc data for samples collected by Team 4 are summarized in Table 77. There were no significant differences between the three regions studied.

Results for dietary intakes are close to the lower end of the range observed in other countries. WHO has recently proposed [94] that the population mean normative requirement for zinc lies between 7 and 16 mg/day for adults, depending on bioavailability. Obviously, if the upper figure is applicable in this case, then these Soviet diets are deficient in zinc. As is the case for iron, nothing is known about the bioavailability of zinc from Soviet diets, but it would not be surprising if it were low enough to be causing problems with zinc nutrition. More suggestive evidence of marginal zinc deficiency is contained in the data for plasma zinc, which are low in comparison with literature data. (Levels of zinc in hair, on the other hand, are similar to values obtained in the UK. However, hair is probably not a good indicator tissue for zinc.)

It would be premature to draw firm conclusions from this study — except that further research is justified.

3.7.3.10. Selenium Nutrition

Selenium nutrition has attracted the interest of scientists and the public [94, 103, 104] in many countries in recent years, including the USSR. Its main known role is as a part of the enzyme glutathione peroxidase, which is one of the antioxidant defence systems of the body. As a free radical scavenger it has attracted some interest as a possible radioprotective agent. (The IAEA is currently supporting a research contract on this topic at the Institute of Biophysics in Moscow.)

Dietary intake of selenium varies by at least two orders of magnitude among different regions of the world. However, the only known disease associated with selenium deficiency is Keshan disease, a cardiomyopathy that affects mainly children and women of childbearing age in certain regions of China. Excessive intakes also occur in some population groups, leading to selenium intoxication [105]. Quite recently [106, 107], selenium has been identified as an essential component of the enzyme deiodinase, which catalyses the production of T3 in the thyroid gland. This raises the possibility that selenium may also play a role in thyroid disease and other symptoms of iodine deficiency.

It was therefore of interest to examine the levels of selenium in samples collected by the Project's nutritional team (Table 78). There are no significant differences between the three regions studied.

Dietary intakes are similar to those found in other western countries and are well within the safe range of population mean dietary intakes recently proposed by WHO (i.e. 40–400 μg/d for adults). Hair levels appear somewhat low, which is interesting in view of the fact that hair is now considered to be a reliable indicator tissue for selenium.

In general, however, these results would probably not merit further comment were it not for the fact that the blood analyses produced some unexpected findings, namely that the values varied widely and included some that are more than an order of magnitude greater than what would be expected. Analytical errors due to sample contamination before analysis usually are not expected for this element.

These results are isolated observations from one analytical laboratory; they still need independent confirmation. Nevertheless, the fact is worth noting here since there are reports that large numbers of selenium pills have been shipped to the region visited by the Project's teams. Information obtained from the Finnish company that acts as the sales agent is that in 1990 alone more than 40 million selenium pills (400 pills per bottle, 100 μg/ pill) were shipped to the USSR. The exact distribution of the pills was uncertain but they were supposed to have been sent to areas affected by the Chernobyl accident. It is tempting to postulate that the observed high blood selenium values (if confirmed) could have been due to self-medication with selenium supplements. If so, this could be a dangerous practice since it is easy to exceed the tolerable dose. Further information on this topic is being sought; meanwhile it would be premature to draw conclusions.

3.7.3.11. Other Elements of Nutritional Interest

Results for other elements became available as part of the programme of analysis of the duplicate diet specimens. Data for some of the more important of them (from the nutritional point of view) are presented in Table 79. In no case were there any significant differences between the three regions visited by the Project's nutritional team.

All of these values are within the normal ranges for other countries and, therefore, do not call for detailed comment — except possibly for the following point:

It is interesting to note that calcium intakes are relatively high, which does not lend support to the theory, voiced by some observers, that people living in the regions affected by Chernobyl may be voluntarily restricting their intake of milk products. (This comment, of course, only refers to the present and not to the time immediately following the accident.)

Results of the field trip questionnaires in both control and contaminated settlements corroborate this. The data are shown in Tables 80–83.

The graphic representation of these tables is given in Figs 90–93.

TABLE 78. Results of Selenium Analyses

Matrix	Region	Number of samples	Unit	Analysis of selenium samples		Comparator values	Analyst(s)
				Mean	SD		
Diet	All	34	μg/d	63	59	34–132[a]	IAEA-1, FIN-1
Hair	All	31	μg/g	0.78	0.46	0.8–2.5[b]	UK-1

[a] Ref. [96].
[b] Analyst's normal range for UK samples.

TABLE 79. Results of Analyses for Other Elements in Diet

Element	Region	Number of samples	Analysis of samples (mg/d)		Comparator values[a]	Analyst(s)
			Mean	SD		
Calcium	All	34	863	778	210–1650	IAEA-3, FIN-1
Copper	All	32	0.82	0.56	0.7–4.8	IAEA-2/3, FIN-1
Magnesium	All	34	270	131	120–500	IAEA-3, FIN-1
Manganese	All	34	3.3	2.5	1.8–8.4	IAEA-2/3, FIN-1
Phosphorus	All	34	1326	785	800–2010	IAEA-3, FIN-1
Potassium	All	34	3170	1910	500–4500	IAEA-2, FIN-1
Sodium	All	34	4670	2800	1900–5480	IAEA-2, FIN-1

[a] Ref. [100].

TABLE 80. Reply to Questionnaire: Did Your Children Drink Contaminated Milk Shortly After the Accident?

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Yes	99	53	121	68	220
No	88	47	58	32	146
Total	187	100	179	100	366

$p = 0.00543$.

TABLE 81. Reply to Questionnaire: Is the Milk Your Family Drinks Now Contaminated?

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Yes	117	50	117	53	234
No	119	50	104	47	223
Total	236	100	221	100	457

$p = 0.512$.

TABLE 82. Reply to Questionnaire: How Many Glasses of Milk Do Your Children Drink per Day Now?

Number of glasses	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
0	2	2	0	0	2
1	35	30	42	31	77
2	43	37	45	33	88
3	10	9	20	15	30
4	9	8	13	9	22
4–10	16	14	16	12	32
Total	115	100	136	100	251

$p = 0.413$.

TABLE 83. Reply to Questionnaire: Our Milk is Now Safe to Drink

Response	Contaminated areas		Control areas		Total
	Number	Per cent	Number	Per cent	
Agree	41	15	39	17	80
Not sure	111	42	142	60	253
Disagree	113	43	55	23	168
Total	265	100	236	100	501

p = 0.00.

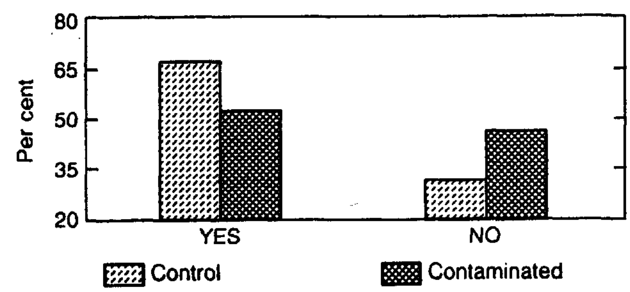


FIG. 90. Per cent of parents who felt that their children were drinking contaminated milk during 1986. p = 0.005, 30% missing.

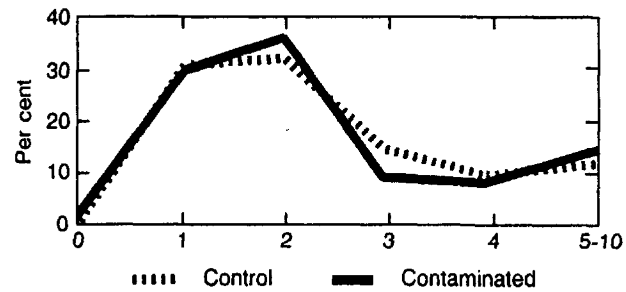


FIG. 93. Glasses of milk consumed per day by children in control and contaminated settlements in 1990. p = 0.413, 30% missing.

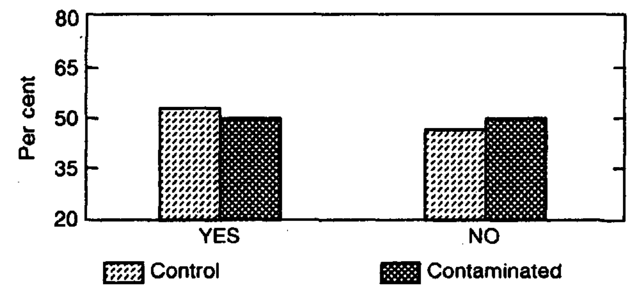


FIG. 91. Per cent of parents who felt that their children were drinking contaminated milk in 1990. p = 0.512, 10% missing.

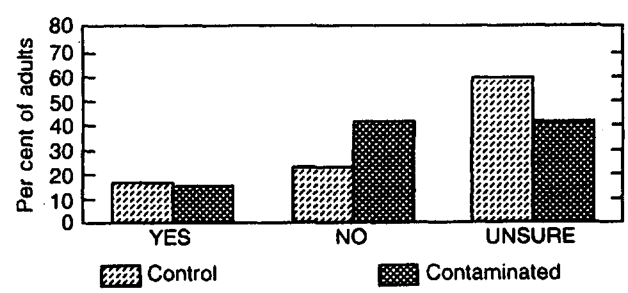


FIG. 92. Per cent of parents who felt that their milk was safe to drink in 1990. n = 501, p = 0.001.

Respondents were asked whether or not their children drank 'contaminated' milk during or shortly after the accident (Table 80). Overall, 60% said 'yes', but the percentage was higher in the uncontaminated (68%) than in the contaminated (53%) settlements. Both figures are high, but they are significantly different, and it must be presumed that recommendations in the contaminated areas had some effect.

It will be seen from Table 81 that in the current situation, 51%, a disturbingly high percentage, believes that the family milk supply is 'contaminated'. There is no difference between settlements in contaminated and uncontaminated areas. It could be argued either that official advice is not being complied with (in both of the areas) or that people do not trust the 'clean' imported milk. It should be noted that there is virtually no change in perceptions over time in the contaminated settlements and relatively little in the uncontaminated ones.

A similar picture is evident with respect to actual consumption rates. We asked "how many glasses of milk do your children drink per day" (Table 82). The norm is about 2 1/2 glasses and there is no difference between contaminated and control settlements. However, when asked to agree/disagree with the statement "our milk is now safe to drink", substantial differences emerged.

Only 16% agree overall, and this response is about the same in both areas. However, significantly more people from contaminated settlements 'disagree', while those from uncontaminated settlements have a high degree of uncertainty, that is, 60% replied 'not sure' (Table 83).

Given the evidence on milk contamination from Task 2, these data strongly reflect the general attitudes of uncertainty and mistrust of authority described in the previous section.

TABLE 84. Organic Microcontaminants in Human Milk (ng/g dry weight)

Compounds	Average	SD
HCB	0.69	0.22
Lindane	0.94	0.3
alpha-HCH	1.4	1.1
beta-HCH	160	110
delta-HCH	1.3	0.8
pp' DDE	240	160
pp' DDD	1.6	1.2
pp' DDT	44	30
op DDD	0.41	0.67
op DDT	0.65	0.61
DDMU	0.99	0.41
Heptachlor	0.2	0.1
Aldrin	—	—
Dieldrin	0.83	0.36
Endrin	1.6	1.7
alpha-endosulf.	0.49	—
beta-endosulf.	0.82	—
endosulf-sulf.	3.8	5.1
Aroclor 1254	33	10
Aroclor 1260	28	13
Total Aroclor	61	20
2,2'	1.8	0.33
2,3	1.8	0.62
2,4,2',5'	0.68	0.21
2,5,2',5'	2.1	0.84
2,4,5,2',3'	0.18	0.09
2,4,5,2',5'	2.0	1.0
2,3,4,2',4',5'	3.8	1.9
2,3,6,2',3',6'	0.1	0.1
2,4,5,2',4',5'	5.9	2.7

It also is interesting to observe that sodium intakes are high, which may reflect the fact that salt is commonly used as a food preservative. In any case, such values are sufficiently high to be considered a possible cause of hypertension in persons who are susceptible to this effect. (In the USA, for example, it has been suggested that approximately 20% of the population is susceptible to the effect of salt at levels of intake exceeding around 6 g salt per day [108]. The mean intake in the Soviet subjects was around 12 g salt per day, and, reportedly, hypertension is common in these regions. Elevated values of body mass index — as observed in this study (see Table 70) — are also reported to have an independent relationship with hypertension [109]. In other countries, high intakes of salt are associated with a high incidence of stomach cancer [110], and reportedly this is one of the most common forms of cancer in this part of the USSR. Salt nutrition may therefore be a topic that would merit further investigation in this population.

3.7.3.12. Organic Microcontaminants

Twelve specimens of human milk (7 from the Bragin region and 5 from the Ovruch region) were analysed for chlorinated pesticides. Measurements were made by the IAEA Monaco Laboratory (Marine Environment Laboratory) using capillary-ECD gas chromatography.

This study was conducted in response to the expressed concerns of several Soviet scientists that diets in the regions affected by Chernobyl might also reveal high levels of pesticide residues. Human milk is a good indicator of such contamination.

Average concentrations of various chlorinated pesticides in these samples are presented in Table 84. Comparison with other values reported in the scientific literature indicates that the Soviet values are in the same range for alpha-HCH, beta-HCH, lindane, pp' DDE and pp' DDT, and somewhat lower for total aroclors. Dietary intakes of infants consuming such milk would be far below the acceptable daily intakes specified by WHO and FAO.

3.7.4. Summary of Nutritional Issues

Evidence from Soviet sources points to the fact that food consumption in some of the affected areas decreased significantly during the months immediately following the accident, but has since then returned to former levels. These changes appear to have taken place without any lasting effects on physical health parameters.

At the time of the missions there were no apparent shortages in the overall supply of staple foodstuffs containing acceptable levels of radioactivity and in amounts sufficient to meet the major nutritional needs of the population (i.e. in terms of energy, protein, fat and carbohydrate). (Actually, one of the settlements, Rakitnoe, was without 'clean' supplies of milk during the time of the visit by the Project's team; however, this was said to be only a temporary problem.) There were also no significant differences in food consumption between the low and high radioactivity regions visited by the teams. Anthropometric data (heights and weights) do *not* suggest any problem of undernutrition in any age group; in fact, for adults, the opposite is more likely to be the case.

Nevertheless, there are a number of desirable nutritional goals that are not being met by some segments of the population. These problems apply equally to all the regions visited by the teams and are not related to the Chernobyl accident per se. They include a high frequency of occurrence of obesity in adults (probably also associated with a high frequency of hypertension); this could be partly genetic in character but is more likely to be caused by personal food habits including a high consumption of fatty foods. Very high intakes of salt were also noted which, in other countries, have been statistically related to hypertension and stomach cancer, both of which are common in these regions of the USSR.

Micronutrient deficiencies also appear to be common in these regions. A number of vitamin deficiencies have been noted by Soviet scientists (but were not studied by the Project teams). However, the Project's study (although based only on a very small number of observations) did reveal the occurrence of nutritional iodine deficiency as judged by current WHO criteria (which call for a population mean intake of 120–150 μg iodine per day for most adults). The practical significance of this finding remains uncertain in the light of the observation (by the medical team) that thyroid hormone levels appear to be unaffected; also, urinary excretion of iodine appeared to be within acceptable limits. Further clarification of this issue is recommended to investigate whether other, more subtle, iodine deficiency disorders — apart from goitre — may be present, particularly in the most susceptible segments of the population (pregnant women and children).

Other micronutrient deficiencies may also be present, e.g. of iron and zinc, though they could not be demonstrated unequivocally; however, some of the observed dietary intakes were sufficiently low to justify further research.

With regard to toxic elements in foodstuffs and in the environment, all the available evidence points to the fact that these are *not* a problem in the areas visited by the teams.

According to Soviet sources, dietary intervention efforts to overcome some of the micronutrient deficiencies noted above are already under way. These include the use of vitamin and mineral supplements. Although these may be justified in the short term, the Project team would — in the long term — prefer to encourage changes in food habits such that dietary goals could be met using only commonly available foodstuffs. To this end it would be desirable to increase the availability of fresh (or suitably conserved) fruits and vegetables during the winter and spring seasons. Changes in food habits to bring about a lower intake of salt and a reduced frequency of occurrence of obesity would also appear to be desirable nutritional goals.

Supplementation programmes (e.g. with vitamins and minerals) — insofar as they may be considered necessary — should in any case be accompanied by appropriate population monitoring, particularly of the main risk groups (e.g. children and pregnant women). The team noted the interest of some Soviet scientists in the idea of introducing selenium supplementation because of its alleged efficacy as a radioprotective agent. Further research would appear to be justified before starting an extensive public health programme. Caution is urged in view of the danger of exceeding the range of safe intakes (40–400 μg/day for adults) — especially if the comments in Section 3.6 are later confirmed indicating that some persons may already be engaging in self-medication.

The Project team also noted (though without collecting any of their own statistics on the subject) that dental hygiene is generally very poor and that dental caries is very common.

Poor nutrition can cause many health effects ranging from the relatively trivial (e.g. increased tiredness) to the serious (e.g. cancer). In view of the changing nutrition scene in the Soviet Union, it will be very difficult to distinguish between health effects caused by poor nutrition and those (if any) caused by radiation. In any case, it would be imprudent to mount a study of the possible effects of radiation in populations affected by the Chernobyl accident unless nutrition is also taken into account.

Irrespective of possible radiation effects, the nutritional status of persons living in the regions affected by Chernobyl is obviously an important issue which deserves continued monitoring and research by Soviet scientists. The Project team strongly recommends using modern analytical techniques; furthermore, it urges that appropriate quality assurance programmes be introduced so as to ensure the intercomparability of the results obtained. The findings of any such studies (including those already carried out) should be made available to the international nutritional community by prompt publication in peer reviewed scientific journals.

3.8. Radiation Induced Lenticular Opacities and Cataracts

3.8.1. Rationale

Radiation induced lenticular opacities and cataracts have been studied for decades [72]. There is no question that acute absorbed radiation doses in excess of 2 Gy to the lens of the eye can cause lenticular opacities. If these are extensive enough they may impair vision and result in a cataract. Such lenticular opacities and cataracts have been observed in workers at cyclotron facilities, after radiation accidents and in the survivors of Hiroshima and Nagasaki [111-116].

Most cataracts take several years to become apparent. As the absorbed dose increases the period to clinical presentation becomes shorter. Determination of the presence of a radiation cataract requires an examination of the lens of the eye for characteristic changes. A radiation cataract is generally defined as a central, posterior, subcapsular opacity, easily visible with a slit lamp biomicroscope or ophthalmoscope. Subtle radiation cataracts can be difficult to differentiate from normal variants in lens structure. Therefore an ophthalmologist experienced in radiation cataracts is needed.

The fact finding mission was told that there may have been an increase in cataracts. It was not clear whether what had been observed were, in fact, radiation cataracts, normal variants or increased detection of the normally occurring senile cataracts. The examination process is too complicated for rural field trips, so the plan was to review Soviet data and to bring a radiation cataract expert to examine specific patients that were identified by Soviet ophthalmologists.

3.8.2. Review of Official Data

3.8.2.1. UkrSSR

The Institute of Microsurgery of the Eye, Kiev, does 80% of all operations for cataracts in this region, and they have not seen an increase in the number of cataracts. It was felt[31] that at the doses and dose rates associated with living outside the 30 km zone, one would not expect any such changes in most people. Some unusual cases were seen in a few of the liquidators. Initially, when slit lamp examinations were done on the 1500 children in Polesskoe there were 14 cases of cataracts reported. When specialists came from Moscow only one case was proven and the others were felt to be normal variants.

3.8.2.2. BSSR

In Minsk the missions were told that there were concerns about radiation cataracts but the team did not see any actual data. It was agreed to contact the Institute of Radiation Medicine directly for a visit of a specialist to see patients of concern.

[31] Dr. T.S. Sergienko (Obninsk).

3.8.3. Results of Field Trips

A team ophthalmologist, who is a radiation cataract expert, examined six patients aged between 39 and 67 (five males, one female) with cataracts at the Hospital of Advanced Training for Physicians in Kiev. He felt that four were definitely senile cataracts but that the fifth case could possibly be a radiation cataract. This 39 year old male was a worker from the Chernobyl plant. He had also had an injury six years ago in his right eye and had a moderate post-traumatic cataract. The other eye had much milder changes localized at the posterior polar subcapsular region with polychromatic sheen. The sixth case had haziness at his embryonal nucleus, probably the result of congenital changes.

The same doctor also examined four patients (three children of ages 6, 4 and 1) who were residents of contaminated areas at the time of the accident, and a 35 year old male who was a worker from the Chernobyl plant. These were examined at the affiliated hospital of the Institute of Radiation Medicine in Minsk. He did not find any lenticular changes by slit lamp on these patients.

3.8.4. Summary of Radiation Cataract Issues

Some long term follow-up in some of the population in the contaminated areas should be considered. This should be done particularly in regard to persons who were infants at the time of the accident. The Hiroshima data show that infants are about two to five times more susceptible to cataract induction for the same absorbed dose. This extends up to about age 5.

The practical threshold for induction of obvious lenticular opacity is about 50 rem (0.5 Sv) of acute exposure. Thus, for infants, an acute absorbed dose to the lens of the eye of 10 rem (0.1 Sv) or more would be important. For a dose rate effectiveness reduction factor of two, this would then suggest that an absorbed dose to the lens of a child's eye in excess of 20 rem (0.2 Sv) may be important.

3.9. Malignant Neoplasms — General

3.9.1. Rationale

Many health effects of radiation are non-specific, that is, a given health effect cannot with certainty be attributed to radiation or another cause. In order to determine whether radiation has caused certain health effects it is necessary to compare age and sex matched exposed and non-exposed populations. If there is a statistically significant excess of a health effect in the exposed population, then there is a given probability that the effect is due to radiation.

Epidemiological studies may be done in either a prospective, a cross-sectional or a retrospective manner. All studies rely on a firm and well designed foundation of data collection and analysis. The most common use of epidemiological studies related to radiation induced health effects is to look for radiation induced neoplasms [50, 74, 117–120]. The spontaneous incidence of malignant neoplasms in most populations is about 20-30% [121]. Radiation is a relatively weak carcinogen and, unless epidemiological studies are carefully and accurately performed, the conclusions of such studies can be erroneous. Carefully controlled studies have clearly demonstrated an increased risk of benign and malignant tumours after radiation exposures [122–131].

There are many confounding difficulties that arise in radiation carcinogenesis studies. The increased risk of radiation induced neoplasms following radiation exposure is expressed over many decades [132]. During this time, there are likely to be changes in the age structure of the population, changes in exposure to other carcinogens as well as advances in detection and treatment of tumours. With these items in mind, it was important to examine current Soviet databases, registries and epidemiological studies that have been performed. Of particular interest were data relating to both leukaemia and thyroid cancer. The reason for this is that leukaemia risk occurs within several years after exposure. Thyroid cancer is of interest because of the avidity of the thyroid for iodine and the large amounts of radioiodine released during the Chernobyl accident.

In any epidemiological study it is important to know the relationship that other carcinogens might play in any effect relationship which is being observed. Information on smoking habits is crucial. Unfortunately, no reliable data in this regard could be located. The best estimate of the Institute of Biophysics is that about 70% of male workers at the Chernobyl plant and about 50% of the females smoke. In the settlements the estimates are that 80-90% of males and 15% of females smoke.

Another major problem in the design and completion of any epidemiological study is that cancer numbers in a given settlement or district are small and are therefore subject to large annual statistical fluctuations. As an example of this problem, official Ministry of Health data indicate that, for the Bragin area of BSSR, there were 12 cases of leukaemia in 1986, 8 in 1987 and 8 in 1988.

As one expands the population to be studied, another potential is that non-contaminated persons might be included unintentionally. The very non-uniform deposition of fallout contamination from the Chernobyl accident causes significant problems in assurance that only exposed persons are being included.

As mentioned earlier, there is likely to be a changing detection rate of tumours because of concerns relating to tumour induction by radiation and advancing technology. The effects of changing treatment regimens over time will be another confounding factor in any long term epidemiological studies.

3.9.2. Review of Official Data

3.9.2.1. UkrSSR

Cancer data in the UkrSSR are routinely collected by the Ministry of Health via a special cancer registration form which is completed in the local hospitals and oncology dispensaries. The information from local hospitals and dispensaries is sent to a special 'methodological department' in the oncology dispensary at the oblast (regional) level. All notifications to the methodological department are checked against hospital records, treatment records, etc. After this check, the data are sent to the Ministry of Health of the Republic, e.g. Kiev for the UkrSSR, and then on to the central Ministry of Health in Moscow. Until 1990 new cases of cancers were reported only for 11 cancer sites: mouth, esophagus, stomach, lung, larynx, rectum, skin, breast, uterus, lymphatic and haematopoietic system and 'all other cancers'. Overall, about 60–70% of the registered cases have histological diagnoses. Since 1989, the Ministry of Health has started to provide tabulations by age and sex and has increased the number of tumour sites registered.

AUSCRM[32] has population age trees of the UkrSSR and the affected regions constructed in 1979. Even at that time there was a greater percentage of older people in the contaminated areas than there were in other areas of the UkrSSR. At present, it is estimated that the population consists of about 40% retired persons in the contaminated regions (males over 60 and females over 55) as compared to about 20% in other areas of the UkrSSR.

With respect to the collection of cancer statistics, this has been a secondary concern of general physicians and surgeons. Thus, the statistics are undoubtedly underreported. Most persons die at home and not in hospitals. Death certificates do not need to be signed by a doctor and may be signed by a physician's assistant.

AUSCRM presented data on cancer incidence in the Narodichi, Polesskoe and Ovruch districts (141 000 population) as compared to the UkrSSR as a whole.

3.9.2.2. Registries and Collection

Obninsk (All-Union Distributed Register)

In Obninsk, there is a computerized register which contains age, sex, occupation and current clinic evalua-

[32] Dr. A.E. Prisyazhnyuk (Kiev).

tions of exposed persons. In general, persons evacuated or relocated do not go to the same location but are widely scattered over several Republics. The Obninsk register comes under the purview of the Ministry of Health. Some scientists in the Republics claim that their data are unique and do not send them to Obninsk. A greater problem is that the work is of such a large volume that there are not enough people to collect and analyse the data and to study all the areas.

As of May 1990, there were 531 000 persons registered. The register is supposed to contain information on persons who were either regular workers or decontamination workers at Chernobyl as well as the affected population. What 'affected population' means is not clear. Some scientists feel that the register should only include those persons with doses over 5 rem (50 mSv). Persons in the register are distributed as follows:

UkrSSR	46%
BSSR	28%
RSFSR	18%

For decontamination workers, cards are filled out either by the staff at Chernobyl power station (for persons on site), and by local clinics for decontamination workers who have returned home to other areas and who have had annual medical examinations.

The staff was able to produce data on the number of persons in the register who actually had an annual medical examination: 46% in 1986, 70% in 1987 and 71% in 1988.

The data are forwarded to the Ministry of Health of the Republic and placed on computer tape. The tapes are then forwarded to Obninsk where three copies of them are made. The original paperwork is destroyed after two years.

As of July 1990, about 70% of persons have had their doses estimated. There are attempts being made to validate the data. As of July 1990, limited data were accessible for retrieval. There was no computer network, so that persons other than the staff at Obninsk could not have direct access to the data.

The register represents a non-representative mixture of populations.

These populations include:

(1) Persons engaged in decontamination (about 200 000);
(2) Populations evacuated from around the plant;
(3) Children born to persons in the above two groups.

About three-quarters of those in the registry live in the UkrSSR or BSSR; 16% of these are children.

Since the population in the register is not representative of that in the Republics as a whole, one cannot easily compare cancer incidence data from this register with data or registers from the Republics. The age, sex and social factors of the population groups are different, as are the methods of data collection and validation in the various registers.

As an example, the age distribution in the register at Obninsk contains 16.4% children, 5.3% adolescents and 78.3% adults. In terms of age distribution 88% of persons in the register are between 25 and 45 years of age.

Moscow

A doctor[33] at Hospital 6, Institute of Biophysics of the Ministry of Health of the USSR, described a register of 40 000 workers who were involved in mitigation efforts at Chernobyl but who also work at nuclear plants elsewhere. These data are prepared in local hospitals and sent to Hospital 6. Seventy-eight per cent of the registrants are male. Thirty per cent are professionals. The annual mortality rate for 1988 of 2.2 per 1000 is lower than the mortality rate of 6.7 per 1000 for the comparable age group from the general public in the USSR, possibly reflecting incomplete ascertainment, a healthy worker effect, etc.

UkrSSR

In the UkrSSR, cancer data are collected, although not by means of a tumour registry as such. Persons must be seen at regular medical examinations in order to be included in the Republic Ministry of Health data collection process.

Four special registers of children maintained at AUSCRM were described[34]. None of these data are passed on to Obninsk since it is for 'research only' purposes. The contents of these registers are as follows:

(1) The 33 000 children living in control regions in the Narodichi, Ovruch, Polesskoe and Ivankov districts.
(2) 5100 children who are designated for special follow-up with estimated thyroid doses of over 2 Gy. It was stated that 47% of these children now live outside of controlled areas. The only map that they had of radioiodine deposition was one with isodose contours of external gamma measurements.
(3) At least 6000 children who were evacuated from the 30 km zone. There were probably at least 20 000 children evacuated from the 30 km zone so that this register is incomplete. There is probably an overlap among the registers with children from (1) or (3) appearing in (2) as well.

[33] Dr. A.R. Tukov.

[34] Dr. V.N. Bugaev.

(4) The children born to parents who received more than 0.25 Gy. These are mostly children of Ukrainian decontamination workers (989 children). The 15 children of survivors of the acute radiation syndrome are also included.

BSSR

Data obtained at the clinic facility of the Institute of Radiation Medicine (Minsk) are sent back to the local physicians who are supposed to send them on their way to the Obninsk registry if needed. This may be a problem in getting data into the registry.

The epidemiologist of the Institute of Oncology of the Ministry of Health of the BSSR (Minsk)[35] indicated that the register of oncologic diseases is 'obligatory'. They were beginning to automate the registry in 1990. The data on incidence or morbidity of cancer come directly to them from outlying dispensaries. There are usually more than one or two such dispensaries in each region. Since 1979 reported data have been formatted by age (five year intervals) and sex as well as by ICD and MKS 9 codes.

As in the UkrSSR, a physician's assistant can sign death certificates. This, in addition to the fact that many patients die at home, makes mortality data unreliable. Since this is known, they report only incidence data. They do not have data regarding the sex or age distribution in the regions. Therefore, results are reported as incidence per 100 000 total population rather than by age and sex.

The head of the Epidemiology of Non-Infectious Disease Institute of Radiation Medicine[36] (Minsk), began a health data collection programme in 1987. His group has been trying retrospectively to collect the data on health from 1979 to 1987. Included are disease categories such as cardiovascular, pulmonary, ENT, gastrointestinal and diabetes. They are looking at morbidity data from hospital reporting. Each time a patient comes to a hospital with a disease it is recorded as a visit for that year for that type of disease. It was not clear how a person with a single disease and multiple visits in a year or a person with multiple diseases and one visit in a year was recorded.

They have reported an increase in many of these diseases but did not know whether this was due to more frequent visits to clinics (due to radiation concerns) than would normally be the case, to increased sensitivity and detection by physicians or to other causes. In the examination of the incidence data for diseases in a certain region, there were years where there was a sudden increase in the recording of a certain disease entity (often by a factor of four or so) that disappeared the next year. This was explained as being due to visits to that region in that year by a team of specialists who always diagnosed more diseases in their specialty than were reported before or since.

RSFSR

No information was available.

3.10. Leukaemia

3.10.1. Rationale

The risks of acute leukaemia and of chronic myeloid leukaemia are increased by irradiation of the bone marrow. The excess risk is largest between 5–15 years after exposure. The magnitude of the excess risk increases with absorbed dose. Age at exposure is important and it is clear that risks are initially higher for those exposed when under the age of 20. The risk, however, decreases more rapidly with time as compared to those exposed at older ages [133–137].

UNSCEAR (1988) [74] estimated the risk of leukaemia (except chronic lymphocytic leukaemia (CLL)) as 9.7 excess lifetime mortality for 1000 persons exposed to 1 Gy organ dose of low linear energy transfer (low-LET) radiation at a high dose rate.

As mentioned earlier, data on the incidence of leukaemia are difficult to find, since in most areas the data were collected under a combined category of 'leukaemia/haematopoietic cancers'. Thus, most data include lymphomas and other neoplasms as well as leukaemia.

Even when leukaemia data are available, the small numbers in any given area are a statistical difficulty as was also pointed out earlier. Knowledge of the cell type of the leukaemia is crucial since chronic lymphocytic leukaemias are not considered to be radiation induced. As an example, in the Bragin area of BSSR in 1988 there were 14 cases listed in the 'leukaemia/haematopoietic' cancer category; of these, eight were leukaemias, of which six were CLL. Thus of the original 14 cases listed in the category only two cases (or less than 20%) are of interest with respect to radiation induced leukaemia.

3.10.2. Review of Official Data

3.10.2.1. UkrSSR

AUSCRM[37] indicated that they currently were looking for leukaemia by examination of risk groups identified by markers of HLA. There is collaborative work[38]

[35] Dr. A.E. Okeanov.

[36] Dr. A. Moshik.

[37] Dr. V.G. Bebeshko.

[38] Professor Gluzman.

TABLE 85. Incidence of Lymphatic/Haematopoietic Cancer in Three Contaminated Regions of the UkrSSR

Year	Rate of incidence per 100 000 persons		
	In three contaminated regions		Rate in entire UkrSSR
	Rate	Number of cases	
1980	4.9	8	11.0
1981	5.6	9	12.0
1982	13.3	21	12.1
1983	11.5	18	12.5
1984	12.4	19	12.6
1985	8.6	13	13.4
1986	10.1	16	13.0
1987	16.6	24	14.1
1988	16.4	23	15.0
1989	15.8	22	15.0

on these problems. They do have data on the contaminated areas and the leukaemia incidence is not yet raised. As an example, in the Kiev region there were between 34 and 46 cases per year with no evidence of an increasing trend. All cases are verified by bone marrow aspiration and verification at the Haematology Institute. Seventy per cent of these cases are acute myelogenous leukaemia (AML). The number of children in the region is 590 000.

Another AUSCRM scientist[39] stated that there was no increase in leukaemia in young children since the accident. In the Kiev district in 1989, 57% of the cases in the lymphatic/haematopoietic cancer category were leukaemia. A special study of three contaminated regions was performed by this scientist. The incidence rates for the combined lymphatic/haematopoietic cancer category are shown in Table 85.

Other data on the actual number of cases of leukaemia/haematopoietic cancers in contaminated districts of the UkrSSR obtained from the Ministry of Health of the UkrSSR are as follows:

District	1985	1986	1987	1988	1989
Polesskoe	—	—	—	1	1
Ivankov	—	—	—	—	1
Ovruch	2	2	1	2	2
Narodichi	—	—	—	—	1

[39] Dr. A.E. Prisyazhnyuk.

For the year 1989 there are even fewer reported cancers in the Ministry of Health data. Presumably, this is due to incomplete reporting.

The incidence of lymphatic and haematopoietic cancers per 100 000 reported in the Obninsk register was

19	(1987)	69 cases
25	(1988)	90 cases

Comparable data are for

All UkrSSR[40]

12.1	(1982)
15	(1989)

Ovruch, Narodichi and Polesskoe (UkrSSR)

13.3	(1982)
17.8	(1989)

All BSSR[41]

15.8	(1989)

Thus, regarding the combined leukaemia/haematopoietic cancer category, the Obninsk register contains higher incidence data than any other data set given to the Project teams. This presumably is due either to biased reporting or to the inclusion of a different age population

[40] Dr. A.E. Prisyazhnyuk (Kiev).
[41] Dr. A.E. Okeanov (Minsk).

TABLE 86. Incidence of Thyroid Conditions in the Population of the Marshall Islands Exposed to Fallout

Population group	Age at exposure	Number of people	Dose (Gy)	Incidence (%) of		
				Hyperthyroid	Nodules	Thyroid cancer
Rongelap atoll	1	6	>15	83	67	0
	2–9	16	8–15	25	25	6
	10 and >	45	3.4–8	9	13	7
Alinganae atoll	<10	7	2.8–4.5	0	29	0
	10 and >	12	1.4–1.9	8	33	0
Controls	<0	229	0	0.4	2.6	0.9
	10 and >	371	0	0.3	7.8	0.8

in their register. The 1989 data for UkrSSR and BSSR are similar to those reported in eastern Europe (15.8 for the German Democratic Republic, 7.1 for Hungary, 15.4 for the city of Cracow in Poland).

3.10.2.2. BSSR

An epidemiologist in Gomel reported that the number of cases of leukaemia in the BSSR were approximately 42 in 1980, 67 in 1983 and 43 in 1988.

A cancer registry was established[42] in the BSSR in 1975. The incidence of cancers of the lymphatic and haematopoietic system (combined) in the entire BSSR has increased from 11.4 per 100 000 in 1985 to 15.8 in 1989. The increase from 1985 to 1989 was more marked in rural areas (11.4 to 17.9 per 100 000) than in urban areas (11.4 to 14.8 per 100 000).

3.10.2.3. RSFSR

No increase in leukaemia was reported for contaminated regions during the period 1986–1989[43].

3.10.3. Summary of Leukaemia Issues

The data that were reviewed do not support contentions that there has been a clear and major increase in the incidence of leukaemia in the contaminated regions. On the other hand, because of the reporting methodology used to collect the data, the fact that a small but significant increase in leukaemia might be present, but remain undetected, cannot be excluded.

A large part of this uncertainty is due to the fact that leukaemias have been lumped in the 'leukaemia/haematopoietic cancer' category and that this category includes many tumour types other than leukaemia. In addition, information concerning the cell type of a leukaemia is vital for analysis. This is necessary since chronic lymphocytic leukaemias are not felt to be radiation induced. Information regarding subcategories of leukaemia were not available for most of the cases.

3.11. Thyroid Neoplasms

3.11.1. Rationale

During the Chernobyl accident, a large amount of radioactive iodine was released into the environment. The incidence of both thyroid carcinoma and thyroid nodules has been observed to be increased in a number of irradiated populations [50–54, 138–142].

Inhabitants of the Marshall Islands were exposed to fallout from the Bravo thermonuclear bomb test in 1954. Thyroid exposure was from external gamma radiation as well as from inhaled and ingested radioiodines. Doses from the short lived radioiodines (^{132}I, ^{133}I and ^{135}I) were assumed to be two to three times that from ^{131}I. The first case of hypothyroidism was seen at eight years post-exposure and the first thyroid tumour was detected in a young girl nine years post-exposure. Although the dose estimation is open to some question, at 27 years post-exposure, the per cent of occurrence of hypothyroidism and other conditions are shown in Table 86.

This and other studies show clearly that there are long term effects of radioiodine absorption. The Marshall Island experience and data are complicated by several factors which will complicate the future evaluation of the Chernobyl accident. The first of these is the occurrence of the 'occult thyroid cancer'. This appears to be present in up to 10% of thyroid glands but is considered to be biologically benign and insignificant. Generally, this type of tumour is excluded from analysis, but excellent

[42] Dr. A.E. Okeanov (Minsk).
[43] Dr. P.V. Ramzaev (Leningrad).

thyroid pathology expertise is essential in making the differentiation from other forms of thyroid cancer.

Note should be made that there are careful follow-up studies which have been done on patients who were given diagnostic doses of ^{131}I. In these studies no increased incidence of thyroid cancer has been found. Under these circumstances it is possible that the effect of internal ^{131}I is substantially less effective than the same dose from external radiation. This may be the result of dose rate or spatial distribution factors.

It is clear that thyroid nodule formation as well as cancer induction is a delayed effect of radiation exposure and is rarely if ever seen in the first five years following exposure. Experience from previous studies indicates that it is necessary to continue observations for decades.

The following generalizations can be made from the literature. Susceptibility to radiation induced thyroid cancer is greatest when exposure occurs in childhood. In those exposed before puberty, however, the tumours usually do not become apparent until after sexual maturation. Females are two to three times more susceptible to both naturally occurring as well as radiation induced thyroid cancer. The same is true for the development of thyroid nodules. The frequency of hypothyroidism and simple goitre is increased in those receiving large absorbed thyroid doses when young. The type of thyroid cancer usually induced by radiation is of the papillary variety. Hormonal stimulation of the thyroid gland is felt to increase the risk of neoplasia [143].

UNSCEAR (1988) [118] has indicated that only about 5–10% of radiation induced thyroid cancers are fatal.

3.11.2. Review of Official Data

3.11.2.1. UkrSSR

It was reported[44] that of five cases of thyroid tumours which occurred in the UkrSSR since the accident in contaminated regions only one has been pathologically verified as a true cancer.

Scientists at AUSCRM in Kiev reported that four cases of thyroid cancer have occurred in regions of contamination since the accident. Two of these were unusual in that they were apparently undifferentiated carcinomas (which are not usually radiation related). As of 1989, it was indicated[45] that no change was detected in the incidence of hypothyroidism or of thyroid cancer. As of October 1990, there had been ten reported cases of thyroid cancer, five cases in the UkrSSR regions and five in BSSR. There is an uncertainty about which slides were reviewed in Moscow but it was felt that they were not the ones from the UkrSSR. Apparently, work on verification of the thyroid tumours was being done[46] in the UkrSSR. Slides for five of these cases are located at the Institute of Endocrinology.

Scientists at AUSCRM reported that there were 17 cases of thyroid cancer in the period 1980–1989 in the three contaminated districts. The average incidence rate for thyroid cancer was 1.1 per 100 000 per year. The youngest case before 1990 was 18 years old. In the first six months of 1990 there were reports of five new cases of thyroid cancer, including two in children aged under ten years. It is unclear whether these diagnoses had been subjected to histological review. No comparable data on thyroid cancer incidence are available for the rest of the UkrSSR. In the three contaminated districts rates per 100 000 persons were as follows:

1985	0.8	(1 case)
1986	0.8	(1 case)
1987	2.3	(3 cases)
1988	2.4	(3 cases)
1989	0.0	(0 case)
1990	4.5	(6 months only, 5 cases)

By the end of 1990, there were 20 verified cases of thyroid cancer in children of the UkrSSR. Eleven of these were from non-contaminated settlements.

3.11.2.2. BSSR

Physicians in Gomel reported that there had been two cases of thyroid tumour in children in this region although the time of occurrence and the baseline rate were not available.

No data on the incidence of thyroid nodules in either the exposed or unexposed populations in the USSR were found by the missions.

3.11.3. Summary of Thyroid Neoplasms

As is the situation with leukaemia, it was concluded from the data that were reviewed on thyroid cancer that there is no clear pathologically documented evidence of an increase in thyroid cancer of the types known to be radiation related. The method of data collection whereby thyroid cancer has been included with the 'all other cancers' category makes it extremely difficult to ascertain what the true baseline incidence rates are. Most of the reports of thyroid cancer were anecdotal in nature with little evidence relative to the population size and age composition from which the cases were derived.

In a similar fashion, the nature of the data makes it difficult or impossible to exclude the fact that there may be an increase in thyroid cancers. One is left with the fact that thyroid cancers which have occurred in other

[44] Dr. Rumyantsev (Moscow).

[45] Dr. A.K. Cheban (Kiev).

[46] Professor N.D. Tron'ko (Kiev).

exposed populations have not occurred within five to ten years of exposure and have been of rather specific cell types. At this point, collection and review of all the pathological slides of thyroid cancer cases that have been or are reported would be recommended. With the large release of radioiodine during the accident, it is expected that there will be a radiogenic excess of thyroid cancer cases in the decades to come. This risk relates to thyroid doses received in the first months after the accident and it will not be significantly altered by later relocation to non-contaminated areas.

The incidence of thyroid cancer needs to be considered in relation to possible endemic goitre regions. While in some goitre regions a high incidence of thyroid cancer has been found, other countries that have been known to be virtually goitre free report even higher figures for thyroid cancer. A number of histological patterns may occur in thyroid tumours and the pattern may also vary widely from one histologic section to another. Treatment with antithyroid drugs can produce histologic patterns in benign goitres which the pathologist may classify as malignant. Accordingly, the diagnosis of a thyroid tumour by most conventional methods is difficult in an endemic goitre region. Fortunately, endemic goitre does not appear to be a major problem in the region around Chernobyl.

An item that has been and will continue to be a problem is the method of detection, definition and treatment of a 'thyroid nodule'. Many of the early studies relied upon physical examination and counted only nodules that were estimated to be 1 cm or more in diameter. With the use of ultrasound, structural abnormalities that are smaller and deep within the gland can be detected. Because of a need for consistency, only abnormalities of 0.5 cm or more are usually recorded. Whether these are significant and how such abnormalities should be treated remains open to question. In any case, it is unreasonable to try to biopsy every structural thyroid abnormality that is found by ultrasound since the vast majority will be benign, even in a population exposed to radioiodine.

3.12. Other Neoplasms

3.12.1. Rationale

An increased incidence of cancer in humans following exposure to ionizing radiation has been observed for almost a century. During the last decade there have been many reports summarizing the nature of the relationship. Unfortunately, tumours induced by radiation are not of a unique cell type and therefore cannot be pathologically distinguished from spontaneously occurring tumours. The most recent international report on radiation carcinogenesis is the 1988 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) entitled "Sources, Effects and Risks of Ionizing Radiation" [118]. In this report the projection for excess lifetime mortality was 71 per 1000 persons exposed to 1 Gy of low-LET radiation at high dose rate. If the dose rate is low the risk is probably half of this.

Not all organs are equally sensitive to radiation induced carcinogenesis. Organs such as the lung, stomach, bone marrow, colon and breast are relatively sensitive (in descending order, respectively). For some organs there appears to be little or no risk for tumour induction by radiation (such as pancreas, uterus and chronic lymphocytic leukaemia). For tumours typically occurring in the adult, there is a latency period of ten years or more between radiation exposure and the time when the tumours become clinically apparent. Exceptions to this are the leukaemias and bone cancers which have minimum latent periods of two to five years.

Most physicians and members of both the press and the public know that there is a relationship between cancer and radiation exposure. The specific nature of that relationship is not clear to most people. It is clear that the public around Chernobyl has been subjected via the media to either a number of claims regarding a marked increase in cancers in the exposed population or in a few cases claims of no increase in cancers. Interestingly enough, the comments and perceptions of scientists, physicians and other persons who were contacted in the several settlements were not uniform in their opinions as to whether there indeed had been an increase in cancers and, if so, what types of cancers.

For example, on Mission 1, physicians in the Bragin area reported that there was no increase in incidence of cancer since the accident. On the other hand, in Ovruch, there were reported increases in gastric carcinoma, leukaemia and lymphoma.

It was felt by the Health Effects Team that it would be important to locate and assess whatever information exists in regard to the incidence of neoplasms both in the contaminated and non-contaminated regions of the three Republics.

3.12.2. Review of Official Data

3.12.2.1. UkrSSR

It was reported[47] that in the contaminated areas of the UkrSSR the leading cancers in males are, primarily, stomach and, secondarily, lung. In the remainder of the UkrSSR the common cancers, in descending order, are lung, skin and stomach. The age adjusted rates of cancer in the UkrSSR prior to and after 1980 were about 300/100 000 for males and 200/100 000 for females.

[47, 48] Dr. A.E. Prisyazhnyuk (Kiev).

The most common cancers in women are cervix, skin and breast, in that order. It was also indicated that the number of genital cancers is higher in the areas of Polesskoe than in surrounding areas, but that this situation also existed prior to the accident.

Data on time trends and regional variations in the 11 cancers which were routinely reported to the Ministry of Health in the UkrSSR from 1980-89 were also presented. In general, the incidence of all cancers increased (from about 250 per 100 000 to 300 per 100 000), due at least in part to the aging of the population (the average age at cancer registration increased from 61 in 1981 to 65 in 1989). Unfortunately, the data which were shown could not be standardized by age. Part of the increase in cancers as a whole was due to a large increase in lung cancer. There is a clear geographical variation in lung cancer within the UkrSSR; it is most common in urban areas and least common in rural areas, especially in the north where the Chernobyl plant is located. Earlier diagnosis and increased detection also may be a reason for the increase in reported rates. Cancers diagnosed in 1989 were at an earlier stage than in 1980 (42% at stages I or II compared to 30% in 1980).

There was a report of a study which was conducted[48] in three of the most contaminated districts of the UkrSSR (Narodichi, Ovruch and Polesskoe), with a total population of 100 000 in 1980 and 140 000 in 1989. Data for this Soviet study were obtained from original hospital and oncology records and as a result of a search of all records, including death certificates for information on new cases of cancer. Thus, it was possible to collect data for more diagnostic categories than those used by the Ministry of Health; this made it possible to separate out thyroid cancer and leukaemia from other cancers. Of the cancers that were identified, 60-70% were histologically verified.

The study compared the collected information on cancer in the three districts with those reported to the Ministry of Health for the same area. The estimates of completeness of the Ministry of Health records was 80% in 1980 and increased each year to attain 95% in 1988. Obviously, more complete records would appear as an increase in cancers even if there had been no actual increase. The trend for all cancers in these three contaminated regions was generally similar to that for the UkrSSR as a whole.

3.12.2.2. BSSR

In Korma, physicians reported that they were worried about the long term risk of radiation exposure and about a rise in oncologic diseases seen in farmers, particularly in throat, lung, stomach, and liver cancers. No exact numbers or data for any particular year were available.

In Gomel, epidemiologists indicated that in 1988 there was an increase in the number of difficult cancer cases. This apparently meant that cancers which were identified were of a much more advanced stage than normal, and they attribute this to the fact that the population was less inclined to have any X ray examination for diagnosis following the accident. This experience was different than reported elsewhere.

Major cancers for men in BSSR are lung and stomach cancer. This varies from region to region by a factor of about two. Cancer data by region (incidence per 100 000) have increased in every region of the BSSR from 1976-80, 1981-85 and 1986-89. There is not a single number that had decreased or remained stable in the years before or following the Chernobyl accident. Soviet scientists felt that this was due to reporting of in situ and precancerous lesions, to increased detection, to an increase in non-radioactive environmental pollutants, etc.

Unfortunately, the data on leukaemia were combined by age (children and adults) as well as with other tumours (leukaemia and lymphomas). There is a limited verification programme which indicates that about 15% of the diagnoses require correction.

3.12.2.3. Obninsk

Preliminary data obtained from the computer at Obninsk were as follows:

All cancers rate/100 000

Obninsk registry	136	(1987)	471 total cases
	153	(1988)	542 total cases

These numbers are lower than those reported in the Republics, possibly secondary to inclusion of the relatively young group of decontamination workers in the Obninsk registry. Another possibility is underreporting.

Data obtained for similar rates obtained from the Republics and AUSCRM are as follows:

Polesskoe	200	(1981)
	280	(1989)
Narodichi	280	(1981)
	320	(1989)

Official Soviet Ministry of Health data in five contaminated regions by year are shown in Table 87.

3.12.3. Summary and Recommendations on Epidemiology

There is an increasing incidence of cancers over the last decade. This increasing trend was present before the

TABLE 87. Incidence of Malignant Neoplasms (Data from USSR Ministry of Health)

Region	Neoplasm	Incidence per 100 000 population				
		1985	1986	1987	1988	1989
Gomel	Lymphatic/haematopoietic	9.8	11.3	12.3	14.8	13.1
	Total malignancy incidence	996	1052	1123	1184	
Mogilev	Lymphatic/haematopoietic	9.8	11.3	12.3	13.6	
	Total malignancy incidence	1046	1077	1124	1142	
All BSSR	Lymphatic/haematopoietic				—	
	Total malignancy incidence				1031	
Bryansk	Lymphatic/haematopoietic	10.3	10.8	10.2	13.1	
	Total malignancy incidence	1323	1394	1419	1432	
All RSFSR	Lymphatic/haematopoietic				11.0	
	Total malignancy incidence				1024	
Kiev	Lymphatic/haematopoietic	10.7	10.8	12.9	14.0	16.0
	Total malignancy incidence	1253	1316	1293	1337	
Zhitomir	Lymphatic/haematopoietic	12.5	12.6	13.5	17.0	18.2
	Total malignancy incidence	1175	1296	1362	1419	
All UkrSSR	Lymphatic/haematopoietic				13.9	
	Total malignancy incidence				1344	

accident and has continued since. Leukaemia (which is a neoplasm that can be radiation induced and may be seen within several years of exposure) has not definitely increased, on the basis of the data which were reviewed. On the other hand, the collection methods and methodology are not adequate to exclude the possibility that a small number of radiation induced cases might have occurred. Until leukaemias per se are recorded in the databases as a specific disease category, and by specific cell type, it will not be possible to determine whether there has been an increase in leukaemia.

Similar statements can be made on the occurrence of thyroid cancers. The data collection methods (particularly grouping thyroid cancers in the 'other' category of cancers) make it difficult to determine whether there has been an increase in this tumour. Most of the reports are anecdotal in nature, and the concurrence verification by a group of well trained thyroid pathologists is lacking. There are some difficulties with the concept of an increase in thyroid cancers at this time. If true, however, the latent period for radiation induced thyroid tumours around Chernobyl has been shorter than in all other radiation exposure situations such as in the Marshall Islands or Japan. In addition, a large percentage of the thyroid tumours reported in the Republics were of the non-papillary or non-follicular varieties; this again is unusual after radiation exposure and should prompt a thorough review of the pathological specimens by a group of experienced thyroid pathologists. Such a review is necessary because thyroid pathology is noted for being extremely difficult.

The team noted that comparison of data from different registers is not likely to be very useful since the data collection methods, verification, completeness of records, age/sex structure, and social habits of persons in the various registers are different. A uniform methodology utilized by dedicated tumour registries in the Republics would be very useful. Unfortunately, it will be difficult, if not impossible, to retrospectively collect such data in a uniform fashion. It is also clear that there are scientists making great efforts and collecting data which they are not willing to share with each other. Whether this can be remedied in the future remains to be seen.

The team felt that it would be useful for the USSR to specifically train epidemiologists, perhaps at the International Agency for Research on Cancer (IARC) in Lyons or elsewhere. It may also be useful to have their cancer registry directors visit IARC Lyons and other cancer registries. Too many epidemiological studies or outcomes examined will dilute efforts and available resources so that all results may be questionable. All studies undertaken should be focused and the testing methodology should be clearly defined.

3.13. Foetal and Genetic Issues

3.13.1. Rationale

Experience with atomic bomb survivors as well as with untoward effects of therapeutic radiation have clearly demonstrated that there are effects of in-utero radiation [144–152]. Somatic effects that have been described in humans are microcephaly, mental retardation and decreased intelligence [148–152]. These effects are probably the result of altered neuronal migration and are most prominent during 8–16 weeks estimated foetal gestational age. Before this period effects appear to be limited to a possible increase in the spontaneous abortion rate. After 16 weeks the main adverse health potential effect of in utero radiation at foetal dose levels of less than 1 Gy is radiation carcinogenesis [153–157].

The detrimental effects of radiation on the development of the foetal central nervous system have not been clearly demonstrated at foetal absorbed doses of less than 0.1 Gy. It appears that in most of the population residing outside the 30 km zone at Chernobyl, foetal doses that may have been incurred during gestation were considerably less than 0.1 Gy, and thus in utero effects of radiation exposure should be unlikely [158].

There are, however, other issues related to the accident that could have affected the outcomes of pregnancy in different ways. Nutritional considerations and stress are of prime importance during pregnancy. Dietary iron, calcium and vitamin requirements are considerably higher than usual during pregnancy. In a population in which the nutrition may have been marginal before the Chernobyl accident, it is possible that the accident may have caused additional problems. In addition, the amount of alcohol consumed by women in these regions is unknown. It is known that smoking can lead to lower birth weight. Thus, in an evaluation of any potential radiation foetal effects that might be found there also needs to be evaluation of such factors as maternal nutrition, anaemia, stress, cigarette smoking, foetal alcohol syndrome, etc.

Long term studies of genetic effects have been conducted in Japan not only on the atomic bomb survivors but also on their first and second generation offspring. Very few, if any, effects have been seen and the genetic effects of radiation appear to be less significant than the possible long term carcinogenic effects [159–165].

Nevertheless, many people are very concerned about the possible foetal and genetic effects of radiation. Most people we spoke with and many media staff are not aware of the normal rate of genetic and spontaneous abnormalities in populations. Typically, about 3–5% of births in most populations around the world demonstrate an obvious congenital abnormality [166–168]. It is this normal spontaneous incidence which complicates any epidemiological study to look for radiation related foetal and genetic effects. There also is a documented higher than normal chromosome anomaly frequency in spontaneous abortions or in non-irradiated infants dying during the perinatal period [169–171]. Confounding factors that occur in epidemiological studies of this nature in the USSR were mentioned[49]. These included a decreasing birth rate and better care of the pre- and postnatal period since the accident. As a result, overall infant mortality had gone down but the percentage of malformations had gone up. This was felt to be secondary to elimination of some of the infectious deaths. Under these circumstances, expression of data either in terms of percentage or by number of cases alone would be misleading.

Because of the known abnormalities that can be induced by high foetal absorbed radiation doses, it was felt to be important to locate and critically examine existing Soviet data in this area.

3.13.2. Review of Official Data

3.13.2.1. UkrSSR

Physicians in Ovruch reported a negative birth rate which they felt was due to an aging of the population as well as to the migration of younger persons out of the area. They also reported a decrease in the weight of newborns in 1987. The child death rate in this settlement was stated to be stable since the accident.

Childhood diseases and malformations (as defined by obvious problems easily seen by any doctor) in control and affected areas were compared[50] and the same incidence rates were found in both places. There was an increase in diseases of the lungs and gastrointestinal complaints but no increase in cardiac problems. The analysis covered the years 1983–1988 in the Narodichi district. The average weight of newborns was between 2.5 and 4.5 kg. The number of births decreased in 1986 and 1987 but increased again in 1988 and 1989.

Malformations were assessed by a review of data submitted by the hospitals; these have varied between 2 and 10 per year and included Down's syndrome. Five per cent of the mothers are over the age of 40.

[49] Dr. Koshel (Moscow).

[50] Dr. E.I. Stepanova (Kiev).

TABLE 88. Birth Weight and Length of Babies Born in Narodichi (Soviet Data)

	1985	1986	1987	1988
Weight (g)[a]	3470 (76)	3272 (75)	3338 (73)	3298 (60)
Length (cm)	51	52	53	52

[a] Standard deviation in parentheses.

Malformations by calendar year in the Narodichi district were reported as:

1986	1
1987	3
1988	3
1989	6
1990	1 (in the first five months)

In addition, size and weight data on children born in Narodichi during the years 1985–1988 were presented. The results are shown in Table 88.

The Kiev Institute of Obstetrics, Gynecology and Paediatrics[51] studied the 533 pregnant women who were evacuated from the 30 km zone at the time of the accident. Since June of 1987 they have also been studying the outcomes of pregnancies occurring in the contaminated zones, and the Institute reportedly has a data bank on over 14 000 births. Obstetrical teams regularly travel to these regions. Their data were from the Narodichi and Polesskoe areas and included data from Yagatin as a control area. There was reported to be a general tendency to decreasing birth rate all over the Soviet Union and in the areas studied as well.

The birth rate per year and 1000 population in two contaminated districts and the control region of Yagatin are shown in Table 89. These data would appear to confirm a decreased birth rate during 1987 and 1988. Narodichi which had a lower than average birth rate in 1989 also had a lower birth rate before the accident.

For larger areas the data are as follows:

	1985	1989
Kiev region	15.0	14.7
Zhitomir region	15.4	14.4
All of UkrSSR	15.0	14.5

The number of natural abortions (spontaneous) for the same districts was given as 2–7%; these data are shown in Table 90.

[51] Professor V.E. Dashkevich (Kiev).

There were no data available concerning medically induced abortions. Apparently, there are a large number of these performed for purposes of birth control. In addition, it was not possible to find data on the number of abortions which might have been performed as a result of fear of radiation from the accident.

Data for the same districts relating to both stillbirths and perinatal mortality are instructive. Overall, the incidence of perinatal mortality has gone down since the accident, perhaps as a result of better prenatal care. Perinatal mortality before the accident was very high.

The percentage of births that were recorded as having foetal anomalies is shown in Table 91[52].

The actual number of reported malformations is small and thus there are large percentage differences reported from one year to another. In addition the team was not shown what the criteria were that were used to report a 'malformation'.

Official data reported from the USSR Ministry of Health include some data which are in addition to and some which overlap those given above. The data for some regions and districts are shown in Table 92.

3.13.2.2. BSSR

Ministry of Health data on the annual birth rate in the different parts of the Gomel region are given in Table 93.

Similar data were also presented for the Mogilev region. In three of the five districts the birth rate decreased between 1986 and 1988. The birth rates per 1000 population for the Mogilev and Gomel regions and for the BSSR are shown in Table 94.

All these data show that, as in the contaminated districts of the UkrSSR, there was a decrease in the birth rate in BSSR during the year after the accident.

Official USSR Ministry of Health data regarding some of the above parameters for five contaminated regions are given in Table 95.

Data from three projects were shared with the teams[53] as follows:

(1) Lymphocyte dicentric analysis of mothers and infants.

This has been done on 805 persons with more than 15 000 metaphases having been examined. The rate in control regions is 0.04% (0.0004 dicentrics per cell). This can be compared with about 0.4% (0.004 dicentrics per cell) in individuals from contaminated regions. The rates in the newborns were only slightly less than those of the mothers. It was not attempted to ascribe a dose to these frequencies since the irradiation is chronic, from different radionuclides, and internal as well as external.

[52] Professor V.E. Dashkevich (Kiev).

[53] Dr. G.I. Lazyuk (Minsk).

TABLE 89. Birth Rate per 1000 Population in Two Contaminated and One Control Area (Soviet Data)

District	1985		1986		1987		1988		1989	
	Birth rate	Total births	Birth rate	Total births	Birth rate	Total births	Birth rate	Total births	Birth rate	Total births
Polesskoe[a]	16.3	544	19.0	322	11.8	320	17.1	328	15.4	460
Total population	33 374		16 947		27 119		19 181		29 870	
Narodichi[a]	11.3	322	12.0	279	8.4	107	12.1	174	10.8	268
Total population	28 496		23 250		12 738		14 380		24 587	
Yagatin[b]	18.1	577	17.7	729	15.0	622	15.8	656	14.5	597
Total population	31 879		41 186		41 467		41 519		41 172	

[a] Contaminated area.
[b] Control area.

TABLE 90. Spontaneous Abortions in Two Contaminated and One Control Area (Soviet Data)

District	Incidence of spontaneous abortions (%)				
	1985	1986	1987	1988	1989
Polesskoe[a]	2.3	7.1	6.8	4.9	7.6
Narodichi[a]	7.2	4.1	15.0	4.3	4.2
Yagatin[b]	7.9	5.1	5.7	4.5	5.2

[a] Contaminated area.
[b] Control area.

TABLE 91. Foetal Anomalies in Two Contaminated and One Control Area (Soviet Data)

District	Incidence of foetal anomalies (%)				
	1985	1986	1987	1988	1989
Polesskoe[a]	1.8	3.1	5.0	0.6	2.8
Narodichi[a]	0.6	0.4	—	1.7	1.9
Yagatin[b]	0.2	0.1	0.2	—	—

[a] Contaminated area.
[b] Control area.

It was pointed out that in any case it would be a small radiation dose. A problem with all these studies is that there are no valid dose estimates for these persons.

(2) Monitoring medically induced abortions for the presence of malformations.

These malformations were reported as clearly visible to the naked eye. No changes were found in the type or frequency distribution of the malformations since the accident, nor was a rise noted in the incidence of microcephaly after the accident.

A large number of medically aborted foetuses (not spontaneous) were examined[54] for both internal and external malformations. The examination included the face, head, limbs, lungs, liver, heart and a search for evidence of hydrocephalus and spina bifida. All specimens were saved and photographs of all cases with malformations were taken. The specimens are received from hospitals in Minsk and from contaminated districts in the Gomel and Mogilev regions. They are sent in a solution with antibiotics so that cytogenetic analysis can also be done. A confounding factor that should be considered is that induced abortions were possibly done earlier on an elective basis immediately following Chernobyl and that these induced abortions might have otherwise resulted in spontaneous abortions. Other major confounding factors include the possibility of increased reporting since the Chernobyl accident and the uniformity of the definition of what constituted a malformation in the minds of the physicians submitting samples. In this study it is noted that the southern Gomel

[54] Dr. G.I. Lazyuk (Minsk).

TABLE 92. Stillbirths and Perinatal Mortality (Rate per 1000 Births) (Soviet Data)

Region	District		1985	1986	1987	1988
Kiev	Ivankova	Births	567	444	395	542
		Stillbirths	7	7	7	2
		Perinatal mortality	11	13	12	5
	Polesskoe	Births	544	322	320	328
		Stillbirths	16	13	18	6
		Perinatal mortality				
Chernigov	Rebkin	Births	574	577	430	520
		Stillbirths	8	5	11	10
		Perinatal mortality	17	18	18	19
	Kozelets	Births	920	925	580	646
		Stillbirths	11	12	10	8
		Perinatal mortality	15	15	10	9
Zhitomir	Ovruch	Births	1266	1215	585	1202
		Stillbirths	7	7	—	4
		Perinatal mortality	7	10	7	7
	Narodichi	Births	323	279	107	174
		Stillbirths	6	11	—	12
		Perinatal mortality	6	14	9	17

TABLE 93. Birth Rates per 1000 Population in Districts of the Gomel Region (Soviet Data)

District	1984	1985	1986	1987
Bragin	13.8	16.0	13.0	10.2
Narovlya	15.9	15.8	15.9	9.5
Vetka	15.8	15.6	14.6	12.0
Korma	22.9	19.5	19.3	16.3
Dobruch	15.5	13.8	14.0	12.7
Tsecher	15.4	16.5	17.0	14.4
Elna	18.5	16.2	17.3	13.0
Gomel	17.5	17.2	17.2	14.9

and Mogilev regions have a higher malformation rate than other areas, with reported rates of about 300/10 000 induced abortions.

Unfortunately, for this study there are no pre-accident baseline data except for other areas. Current rates in 1989 are not different in the contaminated regions from what they were in 1986 and 1987. The slightly higher rates relative to other areas were felt by Soviet scientists to be, possibly, secondary to immune or dietary changes.

(3) Malformations as reported from hospital records.

In the BSSR, the average malformation rate is about 5.6/1000 newborns. Malformation rates in the BSSR as a whole have not changed from before the accident (0.56% for 1980–85, 0.5% for 1986–87). Pre-accident data for the Gomel or Mogilev regions for the years 1982 to 1985 range from 0.3 to 0.5%. The malformation rates now in the Gomel region are higher than in Minsk but the aetiology is not certain since there are many

TABLE 94. Birth Rate per 1000 Population for Two Regions and for the Entire BSSR (Soviet Data)

Year	Mogilev region	Gomel region	BSSR
1981	15.9		16.3
1982	16.0		16.3
1983	17.1		17.6
1984	16.3	17.5	17.0
1985	16.1	17.2	16.5
1986	16.7	17.2	17.1
1987	15.8	14.9	16.1
1988	15.6		

TABLE 95. Birth Rate, Premature Births and Abortions per 1000 Population

Region		1985	1986	1987	1988
Kiev	Birth rate per 1000 population	15.0	15.5	13.7	15.4
	Premature births (%)	3.3	3.3	3.2	3.2
	Spontaneous abortions (%)	4.3	4.3	4.5	4.5
	Abortions per 1000 fertile age	81.4	83.8	82.6	—
Zhitomir	Birth rate per 1000 population	15.4	15.9	14.2	14.4
	Premature births (%)	3.2	2.9	3.6	3.1
	Spontaneous abortions (%)	2.4	2.5	2.7	2.9
	Abortions per 1000 fertile age	70.6	53.4	42.6	—
Bryansk	Birth rate per 1000 population	15.3	16.3	15.9	15.1
	Premature births (%)	3.7	3.4	3.6	3.6
	Spontaneous abortions (%)	3.7	3.8	4.1	—
	Abortions per 1000 fertile age	104.3	108.1	111.5	103.4
Gomel	Birth rate per 1000 population	17.2	17.2	14.9	16.5
	Premature births (%)	3.0	2.5	2.4	2.6
	Spontaneous abortions (%)	3.4	3.5	3.2	3.0
	Abortions per 1000 fertile age	82.9	76.0	67.1	59.0
Mogilev	Birth rate per 1000 population	16.1	16.7	15.8	15.6
	Premature births (%)	3.4	3.0	3.3	3.5
	Spontaneous abortions (%)	4.2	4.4	4.4	4.3
	Abortions per 1000 fertile age	81.9	79.8	77.1	61.2

other differences besides radiation such as microelements, lifestyle, etc. The numbers of malformations are small: 0.4% for Gomel city and 1.1% for the rural areas of Gomel and Mogilev. Thus, the statistical significance of changes in districts and even regions are difficult to assess. The number of such reports in contaminated regions of Gomel were only 40–100 per year. It is reported[55] that the frequency of malformed children born in 17 contaminated districts of Gomel and Mogilev has increased from 4.3 $\pm$ 0.5 per 1000 births in 1986 to 6.9 $\pm$ 0.6 in 1988. Of note, however, is that the rate reported in the uncontaminated Goretsk district of the Mogilev region was 7.1 $\pm$ 1.9 during 1982 and has decreased since. Thus the increase reported in the contaminated areas may be due to differences in reporting after the accident.

No data have been collected on head size in the 1986–87 period as far as looking for smaller head size is concerned, although there was no reported increase in microcephaly from the hospital anomaly data. The head size was and is recorded for each birth and is in the hospital record if anyone cares to look for it.

There has not been a standardized intelligence quotient test in the BSSR so there are no baseline data to use as a historical control for possible epidemiological studies relative to reduced intelligence quotient as a result of in-utero radiation exposure or as a result of iron or iodine deficiency, etc.

It was indicated[56] that in the settlements which have been visited there has been an increase in premature births in the seventh to eighth month estimated gestational age (EGA) range. No cerebral palsy or mental impairment has been seen in children born in the few settlements which were studied. There may be some delay in developmental steps of sitting up and speaking and evidence (obtained by EEG) of 'delayed myelinization'; however, no actual data relating to this claim were presented. It was also indicated that syndactyly (primarily related to the second, third and fourth toes) has also been felt to be more evident since the accident with 1–2 cases/500 births before the accident and 6–8 cases at present. In the settlements which were studied there were about 600 pregnant women 15–40 weeks and 396 at 8–15 weeks EGA at the time of the accident. There is no evidence of mental retardation in these and no Down's syndrome has been seen.

[55] Dr. G.I. Lazyuk (Minsk).

[56] Dr. A.M. Lyaginskaya (Moscow).

It was thought[57] that the syndactyly data related in Moscow were in error since the incidence of all malformations in the BSSR (1979–83) was anencephaly (0.31/1000), spina bifida (0.54/1000), Down's syndrome (1.24/1000), and polydactyly (0.58/1000). The figures for Gomel and Mogilev for 1987–89 were anencephaly (0.34/1000 (8 cases)), spina bifida (0.77/1000 (18 cases)), Down's syndrome (0.60/1000 (14 cases)), and polydactyly 1.19/1000 (28 cases)). It was indicated that these and several other abnormalities are required to be reported to the Republic Ministry of Health by a special form.

3.13.3. Summary of Foetal and Genetic Issues

The qualified conclusion based on data reviewed in Moscow, Minsk and Kiev was that there was nothing to suggest an increase in genetic or congenital disease that was likely to be radiation induced. There may, however, be effects related to social disruption or worsening nutrition.

Two items that need to be considered if any investigations are to consider potential long term studies related to in utero radiation exposure and IQ: (1) the lack of pre-accident baseline data and the need for a satisfactory control group; (2) nutritional issues such as maternal alcohol consumption and the possibility that the studies might be conducted in a localized goitre area. It is clear that iodine deficiency can lead to both goitre and cretinism, and any long term study would have to carefully elucidate this situation.

Some suggestions for future work are as follows:

(1) Visit prenatal screening and diagnosis department in Kiev to more carefully examine data there.
(2) Store DNA cells for as large a sample of exposed persons as possible for future studies as there may be more methods developed for mutation detection. Blood spots on Guthrie cards may also be useful.

[57] Dr. G.I. Lazyuk (Minsk).

4. Radiation Risks Relative to Future Health

4.1. Detrimental Effects

The major long term factor in terms of radiation induced health abnormalities is the risk of cancer induction. As has been pointed out earlier in this report the time of expression of this risk as well as the magnitude is dependent upon a number of factors. In general, children are thought to have two to three times the risk of adults and females are at about 20-50% higher risk than males. Radiation that is delivered in a low dose rate manner (such as from Chernobyl) will likely have about half the effect of radiation that was delivered at high doses and dose rates. In the following, only low dose, low dose rate risks will be quoted.

Experience with the atomic bomb survivors, occupational exposure, other accidents and medical uses of radiation has clearly shown that solid tumours do not usually appear earlier than ten years post exposure. At longer times, solid tumours do appear and the risk appears to continue and increase for 40 years or more. Leukaemias, in contrast, may appear within the first decade but the risk then declines over time.

As a result, there are potential increases in both leukaemia and solid tumours that can occur as a result of the Chernobyl accident. It is important to attempt to assess the magnitude of this risk and place it in the context of the normal spontaneous risk of cancer. Since the population (and its age and sex distribution) is not well known for the regions in the Republics and since the radioactive contamination is deposited in a very non-uniform fashion, it is difficult to estimate the risk for each individual. Within a given settlement the absorbed dose for individuals may easily vary by an order of magnitude based upon the local conditions of food supply, surface contamination, dietary habits, etc. In any case, we can only give estimates of the result of a certain quantity of absorbed dose. Under these circumstances, if an individual knew his or her absorbed dose, they could calculate the attendant risk.

The probabilities of radiation induced fatal cancer vary significantly with age. For children and adolescents the risk after low dose, low dose rate exposure is about 12% per Sv, dropping to about 4% for working adults, and finally to under 1% per Sv for persons exposed over the age of 65. Some of the organ probabilities by age are shown in Table 96.

Calculations can be made of expected years of life lost for different sexes, ages, and populations for site specific and total cancers. Values roughly parallel to those for cancer deaths are obtained; they are shown in Table 97.

TABLE 96. Relative Probabilities of Fatal Cancer in Various Organs for Different Age Groups
High dose, high dose rate, low LET radiation. Average of multiplicative projection model and model of the National Institutes of Health. Adapted from Ref. [172]

Organ	Age group		
	0–19 years	0–90 years	20–64 years
Oesophagus	0.023	0.040	0.062
Stomach	0.243	0.266	0.303
Colon	0.218	0.154	0.078
Lung	0.244	0.203	0.144
Breast	0.030	0.025	0.021
Ovary	0.011	0.017	0.024
Bladder	0.030	0.054	0.081
Bone marrow	0.054	0.091	0.137
Remainder	0.150	0.150	0.150
Total	1.000	1.000	1.000
Risk (10^{-2} Sv^{-1})	12	5.4	4

TABLE 97. Relative Values of Expected Life Lost Due to Induced Cancer in Organs Averaged for Sex, Five National Populations and Two Models
Multiplicative risk projection model and model of the National Institutes of Health. Adapted from Ref. [172]

Organ	Relative life lost
Oesophagus	0.048
Stomach	0.190
Colon	0.148
Lung	0.154
Breast	0.049
Ovary	0.025
Bladder	0.039
Bone marrow	0.197
Remainder	0.150
All cancer	1.000
Total expected years of life lost	1.5 per Gy[a]

[a] This value is for high dose rate, high dose exposure and could be reduced by a factor of two for low dose rate, low dose exposure.

The International Commission on Radiological Protection (ICRP) [172] has estimated the lifetime mortality from radiation induced cancers in a population of all ages after exposure to low dose, low LET radiation. These estimates are shown in Table 98.

Hereditary effects need to be considered in relation to future estimates of health effects. At the present time estimates of severe hereditary effects are about 100 cases per 10 000 person·Sv.

A summary of estimates of probabilities of radiation health effects at exposures of less than several Sv has been prepared by the ICRP [172] and is shown in Table 99.

4.2. Estimation of Detrimental Effects

Since population statistics are not available for each area contaminated to different levels of activity, it is probably most instructive to give examples of the expected effects for a given settlement in which the average absorbed dose rate has been estimated.

Example. A highly contaminated settlement with a general population of 10 000 persons receives a lifetime (low dose rate) absorbed dose of 0.1 Sv. This is the approximate average of the 70 year total absorbed (external and internal) dose for persons living in contaminated settlements visited by Task Group 3.

4.2.1. Cancer induction

The probability of radiation induced fatal cancer for a person of the general population is 5%/Sv. Thus the result of chronic exposure to 0.1 Sv would be a probability of 0.5%. In most developed countries the probability of fatal cancer is about 17%. Thus the radiation dose would increase the probability of fatal cancer from about 17% to 17.5%.

Thus, if in our example the contaminated settlement contained 10 000 persons, the number of fatal cancer cases and leukaemia would rise from an expected number of 1700 to 1750, or an extra fifty fatalities due to the radiation. About half of these fatalities will occur in persons who were children at the time of exposure since children are more sensitive than adults to radiation carcinogenesis. Radiation induced solid tumours and resultant potential fatalities would be expected to arise between 10 and 50 years after exposure.

The probability of radiation induced (non-CLL) leukaemia is about 2 excess deaths per 10 000 person·year·Gy for the 2000 children each receiving 0.1 Sv over 70 years, and 8000 adults receiving 0.06 Sv over 40 years. This would be equal to about 33 000 person·year·Gy or about 6 excess leukaemia deaths.

TABLE 98. Lifetime Mortality in a Population of all Ages from Radiation Induced Cancers
Low dose, low LET radiation. Multiplicative risk projection model and model of the National Institutes of Health. Adapted from Ref. [172])

Organ	Cancer deaths per 10^4 per Sv
Bladder	30
Bone marrow	50
Bone surface	5
Breasts	20
Colon	85
Liver	15
Lung	85
Oesophagus	30
Ovary	10
Skin	2
Stomach	110
Thyroid	8
Remainder	50
Total	500

TABLE 99. Probability of Radiation Health Effects at Low Exposures [172]

Effect	Population	Low LET exposure period	Exposure mode	Probability
		Mental effects		
IQ reduction	Foetus	8–15 weeks of gestation	High dose and high dose rate	30 IQ points per Sv[a]
Severe mental retardation	Foetus	8–15 weeks of gestation	High dose and high dose rate	40×10^{-2} per Sv[a]
		Genetic effects		
Severe hereditary defects	All population	Equilibrium	Low dose and low dose rate	1.0×10^{-2} per Sv
		Cancer		
Fatal cancers	All population	Lifetime	Low dose and low dose rate	5.0×10^{-2} per Sv

[a] Based on linear fit to high dose, high dose rate.

The background rate of non-CLL leukaemias in the USSR is difficult to ascertain but, if rates from the United States are applicable, 25–35 spontaneous non-CLL leukaemias would occur in this population. Radiation induced leukaemias typically appear about 5 to 15 years after exposure.

If we assume that in our example settlement of 10 000 persons (20% children and 80% adults) the average absorbed dose equivalent to the adult thyroid was 100 mGy (10 rad) and to the child it was 500 mGy (50 rad), then the number of excess thyroid cancer cases can be estimated. It must be remembered that only about 10% of thyroid cancers result in a fatality:

8000 adults × 0.1 Gy × 40 years = 32 000 person·year·Gy

2000 children × 0.5 Gy × 60 years = 60 000 person·year·Gy

Total 92 000 person·year·Gy

The risk coefficient is 2.5 per 10 000 person·year·Gy, therefore 9.2 × 2.5 = about 24 thyroid cancers ≈ 2.4 deaths.

Most of the thyroid cancers would be expected to occur in children because of their larger absorbed thyroid dose, longer lifespan and increased sensitivity relative to adults.

Thyroid nodules also may be expected to arise. Typically, the risk factor for these is about three times higher than for thyroid cancers. In our assumed population there would be about 75 cases of thyroid nodules (mostly in children). As mentioned earlier in this report thyroid nodules are quite rare in children, but occur in up to 15% of adults normally. Both thyroid nodules and thyroid cancer typically arise 10 to 40 years after exposure.

4.2.2. Years of life lost

In the same contaminated settlement how many years of lost life are there expected to be? Radiation exposure may increase the probability of contracting cancer and thus shorten lifespan. However, those persons who develop radiation induced cancer would eventually have died of some other cause had they not been irradiated. Estimates of years of life lost are about 0.75 years/Sv for low dose rate radiation. In the same example contaminated settlement of 10 000 persons receiving on the average 0.1 Sv over 70 years, the collective dose is 1000 person·Sv. This would equate to 750 person·years of life lost as a result of the radiation exposure (i.e. about 0.075 years/person or 1 month/ person). This kind of calculation can be a bit misleading since actually the 750 person·years of life is lost by the 50 people who get the cancers (i.e. about 15 years per person who contracts a radiation induced fatal cancer).

4.2.3. Hereditary effects

The risk of severe hereditary effects at equilibrium is estimated to be 1%/Sv. In the case of the example settlement 70 year cumulative dose of 0.1 Sv, the risk would be 0.1%. This would mean 10 cases of hereditary effects in the offspring of the 10 000 persons spread out over the next several generations.

4.2.4. Detriment

Another way of examining the effects of radiation is to examine 'detriment'. This would include other deleterious effects of radiation besides fatal cancers. The ICRP [172] made estimates of detriment due to radiation exposure of the whole body at low dose. Their calculations included the risk of fatal cancer in all relevant organs, a specific allowance for differences in latency which result in different values of expected life lost for fatal cancer in different organs, an allowance for morbidity resulting from non-fatal radiation induced cancers and finally an allowance for the risk of serious hereditary disease in all future generations descending from the irradiated individual. This gives a total detriment of about 7% per Sv or 70 people in 10 000 persons living where they receive an average absorbed dose of 0.1 Sv.

5. Summary and Conclusions

There remain very large areas of the Soviet Union which have contamination levels in the range of or exceeding 15 Ci/km^2 (555 kBq/m^2) of ^{137}Cs. Some of these areas are located as far as 300 km from the plant.

The accident and contaminated areas include three administratively distinct areas of the UkrSSR, BSSR and RSFSR. Populations still living in contaminated areas are probably in excess of half a million with at least 60 000 children still living in these areas.

In terms of review and correlation of the Soviet health effects data, it was apparent that there were major differences in the scientific and medical backgrounds, purposes and capability, not only between the Project Task 4 teams and their Soviet counterparts but also within the Soviet structure itself. It was a credit to the Soviet people that we could work together in an effort to achieve a common goal in terms of assessment of the health effects of Chernobyl.

Correlation and corroboration of the Soviet data internally and with our data were difficult for several reasons. One reason, which was obvious to all involved in the project, was that our Soviet colleagues most often did not have access to technology which is considered quite commonplace in medical diagnosis and practice in many western countries. In some of the institutes and very large hospitals, modern equipment was present but the equipment even in these often was not operating because of the lack of chemical reagents or minor spare parts.

A second problem was more difficult. Many of the Soviet health related studies were performed by well intentioned persons who did not have a firm foundation in the design of scientific experiments and the value of consistent methodology and controls. There were many contradictions in data that were presented to us. While there were some first rate investigations these were in the minority. A number of scientists and physicians appeared to have limited and narrow backgrounds which caused them to make assumptions and conclusions which did not logically follow on a scientific basis. As a result, many of the studies were internally contradictory and assumptions were presented as facts without the benefit of critical review and examination of the studies for biases and design flaws.

While there are published uniform methodologies for follow-up of certain persons affected by the accident, these procedures are rarely, if ever, followed. One reason for this is that the equipment and reagents needed to follow the guidelines are simply not available. Another reason is that the various investigators wish to be independent. Unfortunately, this leads to data that are inconsistent and cannot therefore be compared from Republic to Republic or in some instances between different institutes in the same city.

A third problem was the result of recent acquisition of some modern pieces of equipment by Soviet scientists without the benefit of the necessary support foundation related to useful and accurate operation of the instruments. Calibrating standards were usually not available nor were operating manuals in Russian.

A fourth major problem was the lack of literature for the instrument operators and those scientists and physicians who were designing studies. Some of the studies were aimed at goals which have already been studied extensively in other countries and the negative results of which are already widely published in the open literature. In some cases there seemed to be unrealistic optimism that new technology could provide answers to almost any problem and that the results were automatically correct. The technical and interpretative limitations of medical diagnostic equipment were sometimes not well understood.

In spite of all the above limitations, we were able to correlate a substantial amount of data from a number of Soviet studies. Most of the Soviet studies in which we were able to confirm findings were performed on equipment that was somewhat outdated but which the Soviet scientists understood very well. In other areas (such as tumour incidence data) we were only able to review data and provide comments, but we were not able to verify the data since we could not repeat or successfully sample such large populations in the time we had or with the resources we had. In addition, many of the data had been obtained in past years and the only method of verification that could have been used was a labour intensive process of extensive record and pathology review. It should be clear that our findings pertain only to those persons living in rural areas within 300 km or so of Chernobyl. They do not apply to the decontamination workers, Chernobyl plant operators or persons already relocated. We did have a chance to examine some of the workers and firemen initially severely injured in the accident and we were very impressed with their medical care and outcomes; we did not, however, collect data in this regard.

It should also be clear that these results only represent the state of health during the fall of 1990. We cannot speak of health effects in the period before 1990 except through knowledge of the scientific basis of radiation health effects and what is currently found. Our disease detection process and study was limited to certain specific problem areas and a general physical examination. Even though we detected a significant percentage of people with major health problems requiring medical care, supervision or treatment, it is certain that there were additional abnormalities in the population that could only have been detected with additional tests. Our study is only one set of data points in the investigation of a very large problem. It is certain that there are facets of the accident which need further investigation in the future.

Our review and analysis indicated major health problems in several areas. With some qualifications, there were no direct effects that we were able to confirm as being directly attributable to radiation effects at this time. There are clearly some effects, most notably psychological, which are felt to be the direct result of the accident. Potential future effects such as cancers are considered in Part H (Conclusions and Recommendations).

Data Supplied to IAC Task Group 4 by the USSR Ministry of Health and Various Institutes

Standard Methods of Examination of Patients, Moscow 1986

Radiocaesium and radiostrontium transfer factors in food chains soil-grass and soil-milk on the territory of the UkrSSR for the year 1989

Some recent developments in trace element research in the USSR, Avtsyn, A.P., et al.

Thyroid radiation dose distribution among Narodichi district children

Frequency of thyroid hyperplasias among the children of the Narodichi district 1986 and 1988 and frequency of increase in total T4 hormone, TSH and ultrasonic analysis of the thyroid

Frequency of anaemia and analysis of white cell count in children of the Narodichi and Yagatin districts

Frequency of birth rate and disease rate in children in Narodichi and Yagatin

Frequency of thyroid abnormalities in 1987 and 1988 in Bryansk and Novozybkov

Guide to the evaluation of thyroid exposure doses due to uptake of radioactive isotopes of iodine in the human body, L.A. Il'in

Configuration and description of the All-Union Register (Obninsk), including distribution of registrants, diseases by site and malignancies

The estimate of internal exposure importance in immediate early effects in Chernobyl nuclear power plant accident victims, Gus'kova, A.K., et al., 1988

Distribution of dicentric chromosome analysis among 237 Chernobyl decontamination workers

Statistics on the population

- Gamma dose rate
- ^{137}Cs deposition in the soil
- ^{90}Sr deposition in the soil
- ^{137}Cs concentration in milk
- Projected doses 1986–90
- Body monitoring
- Thyroid doses

Health Impact

for settlements of

- Veprin
- Bragin
- Korma
- Polesskoe
- Narodichi
- Novozybkov
- Zlynka

Indexes of Health for the following regions:

- Bryansk
- Mogilev
- Gomel
- Kiev
- Zhitomir

for the years 1985–1989

These data include also comparative Republic data

Parameters reported are:

- Population total, urban and rural
- Birth rate per 1000 persons
- Death rate
- Neonatal and perinatal death rate
- Infectious disease rate
- Venereal disease rate
- Tuberculosis
- Alcoholism
- Malignant neoplasm rate
- Premature births
- Spontaneous abortions
- Post operative mortality
- Hospital number
- Number of beds
- Average bed stay in days
- Hospitalization rate
- Number of invalids
- Number of doctors and nurses
- Death rate from malignant neoplasms

Maps with levels of caesium in milk for 59 settlements and towns

Maps of stable iodine, cobalt and manganese in soil in the BSSR

Registration forms for health registries in Obninsk, haematological register in Kiev, Ministry of Health of the UkrSSR

Additional registry form used by Dr. Tukov

Genetic consequences of the Chernobyl accident for the populations of Gomel and Mogilev regions, Lazyuk, G.I. (Minsk)

Information on Polesskoe, Narodichi and Yagatin for the years 1985–1989 relative to total births, spontaneous abortions, complicated pregnancies, foetal anomalies and perinatal mortality

Information on leucocyte and lymphocyte subpopulations for some populations in the UkrSSR

Maps of the UkrSSR, BSSR and RSFSR relative to:

- Caesium-137 soil contamination levels
- Strontium-90 soil levels
- Plutonium-239 soil levels.

Map of the administrative regions in the BSSR.

Part F

For Use in the Medical Field Trips

1. Supplied by the USSR Ministry of Nuclear Power and Industry:

   Van for transporting equipment and blood samples

   Large bus for transport

   Two drivers

   Logistical person for arrangements of travel, etc.

   Four interpreters

   Airline travel reservations and tickets

   Letters of invitation for team members

   Hotel accommodation and meals

2. Supplied by the USSR Ministry of Health:

   One trained haematology technician

   Two trained ultrasonographers

   Person to transport blood slides and some samples to Kiev (AUSCRM) every two days during the trip

3. Supplied by Republic Ministries of Health:

   Notification of the physicians in the local settlements so that the persons included in the study could be notified

   Representative(s) of the Ministry of Health to be present when teams are examining patients

4. Items Brought by Field Teams:

   Hitachi Model EUB-310 ultrasound machine (1)

   Siemens ultrasound machines (2)

   Thermal printers, Mitsubishi Video (2)

   Thermal printer paper , Mitsubishi (20 rolls)

   Ultrasound gel, Parker Laboratories (10 L)

   Coulter T 660 haematology analysers (2)

   Coulter sets of spare parts (3)

   Premixed reagents for Coulter (14 cases)

   Haematology centrifuge

   Blood sample mixer (1)

   Coulter printer (2)

   Coulter printer forms (4000)

   Voltage converters (3)

   Power stabilizers and power conditioners (2)

   Stethoscopes (4)

   Sphygmomanometers (4)

   Flashlights (6)

   Batteries (12)

   Tongue depressors (2000)

   Microscope slides, Clay Adams (6000)

   Miniprep slide maker (1)

   Wooden applicators (4000)

   Electrical fan (1)

   Stain (6 L)

   Sticking plasters (4000)

   Gauze pads (4000)

   Syringes 10 mL (2000)

   Vacutainer tube holders (50)

   Vacutainer needles, 21 ga. Becton Dickinson (3000)

   Syringe needles (1000)

   Butterfly paediatric needles (1000)

   Disposable lancets (2000)

   Alcohol pads (6000)

   Gel serum separation tubes (3000)

   Gel serum separation microtainers (600)

   EDTA haematology tubes (4000)

   EDTA microtainers (600)

   Latex gloves (1000 pair)

   Neonatal screening filter papers (3000)

   Questionnaires (3000)

   Computer labels (3000)

   Pens and pencils (250)

   Staplers (3)

   Staples (5000)

   Tools for repairs

   Marking tape (4 rolls)

   Packing tape (4 rolls)

   Portable computer (1)

References

[1] AWA, A.A., Review of 30 years study of Hiroshima and Nagasaki atomic bomb survivors. II. Biological effects: Chromosome aberrations in somatic cells, J. Radiat. Res. (Tokyo) **16** (Suppl.) (1975) 122.

[2] AWA, A.A., et al., Cytogenetic Study of the Offspring of Atomic Bomb Survivors, Hiroshima and Nagasaki, Rep. RERF-TR-21-88, Radiation Effects Research Foundation, Hiroshima, Japan (1988).

[3] KAKODA, M., et al., Increased Somatic Cell Mutant Frequency in Atomic Bomb Survivors, Rep. RERF-TR-18-87, Radiation Effects Research Foundation, Hiroshima, Japan (1984).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Biological Dosimetry: Chromosomal Aberration Analysis for Dose Assessment, Technical Reports Series No. 260, IAEA, Vienna (1986).

[5] KYOISUMI, S., NAKAMURA, N., HAKODA, M., Detection of Somatic Mutations at the Glycophorin-A Locus in Erythrocytes of Atomic Bomb Survivors Using a Single Beam Flow Sorter, Rep. RERF-TR-9-88, Radiation Effects Research Foundation, Hiroshima, Japan (1988).

[6] LITTLEFIELD, L.G., et al., "Cytogenetic dose estimates from in vivo samples from persons involved in real or suspected radiation exposure", The Medical Basis for Radiation Accident Preparedness (HUBNER, K.F., FRY, S.A., Eds), Elsevier and North-Holland, Amsterdam and New York (1980).

[7] LLOYD, D.C., et al., Doses in Radiation Accidents Investigated by Chromosome Aberration Analysis, Rep. NRPB-R-128, National Radiological Protection Board, Oxford (1982).

[8] PRESTON, D.L., et al., Comparison of the Dose-Response Relationships for Chromosome Aberration Frequencies between the T65D and DS86 Dosimetries, Rep. RERF-TR-7-88, Radiation Effects Research Foundation, Hiroshima, Japan (1988).

[9] WANG, Z., et al., Thyroid nodularity and chromosome aberrations among women in areas of high background radiation in China, J. Natl. Cancer Inst. **82** (1990) 478.

[10] AKIYAMA, M., et al., Development of the Assay for Detection of Somatic Mutation in Radiation-Exposed People by Means of Flow Cytometry, Elsevier, Amsterdam and New York (in press).

[11] KYOIZUMI, S., et al., Detection of somatic mutations at the glycophorin A locus in erythrocytes of atomic bomb survivors using a single beam flow sorter, Cancer Res. **49** (1989) 581.

[12] KYOIZUMI, S., et al., Spontaneous loss and alteration of antigen receptor expression in mature $CD4^+$ T cells, J. Exp. Med. **171** (1990).

[13] KYOIZUMI, S., et al., Frequency of Mutant T Lymphocytes Defective in the Expression of the T-cell Antigen Receptor Gene among Radiation-Exposed People, Rep. RERF-TR-10-90, Radiation Effects Research Foundation, Hiroshima, Japan (1990).

[14] BRESLOW, N.E., Extra-Poisson variation in log-linear models, Appl. Stat. **33** (1984) 38.

[15] ANDREWS, G.A., et al., "Haematological effects of whole-body radiation in the human being", Effects of Ionizing Radiations on the Haematopoietic Tissue (Proc. Panel Vienna, 1966), IAEA, Vienna (1967) 75.

[16] BARABANOVA, A.V., et al., Acute Radiation Effects in Man, USSR State Committee on the Utilization of Atomic Energy, USSR Ministry of Health (1986).

[17] CRONKITE, E.P., "Kinetics of human haematopoiesis", Effects of Ionizing Radiations on the Haematopoietic Tissue (Proc. Panel Vienna, 1966), IAEA, Vienna (1967) 6.

[18] GUS'KOVA, A.K., Current problems of radiation sickness prophylaxis and treatment, Med. Radiol. **9** (1986) 3.

[19] Effects of Ionizing Radiations on the Haematopoietic Tissue (Proc. Panel Vienna, 1966), IAEA, Vienna (1967).

[20] METTLER, F.A., MOSELEY, R.D., Medical Effects of Ionizing Radiation, Grune and Stratton, Orlando, Florida (1985).

[21] METTLER, F.A., KELSEY, C.A., RICKS, R.C. (Eds), Medical Management of Radiation Accidents, CRC Press, Boca Raton, Florida, USA (1990).

[22] GUS'KOVA, A.K., et al., "Acute effects of radiation exposure following the Chernobyl accident: immediate results of radiation sickness and outcome of treatment", Medical Aspects of the Chernobyl Accident, IAEA-TECDOC-516, IAEA, Vienna (1989) 233.

[23] FINCH, S.C., FINCH, C.A., Summary of the Studies at ABCC-RERF concerning the Late Haematologic Effects of Atomic Bomb Exposure in Hiroshima and Nagasaki, Rep. RERF-TR-23-88, Radiation Effects Research Foundation, Hiroshima, Japan (1985).

[24] ANDERSON, R.E., WARNER, N.L., Ionizing radiation and the immune response, Adv. Immunol. **24** (1976) 215.

[25] ANDERSON, R.E., WILLIAMS, W.I., Radiosensitivity of T and B lymphocytes versus effective whole body irradiation on numbers of recirculating T cells and capacity to recognize antigens, Am. J. Pathol. **89** (1977) 367.

[26] ANDERSON, R.E., LEFKOVITS, I., TROUP, G.M., "Radiation-induced augmentation of the immune response", Contemporary Topics in Immunobiology (WARNER, N.L., Ed.), Vol. 2, Ch. 8, Plenum Press, New York and London (1980) 245.

[27] ANDERSON, R.E., LEFKOVITS, I., Effects of irradiation on the in vitro immune response, Exp. Cell. Biol. **48** (1980) 255.

[28] ANDERSON, R.E., STANDEFER, J.C., "Radiation injury of the immune system", Cytotoxic Insult to Issues: Effects on Cell Lineages (POTTEN, C.S., HENDRY, J.H., Eds), Churchill Livingstone, Edinburgh (1983) 67.

[29] TALLIAFERRO, W.H., TALLIAFERRO, L.G., JAROSLOW, B.N., Radiation and Immune Mechanisms, Academic Press, New York (1964).

[30] Workshop on Low Dose Radiation and the Immune System, Frankfurt, May 1987, Int. J. Radiat. Biol. (Special Issue) **53** (1988) 1.

[31] BRAEMAN, J., BIRCH, A., DEELEY, T.J., Depression of in vitro lymphocyte reactivity after radical radiotherapy, Ann. Clin. Res. **6** (1974) 338.

[32] GLAS, U., WASSERMAN, J., Effect of radiation treatment on cell-mediated immune response in carcinoma of the breast, Acta Radiol., Ther., Phys., Biol. **13** (1974) 83.

[33] CONARD, R.A., et al., Immunohematological studies of Marshall islanders 16 years after fallout radiation exposure, J. Gerontol **26** 1 (1971) 26.

[34] SASAGAWA, S., et al., Whole-blood Phagocytic and Bactericidal Activities of Atomic Bomb Survivors, Hiroshima and Nagasaki, Rep. RERF-TR-1-89, Radiation Effects Research Foundation, Hiroshima, Japan (1989).

[35] FEYERABEND, T., et al., Incidence of hypothyroidism after irradiation of the neck, Acta Oncol. **29** (1990) 597.

[36] NAGATAKI, S., "Delayed effects of atomic bomb radiation on the thyroid", Radiation and the Thyroid (NAGATAKI, S., Ed.), Excerpta Medica, Amsterdam (1989) 1.

[37] BECKER, D.V., "Medical radiation: Comparison of iodine-131 therapy and alternative treatments of hyperthyroidism", ibid., 57.

[38] STANBURY, J.B., HETZEL, B.S. (Eds), Endemic Goiter and Endemic Cretinism: Iodine Nutrition in Health and Disease, Wiley, New York (1980).

[39] KONISHI, J., et al., "Radiation therapy for Graves' disease in Japan", Radiation and the Thyroid (NAGATAKI, S., Ed.), Excerpta Medica, Amsterdam (1989).

[40] MYRDACZ, P., Die Verbreitung der zu Kriegsdiensten untauglich machenden Gebiete der Verpflichtungen in Oesterreich-Ungarn, VI Int. Congr. Hygiene und Demographie: Arbeiten der Demographischen Sektion, 25, Wien (1887) 1.

[41] LANGER, P., "Eastern and southeastern Europe", Endemic Goiter and Endemic Cretinism (STANBURY, J.B., HETZEL, B.S., Eds), Wiley, New York (1980) 141.

[42] CORREA, P., "Pathology of endemic goitre", ibid., p. 303.

[43] ERMANS, A.M., "Etiopathogenesis of endemic goiter", ibid., p. 287.

[44] ARNDT, H.J., Der Kropf in Russland, G. Fischer, Jena (1931).

[45] KELLY, F.C., SNEDDEN, W.W., "Prevalence and geographical distribution of endemic goitre", Endemic Goitre, WHO (1960) 27.

[46] NIKOLAEV, O.V., Endemic Goitre, MEDGIZ, Moscow (1955) (in Russian).

[47] THILLY, C.H., DELANGE, F., "Epidemiologic surveys in endemic goiter and cretinism", Endemic Goiter and Endemic Cretinism (STANBURY, J.B., HETZEL, B.S., Eds), Wiley, New York (1980) 157.

[48] TROWBRIDGE, F.L., et al., Iodine and goiter in children, Pediatrics **56** (1975) 82.

[49] DUNN, J.T., VAN DER HARR, F., A Practical Guide to the Correction of Iodine Deficiency, Technical Manual No. 3, International Council for Control of Iodine Deficiency Disorders (ICCIDO), WHO (1990).

[50] COMMITTEE ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATION (BEIR), Health Effects of Exposure to Low Levels of Ionizing Radiation, National Research Council, National Academy Press, Washington, DC (1990).

[51] CONARD, R.N., et al., "Thyroid nodules as a late effect of exposure to fallout", Radiation-Induced Cancer (Proc. Symp. Athens, 1969), IAEA, Vienna (1969) 325.

[52] DOBYNS, B.M., et al., Malignant and benign neoplasmas of the thyroid in patients treated for hyperthyroidism: A report of the cooperative thyrotoxicosis therapy follow-up study, J. Clin. Endocrinol. **38** (1974) 976.

[53] HEMPLEMANN, L.H., Risk of thyroid neoplasms after irradiation in childhood, Science **160** (1968) 159.

[54] MAXON, L.R., et al., Ionizing radiation and the induction of clinically significant disease in the human thyroid gland, Am. J. Med., **63** (1977) 967.

[55] MORTENSEN, J.D., WOOLNER, L.B., BENNETT, W.A., Gross and microscopic findings in clinically normal thyroid glands, J. Clin. Endocrinol. Metab. **15** (1955) 1270.

[56] RALLISON, M.L., et al., Thyroid nodularity in children, J. Am. Med. Assoc., **233** (1975) 1069.

[57] ROBBINS, J., ADAMS, W.H., "Radiation effects in the Marshall islands", Radiation in the Thyroid (NAGATAKI, S., Ed.), Excerpta Medica, Amsterdam (1989).

[58] VANDER, J.B., GASTON, E.A., DAWBER, T.R., The significance of nontoxic thyroid nodules: Final report of a 15-year study of the incidence of thyroid malignancy, Ann. Intern. Med. **69** (1968) 537.

[59] SHELINE, G.F., et al., Thyroid nodules occurring late after treatment of thyrotoxicosis with radioiodine, J. Clin. Endocrinol. Metab. **22** (1962).

[60] SARDA, A.K., KAPUR, M.M., Thyroid carcinoma: A report of 206 cases from an area with endemic goitre, Acta Oncol. **29** (1990) 863.

[61] KAPLAN, N.M., Clinical Hypertension, 5th edn, Williams and Wilkins, London (1990).

[62] WORLD HEALTH ORGANIZATION/ INTERNATIONAL SOCIETY OF HYPERTENSION, J. Hypertension **7** (1989) 689.

[63] DYKEN, J.L., et al., Risk factors in stroke, Stroke **15** (1984) 1105.

[64] KANNEL, W.B., DANNENBERG, A.L., ABBOTT, R.D., Am. Heart J. **109** (1985) 581.

[65] KANNEL, W.B., et al., J. Am. Med. Assoc. **245** (1981) 1225.

[66] KAPLAN, N.M., Arch. Intern. Med. **149** (1989) 1514.

[67] SONNE-HOLM, S., et al., Independent effects of weight change and attained body weight on prevalence of arterial hypertension in obese and non-obese men, Br. Med. J. **299** (1989) 767.

[68] AFFARAH, H.B., et al., High carbohydrate diet, antineuretic and blood pressure response in normal men, Am. J. Clin. Nutr. **44** (1986) 341.

[69] BALLANTYNE, D., DEVINE, B.L., FILE, R., Interrelation of age, obesity, cigarette smoking and blood pressure in hypertensive patients, Br. Med. J. **1** (1978) 880.

[70] FAJARDO, L.F., STEWART, J.R., Radiation induced heart disease: human and experimental observations, Drug-Induced Heart Disease (BRISTOW, M., Ed.), Vol. 5, Elsevier and North-Holland, Amsterdam and New York (1980) 241.

[71] FAJARDO, L.F., Pathology of Radiation Injury, Masson Publishing, New York (1982).

[72] RUBIN, P., CASARETT, G.W., Clinical Radiation Pathology, W.B. Saunders, Philadelphia (1968).

[73] STEWART, J.R., FAJARDO, L.F., Radiation-induced heart disease, Front. Radiat. Ther. Oncol. **6** (1972) 274.

[74] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION (UNSCEAR), Ionizing Radiation Sources and Biological Effects, 1982 Report to the General Assembly with Annexes, United Nations, New York (1982).

[75] DISASTER RESEARCH CENTRE (DRC), DRC Publications List, Ohio State University, Columbus, Ohio (1981).

[76] LIPTON, R.J., OLSON, E., The human meaning of total disaster: the Buffalo Creek experience, Psychiatry **39** (1976) 1.

[77] ADAMS, P.R., ADAMS, G.E., Mount Saint Helens's ashfall: evidence for a disaster stress reaction, Am. Psychol. **39** 3 (1984) 252.

[78] SELIGMAN, M.E.P., Helplessness: on Depression, Development and Health, Freeman, San Francisco (1975).

[79] LAZARUS, R.S., Psychological Stress and the Coping Process, McGraw Hill, New York (1966).

[80] COX, T., Stress, coping and problem solving, Work and Stress **1** (1987) 5.

[81] BROWN, G., HARRIS, T., Social Origins of Depression, Tavistock, London (1978).

[82] BAUM, A., GATCHELL, R.J., SCHAEFFER, M., Emotional, behavioural and physiological effects of chronic stress at Three Mile Island, J. Consult. Clin. Psychol. **51** (1983) 565.

[83] COLLINS, D.L., BAUM, A., SINGER, J.E., Coping with chronic stress at Three Mile Island, J. Appl. Soc. Psychol. **128** (1983) 280.

[84] ROMANENKO, A.E., "Protection of health during a large scale accident", Medical Aspects of the Chernobyl Accident, IAEA-TECDOC-516, IAEA, Vienna (1989) 65.

[85] LEE, T.R., Paper delivered at IAEA Scientific Meeting (1988) Vienna (unpublished).

[86] LEE, T.R., "Moving house and home", On the Move: The Psychology of Change and Transition (FISHER, S., COOPER, G., Eds), Wiley, Chichester (1990).

[87] HARSHBARGER, P., "An ecologic perspective on disaster intervention", Emergency and Disaster Management (PARAD, H.J., RESNICK, H.O.P., PARAD, L.G., Eds), Charles Press, Bowie, MD, USA (1976).

[88] COHEN, M.M., DIAMOND, J.M., Are we losing the war on cancer?, Nature **323** (1986) 488.

[89] PARR, R.M., SCHELENZ, R., BALLESTRA, S., IAEA biological reference materials, Fresenius' Z. Anal. Chem. **332** (1988) 518.

[90] PARR, R.M., et al., "Dietary intakes of trace elements and related nutrients in eleven countries: Preliminary results from an IAEA coordinated research programme", Trace Elements in Man and Animals (Proc. 7th Int. Symp. Dubrovnik, 1990), IMI, University of Zagreb, Zagreb (1991).

[91] CORTES TORO, E., PARR, R.M., CLEMENTS, S.A., Biological and Environmental Reference Materials for Trace Elements, Nuclides and Organic Microcontaminants: A Survey, Rep. IAEA/RL/128 (Rev. 1), IAEA, Vienna (1990).

[92] WORLD HEALTH ORGANIZATION, Energy and Protein Requirements, Technical Reports Series No. 724, WHO, Geneva (1985).

[93] INTERNATIONAL COUNCIL FOR CONTROL OF IODINE DEFICIENCY DISORDERS (ICCIDD), A Practical Guide to the Correction of Iodine Deficiency, Technical Manual No. 3, ICCIDD, WHO (1990).

[94] WORLD HEALTH ORGANIZATION, Trace Elements in Human Nutrition, Report of an Expert Consultation, June 1990 (in preparation).

[95] WORLD HEALTH ORGANIZATION, Environmental Health Criteria 3, Lead, WHO, Geneva (1977).

[96] LEE, W.R., MOORE, M.R., Low level exposure to lead — the evidence for harm accumulates, Br. Med. J. **301** (1990) 504.

[97] WORLD HEALTH ORGANIZATION, Evaluation of Certain Food Additives and Contaminants, Technical Reports Series No. 751, WHO, Geneva (1987).

[98] FOOD AND AGRICULTURE ORGANIZATION, Meeting the Nutrition Challenge, a Joint FAO/WHO Framework Paper, FAO, Rome (1990).

[99] FOOD AND AGRICULTURE ORGANIZATION, Requirements of Vitamin-A, Iron, Folate and Vitamin-B12, FAO, Rome (1988).

[100] INTERNATIONAL ATOMIC ENERGY AGENCY, Human Dietary Intakes of Trace Elements: a Global Survey, IAEA-TECDOC (in preparation).

[101] IYENGAR, V., WOITTIEZ, J., Trace elements in human clinical specimens: evaluation of literature data to identify reference values, Clin. Chem. **34** (1988) 474.

[102] PRASAD, A.S., "Clinical spectrum and diagnostic aspects of human zinc deficiency", Current Topics in Nutrition and Disease, Vol. 18, Alan R. Liss, New York (1988).

[103] CASEY, C.E., Selenophilia, Proc. Nutr. Soc. **47** (1988) 55.

[104] ROSENFELD, I., BEATH, O.A., Selenium: Geobotany, Biochemistry, Toxicity and Nutrition, Academic Press, New York (1980).

[105] YANG, G., et al., Endemic selenium intoxication in humans in China, Am. J. Clin. Nutr. **37** (1983) 872.

[106] ARTHUR, J.R., NICOL, F., BECKETT, G.F., Hepatic iodothyronine 5'-deiodinase: The role of selenium, Biochem. J. **272** (1990) 537.

[107] BEHNE, D., KYRIAKOPOULOS, A., MEINHOLD, H., KÖHRLE, J., Identification of type I iodothyronine 5'-deiodinase as a selenoenzyme, Biochem. Biophys. Res. Commun. **173** (1990) 1143.

[108] KAPLAN, N.M., Dietary salt intake and blood pressure, J. Am. Med. Assoc. **251** (1984) 1429.

[109] INTERSALT COOPERATIVE RESEARCH GROUP, Intersalt: An international study of electrolyte excretion and blood pressure: Results for 24 hour urinary sodium and potassium excretion, Br. Med. J. **297** (1988) 319.

[110] JOOSSENS, J.V., Salt and cancer, Nutr. Cancer **8** (1986) 29.

[111] OTAKE, M., SCHULL, W.J., The relationship of gamma and neutron radiation to posterior lenticular opacities among atomic bomb survivors in Hiroshima and Nagasaki, Radiat. Res. **92** (1982) 574.

[112] OTAKE, M., SCHULL, W.J., Radiation-Related Posterior Lenticular Opacities in Hiroshima and Nagasaki Atomic Bomb Survivors Based on T65DR and DS86 Dosimetry Systems, Rep. RERF-TR-4-89, Radiation Effects Research Foundation, Hiroshima, Japan (1982).

[113] CHOSHI, K., et al., Ophthalmologic Changes Related to Radiation Exposure and Age in the Adult Health Study Sample, Hiroshima and Nagasaki, Rep. RERF-TR-8-82, Radiation Effects Research Foundation, Hiroshima, Japan (1982).

[114] CHOSHI, K., et al., Ophthalmologic changes related to radiation exposure and age in adult health study sample, Hiroshima and Nagasaki, Radiat. Res. **96** (1983) 560.

[115] DODO, T., Cataracts, review of thirty years study of Hiroshima and Nagasaki atomic bomb survivors, J. Radiat. Res., Suppl. (1975) 132.

[116] MERRIAM, G.R., SZECHTER, A., FOCHT, E.F., The effects of ionizing radiations on the eye, Front. Radiat. Ther. Oncol. **6** (1972) 346.

[117] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION (UNSCEAR), Genetic and Somatic Effects of Ionizing Radiation, 1986 Report to the General Assembly with Annexes, United Nations, New York (1986).

[118] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION (UNSCEAR), Sources, Effects and Risks of Ionizing Radiation, 1988 Report to the General Assembly with Annexes, United Nations, New York (1988).

[119] HIGH BACKGROUND RADIATION RESEARCH GROUP, China health survey in high background radiation areas in China, Science **209** (1980) 877.

[120] Late Biological Effects of Ionizing Radiation (Proc. Symp. Vienna, 1978), 2 vols, IAEA, Vienna (1978).

[121] DOLL, R., PETO, R., The Causes of Cancer: Quantitative Assessment of Avoidable Risks of Cancer in the United States Today, Oxford University Press, Oxford (1981) (first published in J. Natl. Cancer Inst. **66** (1981) 1191).

[122] BEEBE, G.W., KATO, H., LAND, C.E., Studies of the mortality of A-bomb survivors. 6. Mortaility and radiation dose, 1950–1974, Radiat. Res. **75** (1978) 138.

[123] BEEBE, G.W., KATO, H., LAND, C.E., Studies of the Mortality of A-bomb Survivors. 1. Mortality Experience of A-Bomb Survivors, 1950–1974. Rep. RERF-TR-1-77, Radiation Effects Research Foundation, Hiroshima, Japan (1977).

[124] BERAL, V., et al., Mortality of employees of the United Kingdom Atomic Energy Authority, 1946–1979, Br. Med. J. **291** (1985) 440.

[125] BOICE, J.D., HUTCHINSON, G.B., Leukaemia and women following radiotherapy for cervical cancer: Ten year follow-up of an international study, J. Natl. Cancer Inst. **65** (1980) 115.

[126] BOICE, J.D., et al., "Cancer risk following radiotherapy of cervical cancer: A preliminary report", Radiation Carcinogenesis: Epidemiology and Biological Significance (BOICE, J.D., FRAUMENI, J.F., Eds), Raven Press, New York (1984) 161.

[127] DARBY, S.C., et al., Long term mortality after a single treatment course with X-rays in patients treated for ankylosing spondylitis, Br. J. Cancer **55** (1987) 179.

[128] DARBY, S.C., NAKASHIMA, E., KATO, H., A parallel analysis of cancer mortality among atomic bomb survivors and patients with ankylosing spondylitis given X-ray therapy, J. Natl. Cancer Inst. **75** (1985) 1.

[129] KATO, H., SCHULL, W.J., Studies of the mortality of A-bomb survivors. 7. Mortality 1950–1978; Part 1, Cancer mortality, Radiat. Res. **90** (1982) 395.

[130] PRESTON, D.L., KATO, H., KOPECKY, K.J., FUJITA, S., Life Span Study Report 10, Part 1, Cancer Mortality Among A-Bomb Survivors in Hiroshima and Nagasaki, 1950–1982. Rep. RERF-TR-1-86, Radiation Effects Research Foundation, Hiroshima, Japan (1987).

[131] PRESTON, D.L., KATO, H., KOPECKY, K.J., FUJITA, S., Life span study report 10, Part 1: Cancer mortality among A-bomb survivors in Hiroshima and Nagasaki, 1950–1982. Radiat. Res. **111** (1987) 151.

[132] LAND, C.E., NORMAN, J.E., "Latent period for radiogenic cancers occurring among Japanese A-bomb survivors", Late Biological Effects of Ionizing Radiation (Proc. Symp. Vienna, 1978), Vol. 1, IAEA, Vienna (1978) 29.

[133] CONARD, R.A., Acute myelogenous leukemias following fallout radiation exposure, J. Am. Med. Assoc. **232** (1975) 1356.

[134] FINCH, S.C., "Leukaemia and lymphoma in atomic bomb survivors", Radiation Carcinogenesis: Epidemiology and Biological Significance (BOICE, J.D., FRAUMENI, J.F., Eds), Raven Press, New York (1984) 37.

[135] HUTCHINSON, G.B., Leukemia in patients with cancer of the cervix uteri treated with radiation: A report covering the first five years of an international study, J. Natl. Cancer Inst. **49** (1968) 951.

[136] ICHIMARU, M., et al., Incidence of Leukemia in A-Bomb Survivors by Dose, Years after Exposure, Age and Type of Leukemia, 1950–1971, Rep. RERF-TR-10-76, Radiation Effects Research Foundation, Hiroshima, Japan (1976).

[137] LAND, C.E., McKAY, F.W., MACHADO, S.G., Childhood leukemia and fallout from the Nevada nuclear tests, Science **223** (1984) 139.

[138] CONARD, R.A., "Late radiation effects in Marshall islanders exposed to fallout 28 years ago", Radiation Carcinogenesis: Epidemiology and Biological Sig-

nificance (BOICE, J.D., FRAUMENI, J.F., Eds), Raven Press, New York (1984) 57.
[139] DUFFY, B.J., FITZGERALD, P.J., Cancer of the thyroid in children. A report of 28 cases, J. Clin. Endocrinol. Metab. **10** (1950) 1296.
[140] PARKER, L.N., et al., Thyroid Carcinoma Diagnosed between 13 and 26 Years after Exposure to Atomic Radiation. Rep. ABCC-JNIH-5-73, Atomic Bomb Casualty Commission/Japanese National Institute of Health, Nagasaki, Japan (1973).
[141] RON, E., et al., Thyroid neoplasia following low-dose radiation in childhood, Radiat. Res. **120** (1989) 516.
[142] SHORE, R.E., et al., Thyroid tumors following thymus irradiation, J. Natl. Cancer Inst. **74** (1985) 1177.
[143] NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS (NCRP), Induction of Thyroid Cancer by Ionizing Radiation, Rep. NCRP No. 80, Bethesda, MD, NCRP, USA (1985).
[144] BRENT, R.L., GORSON, R., "Radiation exposure in pregnancy", Current Problems in Radiology, Year Book Medical Publishers Chicago (1972).
[145] DEKABAN, A.S., Abnormalities in children exposed to X-radiation during various stages of gestation. A tentative time table of radiation injury in the human fetus, J. Nucl. Med. **9** (1978) 47.
[146] HOFFMAN, D.A., FELTEN, R.P., CYR, W.H., Effects of Ionizing Radiation on the Developing Embryo and Fetus: A Review, Rep. HHS/PUB/FDA-81-8170, Health and Human Services Publication, Food and Drug Administration, Washington, DC (1981).
[147] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Developmental Effects of Irradiation on the Brain of the Embryo and Fetus, Publication 49, Pergamon Press, Oxford and New York (1986).
[148] MILLER, R.W., MULVIHILL, J.J., Small head size after atomic irradiation, Teratology **14** (1976) 355.
[149] OTAKE, M., SCHULL, W.J., YOSHIMARU, H., A Review of Radiation Related Brain Damage in the Prenatally Exposed Atomic Bomb Survivors, Rep. RERF-TR-4-89, Radiation Effects Research Foundation, Hiroshima, Japan (1989).
[150] OTAKE, M., et al., Congenital Malformations, Stillbirths, and Early Mortality among the Children of Atomic Bomb Survivors: A Reanalysis, Rep. RERF-TR-13-89, Radiation Effects Research Foundation, Hiroshima, Japan (1989).
[151] OTAKE, M., SCHULL, W.J., In utero exposure to A-bomb radiation and mental retardation. A reassessment, Br. J. Radiol. **57** (1984) 409.
[152] OTAKE, M., YOSHIMARU, H., SCHULL, W.J., Severe Mental Retardation among the Prenatally Exposed Survivors of the Atomic Bombing of Hiroshima and Nagasaki: A Comparison of the T65DR and DS86 Dosimetry Systems, Rep. RERF-TR-16-87, Radiation Effects Research Foundation, Hiroshima, Japan (1987).
[153] YAMAZAKI, J.N., WRIGHT, S.W., WRIGHT, P.M., A study of the outcome of pregnancy in women exposed to the atomic bomb in Nagasaki, J. Cell Comp. Physiol. **43** (1954) 319.
[154] YAMAZAKI, J.N., WRIGHT, S.W., WRIGHT, P.M., Outcome of pregnancy in women exposed to the atomic bomb in Nagasaki, Am. J. Dis. Child. **87** (1954) 448.
[155] YOSHIMOTO, Y., KATO, H., SCHULL, W.J., Risk of Cancer among in Utero Children Exposed to A-Bomb Radiation, 1950–1984, Rep. RERF-TR-4-88, Radiation Effects Research Foundation, Hiroshima, Japan (1988).
[156] MacMAHON, B., Prenatal X-ray exposure and childhood cancer, J. Natl. Cancer Inst. **28** (1962) 1173.
[157] COURT-BROWN, W.M., DOLL, R., HILL, A.B., Incidence of leukemia after exposure to diagnostic radiation in utero, Br. Med. J. **2** (1960) 1539.
[158] JABLON, S., KATO, H., Sex ratio in offspring survivors exposed prenatally to the atomic bombs in Hiroshima and Nagasaki, Am. J. Epidemiol. **93** (1971) 253.
[159] ABRAHAMSON, S., "Risk estimates for genetic effects", Assessment of Risk from Low Level Exposure to Radiation and Chemicals: A Critical Overview (WOODHEAD, A.D., et al., Eds), Plenum Press, New York (1985) 223.
[160] NEEL, J.V., et al., Search for Mutations Altering Protein Structure and/or Function in Children of Atomic Bomb Survivors: Final Report, Rep. RERF-TR-10-87, Radiation Effects Research Foundation, Hiroshima, Japan (1987).
[161] NEEL, J.V., et al., Search for mutation affecting protein structure in children of atomic bomb survivors: Preliminary report, Proc. Natl. Acad. Sci. U.S.A. **77** (1980) 4221.
[162] SCHULL, W.J., OTAKE, M., NEEL, J.V., "Hiroshima and Nagasaki: A reassessment of the mutagenic effect of exposure to ionizing radiation", Population and Biological Aspects of Human Mutation, Academic Press, New York (1981) 277.
[163] SCHULL, W.J., OTAKE, M., NEEL, J.V., Genetic effects of the atomic bomb: a reappraisal, Science **213** (1981) 11.
[164] SCHULL, W.J., KATO, H., Malignancies and exposure of the young to ionizing radiation, Cancer Bull. **34** (1982) 84.
[165] YOSHIMOTO, Y., NEEL, J.V., SCHULL, W.J., Frequency of Malignant Tumors during the First Two Decades of Life in the Offspring (F1) of Atomic Bomb Survivors, Rep. RERF-TR-4-90, Radiation Effects Research Foundation, Hiroshima, Japan (1990).
[166] CZEIZEL, A., The base-line data of the Hungarian congenital malformation Registry, 1970–1976, Acta Paediatr. Acad. Sci. Hung. **19** (1978) 149.
[167] CZEIZEL, A., The Hungarian congenital monitoring system, Acta Paediatr. Acad. Sci. Hung. **19** (1978) 225.
[168] MYNANTHOPOULOS, N.C., CHUNG, C.S., "Congenital malformations in Singletons: Epidemiological survey", Vol. 10, Birth Defects Original Article Series, The National Foundation, March of Dimes, White Plains, New York (1974) 1.
[169] KULESHOV, N.P., Chromosome anomalies of infants dying during the perinatal period, Hum. Genet. **23** (1976) 151.

[170] MAEDA, T., et al., A cytogenetic survey of consecutive liveborn infants: incidence and type of chromosome abnormalities, Jap. J. Hum. Genet. **23** (1978) 217.

[171] WALZER, S., GERALD, P.S., "A chromosome survey of 13 571 male newborns", Population Cytogenetics: Studies in Humans (HOOK, E.B., PORTER, I.H., Eds), Academic Press, New York (1977) 45.

[172] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. 1990 Recommendations of the International Commission on Radiological Protection, Publication 60, Pergamon Press, Oxford and New York (1990).

Annex
List of Analysts and Methods

Analyst code	Address of institute	Responsible analyst(s)	Elements analysed	Matrix	Analytical method	Quality control
AUS-1	Bundesanstalt für Lebensmitteluntersuchung und Forschung Kinderspitalgasse 15 A-1090 Vienna, Austria	F. Vojir R. Zahlbruckner	Lead, cadmium	Foodstuffs, diets	AAS (atomic absorption spectrometry) with Zeeman background correction; graphite furnace with platform; ammonium phosphate as matrix modifier	Reference materials: IAEA-155, IAEA-H-9, IAEA-V-10, Bowen's Kale, ARC/CL-TD, NIST-SRM-1575
AUS-2	Bundesanstalt für Lebensmitteluntersuchungen Beethovenstraße 8 A-8010 Graz, Austria	H. Holzer R. Schindler	Lead, cadmium	Foodstuffs, diets, milk	AAS with Zeeman background correction; graphite furnace, palladium/magnesium nitrate (for lead) and palladium/magnesium nitrate + ammonium phosphate (for cadmium) as matrix modifiers	Reference materials: IAEA-155, IAEA-H-9, IAEA-A-11, Bowen's Kale, ARC/CL-TD
FIN-1	Agricultural Research Centre of Finland Central Laboratory SF-31600 Jokioinen, Finland	J. Kumpulainen	Boron, calcium, cadmium, iron, potassium, magnesium, manganese, sodium, phosphorus, lead, selenium, zinc	Diets	AAS with Zeeman background correction and using ammonium-di-hydrogen-phosphate matrix modifier for cadmium and lead, method of standards addition for cadmium, lead and selenium; ICP-ES (inductively coupled plasma emission spectrometry) simultaneously measured for other elements	Reference materials: IAEA-153, ARC/CL-TD, Bowen's Kale, NIST-RM-8431a, internal materials
GER-1	Medizinische Universitätsklinik für Innere Medizin Ratzeburger Allee 160 D-W-2400 Lübeck, Germany	R. Gutekunst	Iodine	Urine	Spectrophotometry	Internal standards
IAEA-1	International Atomic Energy Agency Laboratory Seibersdorf A-1400 Vienna, Austria	R. Ogris	Mercury, cadmium, selenium, cobalt, rubidium, chromium, iron, zinc	Diets	NAA (neutron activation analysis); most analyses done instrumentally; some values checked by the use of a radiochemical separation (solvent extraction) prior to the activity measurement	IAEA certified biological reference materials
IAEA-2	International Atomic Energy Agency Laboratory Seibersdorf A-1400 Vienna, Austria	E. Wehrstein-Werner	Lead, cadmium, potassium, sodium, copper, manganese, zinc	Diets, water	AAS: flame AAS for zinc, potassium, sodium; rest: graphite furnace with Zeeman background correction, matrix modifiers: ammonium phosphate for lead and cadmium, lanthanum for sodium and potassium	Reference materials: IAEA-A-11, IAEA-H-9, NIST-SRM-1643b

Part F

Analyst code	Address of institute	Responsible analyst(s)	Elements analysed	Matrix	Analytical method	Quality control
IAEA-3	International Atomic Energy Agency Laboratory Seibersdorf A-1400 Vienna, Austria	E. Zeiler	Calcium, magnesium, manganese, phosphorus, copper, zinc	Diets	ICP-ES, copper sequentially, rest simultaneously	Reference materials: IAEA-H-9, NIST-SRM-1643b
ITA-1	ENEA CRE Casaccia Area Ambiente AMB-BIO S.P. Anguillarese 301 I-00600 Rome, Italy	G. Ingrao	Scandium, rubidium, zinc, iron, cobalt, barium, nickel, manganese, selenium, europium, antimony, silver, cerium, selenium, mercury, chromium, caesium	Diets	INAA (instrumental neutron activation analysis)	Reference materials: IAEA-H-9, Bowen's Kale
ITA-2	National Institute of Nutrition Via Ardeatina 546 I-00179 Rome, Italy	G.P. Santaroni	Lead	Diets	AAS, method of standard additions	Reference material: IAEA-H-9
NET-1	Delft University of Technology Interfaculty Reactor Institute Department of Radiochemistry Mekelweg 15 NL-2629 JB Delft Netherlands	G.J. van den Berg M.J.J. Ammerlaan K.J. Volkers U.D. Woroniecka H.T. Wolterbeek	Lead, cadmium	Lichen	INAA for cadmium, AAS graphite furnace for lead, method of standard additions	Reference material: BCR-CRM-060; internal standards
SWE-1	Department of Occupational Medicine University Hospital S-22185 Lund, Sweden	A. Schütz M. Abdulla	Lead, cadmium, zinc, iron, copper	Blood	AAS, flame and graphite furnace	Internal standards, Seronorm
UK-1	Surrey Chemical Trace Analysis Research Department of Chemistry University of Surrey Guilford, Surrey GU2 5XH United Kingdom	N. Ward	Aluminium, arsenic, boron, barium, bromine, calcium, cadmium, cobalt, copper, chromium, iron, manganese, magnesium, molybdenum, nickel, lead, rubidium, selenium, strontium, vanadium, zinc	Hair	ICP-MS (inductively coupled plasma mass spectrometry), multielement scan conditions	SINR Chinese reference hair (RM)
YUG-1	E. Kardelj University Jozef Stefan Institute Nuclear Chemistry Department Jamova 39 YU-61111 Ljubljana Yugoslavia	P. Stegnar A. Prosenc M. Dermelj V. Stibilj	Selenium, cadmium, iodine	Diets, salts, blood	RNAA (neutron activation analysis with radiochemical separation)	Reference materials: NIST-SRM-1566a, NIST-SRM-1549, IAEA-MA/86, IAEA-MA(S), NRCC-TORT-1

Part G
Protective Measures

Contents

1. Introduction

One of the main objectives of the International Chernobyl Project was to conduct an independent evaluation of the protective measures taken or proposed since the accident, in particular those taken to ensure that people in the affected areas could continue to live there 'safely'. As indicated in Part B, 'safety', 'safe' and 'safely' are complex concepts. In common language they convey a sense of freedom from danger. In technical language, however, the terms are used to help formulate effective methods of preventing or minimizing harm. The difference between these two meanings has caused many problems of interpretation in the past and, indeed, was found to be one of the more difficult issues to be addressed in the affected areas. It has to be recognized that total freedom from risk, or absolute safety, is impossible to achieve even in everyday life.

Decisions on the introduction of protective measures are complex in that they require a balance to be made between a number of conflicting objectives. In the simplest of cases such decisions are complex and, inevitably, will be open to criticism and challenge because value judgements will often be implicit in the process. Given the unprecedented scale and extent of the protective measures which had to be taken following the Chernobyl accident, it is hardly surprising that there has been much debate and disagreement over the measures taken. The continuing need to take measures several years after the accident has exacerbated these difficulties; it has provided the opportunity for continuing debate of the issue among various groups with diverse interests which, in turn, may have led to increased anxiety among those affected. The politicization of the issue in the more recent past, together with the changes under way in the Soviet political and economic system, have added to the difficulty of achieving consensus in the USSR on this topic.

Matters beyond those which are strictly concerned with radiological protection are central to attitudes and decisions on what constitutes the most appropriate strategy of protective measures in the current circumstances. The problem cannot be assessed in the abstract and due consideration is needed of the prevailing circumstances in which decisions in this area need to be taken. Consequently, judgements on the most appropriate protective measures may differ, even for the same radiological circumstances, where factors of a social or political nature are dominant. In undertaking this evaluation, an attempt has been made, as far as was possible, to make a clear separation between the sociopolitical aspects of the problem and the somewhat more tangible aspects, such as the health risks of continuing to live in the affected settlements and the costs of protective measures to ameliorate them.

The evaluation of protective measures consisted of three main parts. First, the criteria adopted or proposed by the Soviet authorities for the introduction of protective measures were compared with international guidance, in particular that developed by the IAEA. Both the numerical criteria and their conceptual bases were compared. Second, an evaluation was made of the additional risks to health of continuing to live in the affected areas and also of the costs and the doses (and risks) that could be averted by the introduction of two of the protective measures, restriction of foodstuffs and relocation. This analysis was undertaken in order to put into perspective the additional risks of continuing to live in the affected areas and the monetary resources being spent, or proposed to be spent, to ameliorate them. Comparisons with other risks experienced in everyday life and with expenditures on health improvement in other areas provide one means of doing this; however, factors other than cost and risk reduction are often relevant to judgements on the introduction of protective measures. Third, an evaluation was made of those other factors (in addition to cost and risk) which may be relevant to decisions on the introduction of protective measures in the affected areas. This was accomplished largely by holding five Decision Conferences (at the level of each Republic, at the All-Union level and a final combined Conference) which were attended by those with responsibility for policy on intervention, together with their scientific and technical advisers. The potentially relevant factors were elicited in these Conferences and insights gained on the relative importance being accorded to each.

The evaluation naturally focused on the measures taken, or planned to be taken, from 1990 onwards, as this was the central issue raised by the Soviet authorities in their request to the IAEA. The evaluation of measures taken prior to 1990 was undertaken largely to obtain a historical perspective but, more importantly, because past actions often influence or constrain future options. The evaluation of pre-1990 measures was, however, confined largely to the first of the three elements identified above, that of comparing the criteria and their conceptual basis with international guidance.

The evaluation was constrained by the short time available for its completion and by the lack of adequate data. In some cases the intended evaluation approach had to be changed in order to accommodate these constraints, in particular in the following two areas. First, the evaluation of costs and benefits of relocation had to be undertaken generically, rather than for a number of individual settlements having different social and economic characteristics. Second, the evaluation of the costs and benefits of food restrictions was severely constrained by the few data on the costs and efficacy of the wide range of measures that have been successfully implemented to reduce internal exposures. As a consequence of these limitations, the evaluation was less rigorous and comprehensive than originally intended; the conclusions reached from the evaluation are, therefore, in need of greater qualification than would otherwise have been necessary.

The international guidance on protective measures is summarized in Section 2, and more fully in Annex 1 in this Part. The criteria adopted or proposed by the Soviet authorities for the introduction of protective measures are described in Section 3. The evaluation of each of the protective measures is set out in Section 4 and the conclusions and recommendations reached in Section 5. More detail is provided in Annexes 2 and 3 on the cost–benefit analyses undertaken of relocation as a protective measure, and on the Decision Conferences, where radiological and non-radiological factors and the weight being given to them were studied.

2. International Principles for Intervention Following a Radiological Accident

2.1. Introduction

The control of exposures following an accident in which radionuclides are released into the environment can only be achieved by some form of intervention. The intervention is implemented using one or more of a range of protective measures: sheltering, administration of stable iodine (if radioiodine is a part of the source term), evacuation, relocation, respiratory protection, personal decontamination, control of access, food and water controls, decontamination of land and property and the use of personal protective clothing. The principles that have been developed internationally on intervention are broad, leaving room for the particular circumstances of the occurrence to dictate the action that is to be taken. Such decisions cannot be undertaken lightly, since all of these measures either modify the environment or restrict people's freedom of action or choice. Intervention will therefore impose costs on society and may cause direct harm and disruption of life to some people.

Intervention can be said to be justified when there is a net benefit in taking action. This statement is not as simple as it may seem. Providing the exposure is well below the thresholds for deterministic effects, the harm of intervention may outweigh the good achieved by avoiding the exposure. Most intervention is disruptive to normal or routine social and economic life. Change causes anxiety, which could be more harmful to overall health and well-being than the radiation itself. On the other hand, not receiving protective measures can also cause anxiety, which in turn is often enhanced by the media. These considerations complicate decisions on intervention which, in general, must involve persons and perspectives from outside the radiation protection community.

Once a course of intervention has been chosen, the protective measures taken should be optimized. Broadly speaking, this means that the reduction of doses achieved: the doses averted, should be balanced against the cost (in the broadest of senses, i.e. monetary, social, etc.) of the measures taken to reduce these doses.

2.2. Basic Principles for Intervention

The principles underlying intervention are described fully in Annex 1. They can be summarized as follows:

(a) The intervention should be justified in the sense that introduction of the protective measure should achieve more good than harm.
(b) The level at which the intervention is introduced, and the level at which it is later withdrawn, should be optimized so that they will produce maximum net benefit.
(c) All possible effort should be made to prevent serious deterministic health effects by restricting doses to individuals to levels below the threshold for such effects.

2.3. Misconceptions on Intervention Levels and Dose Limits

A number of misunderstandings or misconceptions have been evident regarding the basic principles that underlie intervention. Some of the more common of these concern the relevance of dose limits, the relevant dosimetric quantity to be used in balancing the costs and benefits of intervention, and the degree of realism to be included in dose and cost estimates. Those aspects are considered in more detail in Annex 1 and in Refs [1, 2] and clarification is provided of some of the more important issues in what follows.

2.3.1. Intervention Levels and Dose Limits

There has been much confusion over the role of dose limits in the establishment of intervention levels following an accident. Several factors have contributed to this confusion, not least the numerical equality between some of the intervention levels of the dose proposed and the annual dose limits. Notwithstanding such equality, the two are very different in principle, in their aims and how they are derived. It is important that these differences are recognized; failure to do so may lead to the use of dose limits in situations for which they are not appropriate and to the introduction of intervention levels that may not be in the best interests of those affected.

The aims of intervention levels are quite different from those of dose limits. The dose limits recommended by the International Commission on Radiological Protection (ICRP) [3] are meant to apply to the sum of the doses from a specified combination of sources, a combination which, among others, does not include exposures from nuclides present in the environment due to accidents. Intervention levels relate specifically to the course of action or protective measure being considered following the accidental release of radionuclides and concern solely the situation following an accident. The choice of intervention levels should, in principle, depend upon the circumstances of an accident, although it may be possible to establish levels which are sufficiently 'robust' for application in a wide range of circumstances.

One area where there has been much confusion over the role of dose limits in determining intervention has been the imposition of foodstuff restrictions in the longer term following an accident and at distances far from the release (e.g. the situation in western Europe and elsewhere after the Chernobyl accident). It has been argued that, because exposures from contaminated foodstuffs are controllable (i.e. by restricting their production or consumption), they should be subjected to the full system of dose limitation, including the application of the dose limits recommended by the ICRP. However, this represents a misinterpretation of the intent of the ICRP's recommendations [3].

The situation with regard to the control of exposure from foodstuffs contaminated as a result of an accident is similar in nature to that for some sources of natural radiation which are also excluded from the combination of sources to which the dose limits apply. Unlike controllable sources of radiation to which the dose limitation system applies, the detriment associated with these natural sources is not offset by any corresponding net benefit. Intervention can only mitigate the problem and, at best, reduce the radiological component of the detriment to zero.

Controllability must, therefore, be a major consideration in determining the combination of sources to be included within any system of dose limitation. From this viewpoint, there is a clear difference between existing exposure situations (e.g. from radionuclides already present in the environment from whatever origin), where any control would involve intervention or remedial measures within that environment (i.e. either directly or on people), and future situations (e.g. effluents from nuclear installations) which can be subject to limitation and control during the design and planning stages. For radionuclides already present in the environment, exposures can only be altered by taking remedial measures. As an aid to decisions on the introduction of such measures, the ICRP has recommended the use of intervention levels specific to the protective measure being considered [4]. Such intervention levels, however, should not be determined, nor indeed be overly influenced, by the existence of any limits intended for application to future situations, nor specifically by the primary dose limits recommended by the ICRP for members of the public [3].

2.3.2. Relevant Doses for Comparison with Intervention Levels

In accordance with the underlying principles of intervention, only those pathways and doses that may be influenced by the protective measure, i.e. the doses averted, should be taken into account in judging whether the protective measure should be implemented and, if so, at what level. The inclusion of doses that have already been received before a protective measure is implemented in estimating the dose for comparison with the intervention level is wrong in principle and practice. The projected dose averted by the protective measure is the relevant quantity that should be used for this purpose.

2.3.3. Realism in the Application of Intervention Levels

The guidance developed internationally on realism in the application of intervention levels is clear. In general, the criteria should be applied to an average member of the group affected by the protective measure and the estimate of dose, or other quantity for comparison with the intervention level, should be as realistic as possible. The adoption of conservative approaches in either the choice of a critical group or the dose assessment will result inevitably in action being taken that is sub-optimal and contrary to the principles and purposes of intervention.

The adoption of a conservative approach in the estimation of dose is often defended as being beneficial to those affected on the grounds that action will be taken at lower doses than intended and this is in their best interests. This view is, however, misguided and ignores the negative features of the protective measure itself, which may be considerable. The assumption of habits typical of more extreme members of the affected group would distort the overall balance being attempted between the radiation risk averted and the risk and cost resulting from the protective measure; the inevitable outcome of this would be that the overall risk and/or cost to which the affected group would be exposed would be higher than it need have been. If the intervention criterion has been properly evaluated as being the best for the prevailing circumstances, the subsequent inclusion of pessimism or optimism in any aspect of its application can only be detrimental and in conflict with the principles and objectives of intervention.

The choice of average habits will, however, only remain reasonable provided the variation in risk (both that associated with the exposure and the protective measure) within the affected group is not too great. In establishing intervention levels for application to general groups in the population, it will be necessary, therefore, to ensure that the variation in the overall risk within the affected group is not too great. Where it is, consideration should be given to the establishment of intervention levels for particular subgroups in a population and to the introduction of protective measures in a differential manner. The potential difficulties of introducing protective measures selectively into a general population should not, however, be underestimated (e.g. selective evacuation of individual members of a family group) and in some cases they may be sufficient to preclude such a course of action.

3. The USSR's Policy of Protection Following the Chernobyl Accident

3.1. Introduction

After the Chernobyl accident occurred, a number of radiation protection criteria were adopted by the authorities to protect the public in the affected areas. The basic intervention criteria and related action levels were established for two time periods: 26 April 1986 to 31 December 1989, and from 1 January 1990 onwards. The criteria were established by the National Commission for Radiological Protection (NCRP) of the USSR and approved by the Ministry of Health of the USSR as temporary dose limits, lifetime dose limits, surface contamination limits and derived intervention levels [5-9].

If the projected (calculated) doses over a given time period to the affected population exceeded the intervention level for a given protective measure, this measure was introduced. People were allowed to continue to live normally in areas only if the projected doses were less than the intervention level. Measures were introduced as soon as practicable once the projected doses to the critical group were estimated to exceed the intervention level, even where this could only occur far in the future.

3.2. Evacuation and Thyroid Blocking

3.2.1. Criteria and Their Practical Implementation

Early countermeasures, such as sheltering, stable iodine administration and evacuation, were introduced following the accident. The intervention levels of doses adopted for these protective measures were below the threshold doses for deterministic effects. The objective of the early protective measures was to reduce the health risks (i.e. of cancer in those exposed and hereditary effects in their descendants) for those groups potentially at greatest risk from the accident. In 1983, the Ministry of Health of the USSR approved the 'Criteria for Decision Making on Measures to Protect the Population in the Event of a Reactor Accident'. Intervention levels for evacuation expressed as doses projected over the first week after the accident were given for whole body exposure and exposure of separate organs. These intervention levels are shown in Table 1 [10].

TABLE 1. Intervention Levels (ILs) for Evacuation and Thyroid Blocking

Organ of reference	IL (mGy)[a]	
	Evacuation	Thyroid blocking
Whole body	250-750	—
Thyroid	300-2500	300—2500

[a] Dose projected in the first week of the accident to be compared with the intervention level.

TABLE 2. Derived Intervention Levels (DILs) for Evacuation

Evacuation strategy	DIL (mGy/h)[a]
Immediate and compulsory for everyone	>1.0
For women and children	0.1—1.0
No evacuation	<0.1

[a] Gamma dose rate measured 1 m above the ground surface.

On the basis of the above intervention levels of dose, derived intervention levels were established and were used as the basis for decisions on evacuation. The derived levels were expressed in terms of the gamma dose rate from deposited material on ground surfaces and are summarized in Table 2.

In calculating the derived intervention levels (DILs), account was taken of all relevant pathways of exposure (external radiation from the cloud and deposited material and inhalation) and of the influence of shielding while indoors. Reduction factors of 0.46 and 0.24, respectively, were applied to the external dose rates measured in open areas to take account of time spent indoors in rural and urban areas. A gamma dose rate at day 1 of 1 mSv/h corresponded to an integrated dose from deposited material over one week of about 50 mSv and 100 mSv in urban and rural areas, respectively. Doses in urban areas are lower than those in rural areas because urban buildings generally afford more protection.

3.3. Decontamination of Surfaces

In May–June 1986, DIL values for decontamination of different surfaces were established [11, 12]; these were expressed as gamma exposure rates. The values are shown below:

- Clothes, bedclothes and footwear: 0.1 mR/h[1]
- Outer surfaces of buildings: 0.7 mR/h
- Inner surfaces of buildings: 0.3 mR/h
- Internal surfaces of vehicles: 0.2 mR/h
- Outer surfaces of vehicles: 0.3 mR/h
- Road surfaces, outside populated areas: 1.5 mR/h
- Road surfaces, inside populated areas: 0.7 mR/h

If the exposure rate measured at these surfaces exceeded the DILs, decontamination of the surfaces was introduced.

[1] 1 röntgen (R) = 2.58×10^{-4} C/kg.

3.4. Food Restrictions

3.4.1. Intervention Levels

Intervention levels, specified as doses to be averted from contaminated foodstuffs, are shown in Table 3 [5]. The intervention levels for the years 1986–1989 were calculated from the temporary dose limits (see Table 5) and the assumption that the ratios of internal to external dose were 1:1 in 1986 and 1:2 in each of the years from 1987 to 1989 [5].

3.4.2. Derived Intervention Levels for Foodstuffs

The DILs for foodstuffs were based on the intervention levels of doses in Table 3. The values for ^{134}Cs, ^{137}Cs and ^{131}I are shown in Table 4 [5, 13-16] and were promulgated by the authorities in the USSR. In the BSSR, lower values were adopted.

The following dietary intake, which is a rough average, was used to calculate the DILs:

- Children: 0.7 L/d of milk,
- Adults: 100 g/d of pork, 50 g/d of beef, 210 g/d of vegetables and fruits, 500 g/d of potatoes, 200 g/d of cereals, 0.7 L/d of milk.

Before the accident, a DIL for ^{131}I in milk of 3700 Bq/L existed. This corresponded to a committed dose equivalent of 300 mSv to the thyroid. The same value was introduced after the accident (May 1986) [13]. Samples of foodstuffs were controlled by measurements and, if the activity content exceeded the DILs the foodstuffs were restricted for human consumption.

TABLE 3. Intervention Levels (ILs) of Dose for Foodstuff Restriction [5]

Year	IL (mSv)[a]
1986	50
1987	10
1988	8
1989	8
1990	5

[a] The dose to be compared with the IL is the committed effective dose equivalent from the total annual dietary intake.

TABLE 4. Derived Intervention Levels (DILs) (in Bq/kg[a]) Set by the Authorities in the USSR for ^{134}Cs + ^{137}Cs and ^{131}I in Foodstuffs [5, 13–16]

Foodstuff	^{134}Cs + ^{137}Cs		^{131}I	
	1986–1987	1988–1989	1986	1990
Drinking water	370	18.5	3700	18.5
Milk, dairy products	370–7400[b]	370	3700–74 000[b]	370
Meat, fish, eggs	1850–3700		740–37 000[c]	1850–2960
Potatoes, root crops	3700	740	—	592
Vegetable oil, animal fat	7400	370	—	185
Children's food	—	370	Ten times lower than the above values	185

[a] Fresh weight.
[b] Ranges indicate that each foodstuff in a food category has its own DIL.
[c] DIL set for fish only.

3.5. Relocation

Various concepts and criteria have been adopted and proposed for relocation following the accident. These include temporary dose limits, surface contamination criterion and the lifetime dose limit; each is summarized below.

In the second half of 1990, a multidisciplinary commission was established, comprising some 60 members under the chairmanship of Dr. S.T. Belyaev, to develop "principles and criteria to substantiate practical measures on mitigation of possible negative impacts of the Chernobyl accident on public health and to compensate for damages caused". The work of this commission was incomplete at the time the evaluation was undertaken by the International Chernobyl Project and is therefore not dealt with in this Report.

3.5.1. Temporary Dose Limits

The Ministry of Health of the USSR, on the recommendation of the NCRP, and with the approval of the State Committee on the Rectification of the Consequences of the Chernobyl Accident, introduced immediately after the accident a previously prepared regulation [10] establishing the maximum acceptable dose (MAD) of 10 rem (100 mSv) for accidental whole body irradiation of the population in the first year after the accident; in addition, an MAD of 30 rem (300 mSv) in the first year was proposed for the thyroid. These MADs had their origin in safety goals for nuclear power plants [10].

The NCRP subsequently recommended temporary dose limits for each of the years 1987 to 1989. These limits were approved by the Ministry of Health of the USSR and they are given in Table 5, together with the MAD used in 1986 [6, 7].

TABLE 5. Maximum Acceptable Dose (1986) and Temporary Dose Limits for Relocation

Calendar year	Maximum acceptable dose and temporary dose limits[a] (effective dose equivalent) (mSv/a)
1986	100
1987	30
1988	25
1989	25

[a] Dose limits apply to the sum of all sources of exposure from the accident (for 1986 external radiation only) and to children born in 1986.

3.5.2. Lifetime Dose Limit Concept

In 1988, the NCRP recommended a lifetime dose limit of 350 mSv as a criterion for determining the need for additional relocation after 1989. The dose to be compared with the dose limit is that received by a child born in 1986 and comprises the sum of the following two components: the total dose received from April 1986 to the end of 1989, taking account of the protective measures applied during this period; and the dose predicted for the period 1990–2056 on the assumption that no protective measures are taken. The rationale for this lifetime dose limit was set out by the NCRP as follows [8]:

> "The lifetime dose limit has *not* emerged as the product of a life span of 70 years and the (former) annual dose limit of 5 mSv recommended by the ICRP for planned situations. The rationale behind the limit was presented as based on all the accessible information on the causal relation between radiation doses and possible health effects, especially leukaemia. An analysis was made of all this material which included the exposed populations in Hiroshima and Nagasaki, exposed workers in the nuclear industry, physicians and nurses with occupational exposures, watch dial painters, cancer patients having received large therapy doses, the exposed population of the Bikini atoll, the population near Kyshtym and the population near the River Techia.
>
> "An analysis of statistically reliable data on these cohorts had not shown significant effects, either oncogenic or genetic, of total exposure below 500 mSv at a high dose rate. At low dose rates, the minimum dose can be increased at least by a factor of 2 (UNSCEAR, 1972). Because children are more sensitive to radiation, also by a factor of 2, the minimum dose for negative effects at low dose rates of low-LET radiation would be no less than 500 mSv. Nevertheless, to take a possible uncertainty of radiosensitivity into consideration, a value of 350 mSv was proposed as a lifetime dose in the form of an intervention level."

The rationale would thus appear to be that maintenance of doses below the limit would preclude the likelihood of any statistical excess of cancer or hereditary disease being detected in the affected population. The lifetime dose limit of 350 mSv was said to provide a high degree of safety because account is also taken of all the doses received from the accident, not just those that could now be averted by relocation. The inclusion of past doses received was to reassure the public and their political representatives, who apparently were shocked when they were informed that there was a statistical possibility of detrimental health effects from exposures at low doses. Considerable opposition to the lifetime dose limit arose in the affected Republics and it was never formally adopted, being superseded by a surface contamination criterion in 1990 (see below).

3.5.3. Surface Contamination Concept

Surface contamination criteria have, since the accident, been used to delineate affected areas for, among other matters, the payment of compensation, etc. Strict control zones are those areas with a surface contamination level of ^{137}Cs above 15 Ci/km^2 (555 kBq/m^2) and controlled zones with a surface contamination level between 5 and 15 Ci/km^2 (185–555 kBq/m^2).

In April 1990, the Supreme Soviet of the USSR implemented the All-Union State and Republican Programme for the Elimination of the Consequences of the Chernobyl Accident, 1990–1992 [9] in which criteria for relocation were specified in terms of surface contamination. A surface contamination level for caesium of 40 Ci/km^2 (1480 kBq/m^2) was adopted as the criterion for compulsory relocation. For pregnant women and children, the level was 15 Ci/km^2 (555 kBq/m^2). In the BSSR, a level of 15 Ci/km^2 (555 kBq/m^2) was adopted as the criterion for compulsory relocation. A more detailed description of the Programme is given in Annex 2 in this Part.

4. Evaluation of the Protective Measures Taken in the USSR

4.1. Introduction

In evaluating the protective measures taken in the USSR following the Chernobyl accident, the International Project has focused on the measures taken, or planned to be taken, from 1990 onwards. This was the central issue raised by the Soviet authorities in their request. The Project also evaluated those measures taken prior to 1990 to provide historical perspective and, more importantly, because past actions often influence or constrain future options. The evaluation of pre-1990 protective measures was, however, confined to comparisons with international guidance.

However, the evaluation of the post-1990 protective measures goes beyond these comparisons. Detailed consideration has been given to the cost per unit of dose averted by each of the measures proposed (and also by a range of alternatives) and to the influence of issues of a more social or political nature. In addition, while the evaluation has concentrated on the protective measures taken, or to be taken, within the framework of the All-Union State Programme, significant departures from this Programme by the individual Republics have also been evaluated.

The evaluation was constrained by the unavailability of some essential data. In some cases, the intended approach had to be changed in order to accommodate this constraint. Consequently, the evaluation is less rigorous and comprehensive than was originally intended, and the conclusions reached are less 'robust' and in need of greater qualification than they would otherwise have been.

TABLE 6. Comparison of Intervention Levels of Dose for Evacuation

Organ of reference	USSR Absorbed dose	IAEA Dose equivalent [2]
Whole body	250–750 mGy[a]	About ten to a few hundred mSv[b]
Single organs	300–2500 mGy	—[c]

[a] For low LET radiation, the absorbed doses expressed in mGy are, to a good approximation, equal to the dose equivalents expressed in mSv.

[b] In earlier international guidance [4, 17], a range of 50–500 mSv was proposed for the whole body.

[c] In earlier international guidance [4, 17] a range of 500–5000 mSv was proposed for single organs.

Sheltering, the administration of stable iodine, evacuation and restrictions on food consumption were the major *short term* protective measures implemented during the early stages of the accident. They were introduced to protect the public from exposure to direct irradiation from the airborne plume, from inhalation of radioactive material in the plume and from exposure to direct radiation from and ingestion of foods containing radioactive material deposited on the ground. Relocation, food restrictions and decontamination were the principal *longer term* measures for protecting the public from external exposure due to deposited material, from inhalation of any resuspended radioactive particulate materials and from the ingestion of contaminated foodstuffs. With the exception of sheltering, each of the major protective measures implemented following the accident is evaluated.

4.2. Evacuation

The resources required to evaluate the practical implementation of the evacuation and thyroid blocking protective measures were far in excess of those available to the Project. Consequently, only a superficial analysis was made of these aspects on which no further conclusions can be made.

The basic underlying principle for introducing evacuation is the appropriate balancing of the positive factors of individual doses averted by evacuation and subsequent reassurance against the negative factors of monetary cost and individual disruption and risk. The criteria used in the USSR for evacuation of the population during the accident (i.e. the time when radioactive material was being released) are summarized in Table 6 [2, 4, 17], where they are compared with current IAEA indicative guidance.

The decision to evacuate the population within the 30 km zone around the power plant was based on the severity of the accident and on measurements in the surrounding areas of the external gamma dose rate from the passing plume and the radioactive material deposited on ground surfaces. Doses above the intervention levels could have been received if evacuation had not been introduced.

The decisions on evacuation were consistent with the established intervention policy, i.e. the potential doses averted could have exceeded the intervention level and evacuation was therefore justified.

The range of the Soviet intervention levels for whole body dose is in fairly good agreement with the international guidance available at the time of the accident. The lower bound of the Soviet range is somewhat higher than that in the international guidance and this difference is further accentuated when comparison is made with the current guidance [2].

The Soviet intervention levels for single organ doses are in broad agreement with the earlier international guidance [4, 17], with the Soviet levels being lower by approximately a factor of 2.

4.3. Thyroid Blocking

The basic underlying principle for administering stable iodine as a protective measure against inhalation doses and doses from the intake of food from radioisotopes of iodine is to balance the positive factor of the doses averted against the negative factors of cost, and the possible risk from the procedure itself.

The effectiveness of an iodine programme depends on the quantity of stable iodine taken in the form of KI tablets (normally 100 mg for an adult) and on the time between intake of radioiodine and the administration of the KI. Taking 100 mg of iodine one hour after the intake of radioiodine reduces the uptake of ^{131}I by 90%, two hours after by 84% and three hours after by 60%.

The criteria used in the USSR [10, 18] for the administration of stable iodine are summarized in Table 7, where they are also compared with the current IAEA indicative guidance.

The range of the Soviet intervention levels differs from both the earlier and the current international guidance. The Soviet range is about a factor of 5 higher than the earlier guidance and this difference is accentuated when comparison is made with the current guidance.

The introduction of the iodine programme, in which several million potassium iodide (KI) tablets were distributed, would have been expected to avert some thyroid doses from inhalation. There are indications that only a small fraction (around 20%) of the distributed tablets were used (see Part F).

The administration of stable iodine is normally used to mitigate exposures from the inhalation of iodine. It would also mitigate exposures from ingestion, but, in general, such exposures should be avoided by the timely introduction of foodstuff restrictions. From the very high levels of thyroid dose reported in some settlements it is apparent that there was some failure to prevent the ingestion of foodstuffs contaminated by iodine, because measures either were not taken sufficiently soon or were not followed by some members of the population. Given the unprecedented scale and duration of the accident, some failure in this area is not surprising. Notwithstanding the benefits of iodine administration in these cases, its use as a more general means of mitigating ingestion doses is not recommended. This is better achieved through avoiding exposure in the first place.

The decision to use KI tablets as a thyroid blocking measure was based on the severity of the accident and measurements of iodine in the environment. If not introduced, doses above the intervention levels might have been received, especially during the evacuation operation. The decision on the use of KI tablets was in agreement with the established intervention policy and therefore justified.

TABLE 7. Comparison of Intervention Levels of Dose for Stable Iodine Administration

Organ of reference	USSR Absorbed dose	IAEA Dose equivalent [2]
Thyroid	300–2500 mGy[b]	A few tens to a few hundred mSv[a]

[a] In earlier international guidance a range of 50–500 mSv was proposed [4, 17].

[b] For low LET radiation, the absorbed doses expressed in mGy are, to a good approximation, equal to the dose equivalent expressed in mSv.

4.4. Food Restrictions

4.4.1. Criteria and Their Underlying Principles

4.4.1.1. Intervention Levels of Dose

The basic criteria used in the USSR for placing restrictions on food consumption following the Chernobyl accident are expressed in terms of dose (intervention levels of dose) and the values adopted are compared with current IAEA indicative guidance in Table 8.

The Soviet and IAEA indicative intervention levels cannot, however, be compared directly in the form in which they are tabulated. This is a consequence of the Soviet intervention levels applying to diet as a whole and the IAEA levels applying separately to each of six major categories of foodstuffs. This difference in approach, while conceptually important, may be more cosmetic than real when account is taken of how the Soviet intervention levels have been applied in practice (see below), in particular in the use of different DILs for each foodstuff.

The choice of intervention levels for food involves a balancing of, among other factors, the risk of deleterious health effects, the cost of the lost produce, the ease and

TABLE 8. Comparison of Intervention Levels for Restricting Foodstuffs

Calendar year	Effective dose equivalent (mSv)[a]	
	USSR[b]	IAEA[c] [2]
1986	50	About one to a few tens[c, d]
1987	10	
1988	8	
1989	8	
1990	5	

[a] The dose to be compared with the intervention level is the committed dose equivalent from dietary intakes in that year.
[b] The dose to be compared with the intervention level is that from the whole dietary intake.
[c] The dose to be compared with the intervention level is that which arises separately from each of the following six main categories of foodstuffs: dairy products, meats, vegetables, grain, fruit, and drinking water and beverages.
[d] In the earlier international guidance a range of 5–50 mSv was proposed [4, 17].

cost with which alternative, less contaminated supplies can be obtained, the importance of that foodstuff in achieving a balanced diet, etc. Significant differences can be expected among these factors for different foodstuffs and, at least in principle, these should be reflected in differences in intervention levels. The IAEA approach is to establish intervention levels on a case by case basis for individual foodstuffs, while the Soviet approach was to establish a level for dietary intake as a whole. If allowance is made for this difference, the Soviet levels fall within the IAEA range.

It is noted that the levels adopted in the USSR in more recent years are very close to the lower bound of a range of values that could be inferred from the IAEA guidance for diet as a whole. Intervention levels in this region would, in general, be expected to be justified and optimal only where alternate food supplies were readily available at little or modest cost.

4.4.1.2. Derived Intervention Levels

The aim of a control regime after an accident is to adopt an overall strategy for food and agricultural countermeasures that optimizes the situation. In practical terms this will involve setting DILs for particular categories of foodstuffs that take account of, among other things, the typical levels of contamination and dietary intake; the existence, effectiveness and cost of any agro-industrial techniques that could be applied to control the activity content of that food to reduce the activity intake; and whether other foodstuffs are readily available to make up for any deficits. The development of an optimal strategy is complex, requiring careful and considered analysis.

Food restrictions have been applied in the USSR through the use of these DILs for particular categories of foodstuffs. Limiting concentrations have been established for each foodstuff and, if exceeded, food is withdrawn from consumption and either destroyed, processed such that its concentration is reduced below prevailing limits, or used as animal feed. In addition, agricultural countermeasures (such as the ploughing of natural pasture, the addition of fertilizers to the land and the removal of grazing animals to less contaminated pastures) are planned and executed such that anticipated concentrations in the resulting foodstuffs will satisfy the criteria.

TABLE 9. Maximum Permissible Content of ^{131}I in Drinking Water and Food Products Adopted on 6 May 1986 [13][a, b, c]

Item	Permissible concentration (Bq/kg or Bq/L)	Assumed daily consumption
Drinking water	3 700	1 L
Milk	3 700	1 L
Cream cheese	37 000	100 g
Sour cream	18 500	200 g
Cheese	74 000	50 g
Butter	74 000	50 g
Fish	37 000	100 g
Green vegetables	37 000	100 g

[a] These figures are based on a permissible total dose to the thyroid gland over the course of a month of 300 mGy for adults, not including contributions from other radioisotopes.
[b] The permissible ^{131}I levels in food products used in organized children's collectives were ten times lower than the above values.
[c] Where ^{131}I levels in food products were higher than those cited above, the products were, wherever possible, diluted with less contaminated products, or were shipped for processing.

TABLE 10. Temporary Permissible Levels for Total Beta Activity in Food Products, Drinking Water and Medicinal Herbs Adopted on 30 May 1986 [14]

Item	Permissible[a] content (Bq/kg or Bq/L)
Drinking water	370
Milk[b]	370
Condensed milk	18 500
Dried milk, cream cheese, sour cream	3 700
Cheese, butter, vegetable fats, margarine	7 400
Meat and meat products, poultry, fish	3 700
Eggs	1 850 each
Green vegetables, root crops, potatoes	3 700
Fruits, berries, juice	3 700
Grain and grain products	370
Sugar	1 850
Mushrooms	18 500
Medicinal plants	18 500

[a] Fresh weight.
[b] Valid as of 1 August 1986; the prior value was 3700 Bq/L.

In the first several weeks after the accident, the main radionuclide giving rise to radiation exposure was ^{131}I, which, when ingested, is concentrated in the thyroid. This nuclide also has a relatively high mobility in the food-chain, particularly through the pasture–cow–milk pathway and from direct deposition onto vegetables. Temporary permissible radioactive iodine contents (^{131}I) for drinking water and food products were adopted on 6 May 1986 [13]. These values are presented in Table 9, together with the assumed daily consumption rate.

By the end of the first month, the dose contribution from ^{131}I in food had fallen below the contribution made by other radionuclides and the temporary permissible levels for activity in foodstuffs were revised to include all beta activity on 30 May 1986. These values are given in Table 10.

After the first months [16] following the accident, the radioactive isotopes of caesium (i.e. ^{134}Cs and ^{137}Cs) became the dominant contributors to dose from food. The DILs were amended again [16] and expressed in terms of ^{134}Cs + ^{137}Cs activity concentrations in foodstuffs; the values adopted are summarized in Table 11 [19, 20], where they are presented along with levels contained in a Commission of the European Communities (CEC) Regulation and with those recommended by the WHO/FAO Codex Alimentarius Commission [20].

However, these levels were derived for different purposes and are, therefore, strictly not comparable. A discussion of this, together with the levels originally set by the CEC on 30 May 1986 for the import of food into the European Community, and the levels recommended by the Article 31 Group of Experts [19], is given in the box. As can be seen, the derivation of some of these levels was confounded by political factors at the time.

The Soviet DILs were evaluated on the basis of the dietary intake given in Section 3.4.2 and the assumption that the total intake of each foodstuff was contaminated at the respective intervention level. The Republics and lower administrative bodies were free to set more restrictive levels and some of these are summarized in Table 12 [21].

The doses that would result from the dietary intake given in Section 4.3.2, where all food was contaminated at the level mentioned above, are given in Table 13.

The DILs currently used in the USSR are, for many of the more important sources of dietary intake, two to three times lower than those established by the CEC for use in any future accident and lower by similar, but somewhat smaller, factors than the exemption levels established by the Codex Alimentarius Commission for foodstuffs in international trade (Table 11). The levels in use in the BSSR are even lower for major food items. The USSR should assess the degree to which the measures are achieving what may be too effective results, in that doses in most cases are being maintained below 2 mSv/a, which is three to four times lower than their own current policy (Table 8).

Insufficient data were made available to the Project to evaluate the cost per unit of dose averted of the food restrictions that were imposed. For example, there were no data available on the quantities of food restricted, the distribution of contamination within it, or the costs of disposal, processing and/or provision of less contaminated supplies. From what is known by way of discussions in the literature, however, these aspects do not appear to have received much attention within the USSR. This whole area warrants more analysis in the future, as it is important for decisions relating to the optimal allocation of resources to dose reduction.

Two other factors should be recognized that could be used to justify an *increase* in intervention levels in the USSR. These are the current food shortages and the adoption of intervention levels that are so low that they may cause some to conclude that life is no longer viable in such areas as farmers cannot produce their own food. Adoption of such low levels may lead to the unnecessary

Historial Perspective on Foodstuff Intervention Levels

Owing to the wide variation in contamination levels in member states of the European Community (EC) soon after the Chernobyl accident (e.g. a maximum deposition of 100 kBq/m^2 in Italy and 0.1 kBq/m^2 in Portugal), the Council of Ministers and the Commission of the European Communities (CEC) had to act urgently to set foodstuff intervention levels in order to avoid major trade conflicts between member states. By 12 May 1986, imports into the EC of a range of agricultural products originating in certain east European countries had been suspended until the end of that month. Subsequently, maximum permitted total caesium levels applicable to food imported into the EC were adopted: 370 Bq/kg for milk and infant food and 600 Bq/kg for other foodstuffs. These values are still valid and now some 15 non-member-states have also adopted the levels. Member states remained free to apply their own limits to national produce for internal consumption; where any such limits exceeded the EC values mentioned above, this limit would also apply to imports from within the EC, but in no case would the import limits be less than the EC values. At the same time that it issued its preliminary opinion on the value of DILs for caesium nuclides, the Article 31 Group of Experts was asked to undertake a detailed examination of the problem of foodstuff intervention levels; the Group proposed generalized DILs for all potentially important nuclides to be applied in the event of a future accident. Derived intervention levels for caesium isotopes of 4000 Bq/kg for milk and milk products, 5000 Bq/kg for all other major foodstuffs and 800 Bq/L for drinking water were proposed. These levels were intended for general application; they are based on a committed effective dose of 5 mSv in one year. It was recognized that values could be based on a reference level of dose up to ten times higher. They apply to the sum of all nuclides other than iodine, strontium and alpha emitting isotopes, notably ^{134}Cs and ^{137}Cs. They assume that the annual average contamination of food over the year following an accident would not exceed 10% of the concentration levels on which controls would be based. On 22 December 1987, the Council adopted a regulation with values of 1000 Bq/kg for dairy produce and 1250 Bq/kg for all other foodstuffs (except minor foodstuffs). The main differences between the Article 31 Group recommendation and the Council regulation were as follows:

(a) The term 'maximum permitted levels of radioactive contamination of foodstuff' was used rather than the term 'derived intervention levels'.
(b) The DILs applicable for milk and other foodstuffs were reduced by a factor of 4 to take account of the fact that many non-EC countries were applying levels at or about the resulting derived levels; another reason for the reduction was to maintain public confidence in the proposed system. This reduction was equivalent to assuming that the average annual contamination of food would not be greater than 40% of the concentration levels on which controls were based. Levels were later derived for liquid foodstuffs and baby foods, that for infant foods being 400 Bq/kg for these nuclides.

The following discussion details the FAO/WHO Codex Alimentarius Commission guideline values that were adopted at its July 1989 meeting in Geneva. These values were developed for ease of application in international trade and mean that when the guideline levels are exceeded governments should decide whether and under what circumstances the food should be distributed within their territory or jurisdiction. The main criterion in choosing these values was that it should be simple, easy to apply and versatile; the levels can be applied to any accidents involving any radionuclides and at any time period. The values are not influenced by optimization and can be regarded as being "below regulatory concern". It could be considered that levels above these do not necessarily constitute a health hazard. They are merely action levels at which a fuller dose assessment may be made. Conservative assumptions were made in order to reduce the risk of potential adverse health effects to an insignificant level compared with other risks. The level is 1000 Bq/kg for ^{134}Cs and ^{137}Cs. The very different origins and purposes of both the EC and Codex levels compared with the Soviet levels needs to be recognized and this largely precludes direct comparisons being made between them.

destruction of traditional farming communities which contribute much to the quality of life of those affected. To set unnecessarily low values for foodstuffs in these areas is simply to add to the already high stress levels among the population.

A more restrictive policy is currently being adopted in the USSR for food control compared with practices elsewhere, and the systems of derivation vary. For example, in Norway, where because of a combination of many factors (such as heavy rainfall at the time of passing of the Chernobyl plume and high concentrations of caesium in mushrooms and lichen, which is the staple diet of sheep and reindeer), the concentrations of caesium in some reindeer meat, sheep grazing the open fells, wild game and fish exceeded the temporary levels of 370 Bq/kg for milk and baby food, and 600 Bq/kg for

TABLE 11. Derived Intervention Levels (in Bq/kg) for $^{134}Cs + ^{137}Cs$ in Various Foodstuffs for the USSR, the CEC and the Codex Alimentarius Commission

	USSR [5, 14–16]		CEC [19][a, b]	Codex [20][c]
	1988–1989	1990		
Drinking water	18.5	18.5	1000	1000
Milk, dairy products	370	370	1000	1000
Meat, fish, eggs	1850–2960	740	1250	1000
Potatoes, root crops	740	592	1250	1000
Vegetable oil, animal fat	370	185	1250	1000
Baby food	370	185	400[d]	1000

[a] The level applicable to concentrated or dried products shall be calculated on the basis of the reconstituted product as ready for consumption.

[b] The levels apply to all nuclides other than the isotopes of strontium, iodine and plutonium; they are assumed here to apply solely to $^{134}Cs + ^{137}Cs$ as these are the only nuclides of practical relevance in light of the Chernobyl accident.

[c] The levels can be regarded as being 'below regulatory concern'.

[d] Baby foods are defined by the CEC as those foodstuffs intended for the feeding of infants during the first six months of life which meet, in themselves, the nutritional requirements of this category of person and are put up for retail sale in packages which are clearly identified and labelled 'Food preparation for infants'.

TABLE 12. Derived Intervention Levels (in Bq/kg) for Foodstuffs Adopted by Different Authorities in the USSR

Item	USSR [14][a]	USSR [16][b]	BSSR [21][c]	Gomel [21][d]
Drinking water	370	19	19	19
Milk	370	370	185	185
Milk products	3 700–18 500	370–1850	37–740	37–740
Meat/meat products	3 700	1850–2960	590	370
Fish	3 700	1850	590	590
Vegetables	3 700	740	185–590	185–590
Grain/bread	370	370	370	370
Sugar	1 850	370	370	370
Mushrooms	18 500	—	370	370

[a] *Interim* maximum permissible levels for the USSR of *all* beta activity in foodstuffs, adopted on 30 May 1986.

[b] Interim maximum permissible levels for the USSR of $^{134}Cs + ^{137}Cs$ activity in foodstuffs, adopted on 10 June 1988.

[c] Levels adopted for 1990 in the BSSR for $^{134}Cs + ^{137}Cs$ in foodstuffs.

[d] Levels adopted from 1988 in the Gomel region for $^{134}Cs + ^{137}Cs$ in foodstuffs.

TABLE 13. Doses Implied by the DILs Recommended by Different Authorities in the USSR. *Committed effective dose equivalent from the annual intake of food products contaminated at the respective DIL (mSv)*[a]

Item	Intake rate (g/d)	USSR 1988 (mSv)	BSSR 1990 (mSv)	Gomel 1988 (mSv)
Pork	100	0.9	0.3	0.2
Beef	50	0.8	0.2	0.1
Fruits/vegetables	210	0.8	0.6	0.6
Potatoes	500	1.9	1.5	1.5
Cereals	200	0.4	0.4	0.4
Milk	0.7 L/d	1.3	0.7	0.7
Total		6.1	4.4	2.7

[a] Assumed dose/unit intake = 1.4×10^{-8} Sv/Bq. The doses implied by Soviet levels adopted on 30 May 1986 are not presented, since these levels were for *all* beta activity and not just radiocaesium. All food was assumed to be contaminated at the relevant DIL.

TABLE 14. Variation in the Optimal Intervention Level for ^{134}Cs + ^{137}Cs Concentrations in Foodstuffs (Bq/kg)[a]

Cost of man-sievert (roubles/man-sievert)	Food cost (roubles/kg)				
	0.1	0.3	1	3	10
3 000	2400	7100	24 000	71 000	240 000
10 000	710	2100	7 100	21 000	71 000
30 000	240	710	2 400	7 100	24 000
100 000	70	210	710	2 100	7 100

[a] Optimal only in so far as the monetary cost of the protective measure and the reduction in risk achieved are the sole, or only significant, factors.

meat adopted by the Norwegian Government [17]. The implementation of protective measures to ensure that radioactivity was below these levels had a severe effect on the social and mental health of certain ethnic groups (Lapps), in the form of major disruptions to normal practices and ways of life. In November 1986, the temporary level was accordingly increased to 6000 Bq/kg, a level that was considered to be an optimum balance between controlling exposures, maintaining the livelihoods of the people affected and also maintaining confidence in the control system. Similarly, in July 1987, the level for freshwater fish and game was increased to 6000 Bq/kg. Retrospective analyses of the cost per unit of dose averted as a result of these decisions have shown them to be extremely reasonable [22] given the particular circumstances.

Other examples can be given where a strategy for food control has been implemented that takes into account local conditions. However, the continued absence of data on the Soviet cost per unit of dose averted precludes firm conclusions being reached on what constitutes an optimal protective measures strategy for foodstuffs in the USSR.

4.4.2. Optimization of Food Restrictions

Indicative estimates can be made of the optimal levels for restrictions in those cases where the dominant considerations are the monetary costs of the restrictions and the reductions in dose achieved, assuming complete replacement of contaminated food. Subject to these

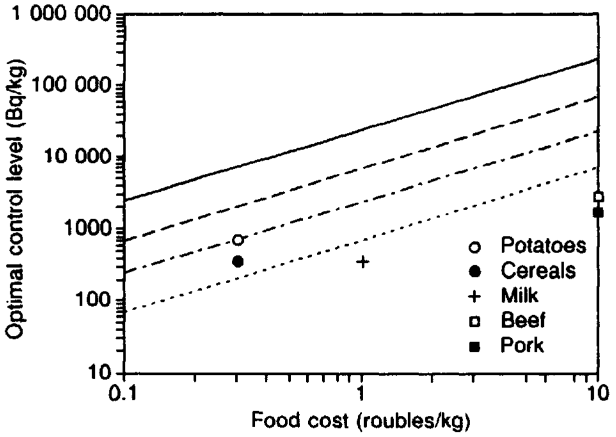


FIG. 1. Optimal DILs for $^{137}Cs/^{134}Cs$ contamination versus food costs in the USSR for several values of the cost of a man-sievert, α. The DILs are 'optimal' only insofar as the monetary cost of the protective measures and the reduction in risk achieved are the sole, or only significant, factors. The cost of foodstuffs in the USSR are based on Ref. [24]. (——: 3000 roubles/man-sievert; – – –: 10 000 roubles/man-sievert; —·—·—: 30 000 roubles/man-sievert; ·········: 100 000 roubles/man-sievert.)

caveats, the optimum level, A_{opt}, expressed in terms of the concentration of a given radionuclide in a foodstuff, can be expressed as [2]:

$$A_{opt} = b/(\alpha H_E) \quad (1)$$

where

- b is the cost per unit mass of the specific foodstuff (roubles/kg),
- α is the cost per unit of collective dose (roubles/man-sievert),
- H_E is the committed effective dose per unit of activity ingested for the nuclide (Sv/Bq) taken from ICRP Publication 30 [23] for ^{137}Cs and ^{134}Cs to be 1.4×10^{-8} Sv/Bq.

For ^{134}Cs and ^{137}Cs in foodstuffs, the optimal concentration at which to introduce restrictions is illustrated in Table 14 and Fig. 1 [24] as a function of the cost of a foodstuff and the cost assigned to unit collective dose.

Figure 2 presents the same information for the 1990 DILs in the BSSR and the Gomel region. It is clear that the levels for milk and meat are even less 'optimal' and justified than those set by the Soviet authorities.

In a similar way estimates can be made of the implied value being assigned to the cost of the man-sievert, resulting from the adoption of the DIL and the cost of providing alternative food supplies. The implied values for the cost per man-sievert saved are summarized in Table 15 and calculated from Eq. (1) as:

$$\alpha = b/(DIL\ H_E)$$

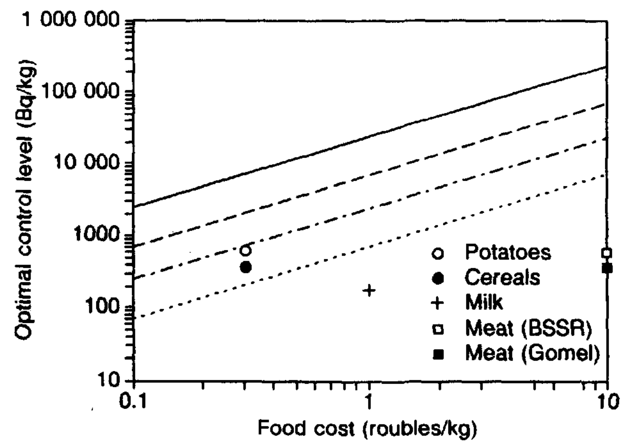


FIG. 2. Optimal DILs for $^{137}Cs/^{134}Cs$ contamination versus food costs in the BSSR for several values of the cost of a man-sievert, α (see Fig. 1 for further details). (——: 3000 roubles/man-sievert; – – –: 10 000 roubles/man-sievert; —·—·—: 30 000 roubles/man-sievert; ·········: 100 000 roubles/man-sievert.)

TABLE 15. Implied Cost Assigned to Unit Collective Dose from the Adopted DILs

Food	Assumed food cost (roubles/kg)	Implied cost per unit collective dose saved (million roubles/man-sievert)		
		Gomel 1988	USSR 1988	BSSR 1990
Pork	10	2	0.39	1.2
Beef	10	2	0.24	1.2
Potatoes	0.3	0.036	0.029	0.036
Cereals	0.3	0.058	0.058	0.058
Milk	1	0.39	0.19	0.39

For a range for the cost of the man-sievert of between 3000 and 100 000 roubles, which, after conversion between currencies bounds most values that have been used or proposed for radiation protection purposes (see Table 27, Section 4.5.4), it is clear by comparing 3000–100 000 roubles/man-sievert with the values in Table 15 of 190 000–200 000 roubles/man-sievert for milk and meat that the levels for restrictions on milk and meat again appear unjustified in general, and in the BSSR and Gomel especially so, unless alternative food supplies are plentiful and available at costs which are very much lower than those indicated in Table 15. These observations are of course conditional upon monetary cost and risk reduction being the only significant factors determining the 'optimum' intervention level. Other factors of a social and political nature, however, often enter into decisions of this nature.

Figure 3 presents the same information for the 'optimal' intervention levels for ^{131}I depending on the cost of alternative food supplies. The Soviet intervention levels used in May 1986 are also presented for comparison.

In contrast to the results for radiocaesium, the intervention levels for radioiodine appear to have been towards the upper end of the justifiable region. This is particularly so for green vegetables, unless very high costs were assigned to providing alternative food supplies or very low values assigned to the cost of the man-sievert. Table 16 provides the implied cost per unit of dose averted.

It is clear that there is an inconsistency between the cost assigned to the unit collective dose implied by current countermeasures to reduce the intake of caesium compared with those adopted soon after the accident for radioiodine. There may be good reasons for this, e.g.

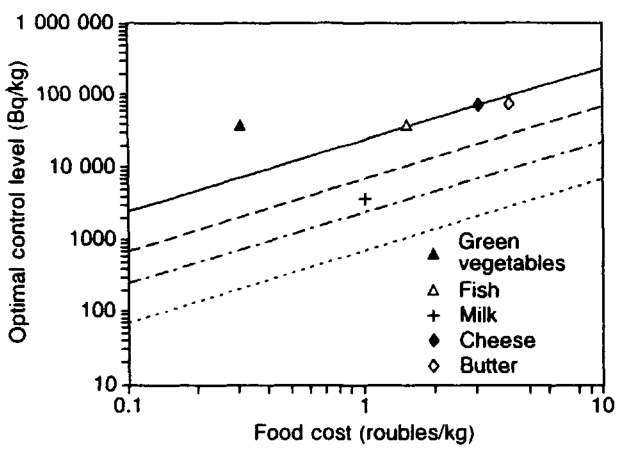


FIG. 3. Optimal DILs for ^{131}I contamination level versus food costs in the USSR for several values of the cost of a man-sievert, α (see Fig. 1 for further details). (——: 3000 roubles/man-sievert; — — —: 10 000 roubles/man-sievert; —·—·—: 30 000 roubles/man-sievert; ·········: 100 000 roubles/man-sievert.)

TABLE 16. Implied Cost Assigned to Unit Collective Dose from DILs for Foodstuffs Contaminated by ^{131}I

Foodstuff	Food costs[a] (roubles/kg)	Cost assigned to the unit collective dose (roubles/man-sievert)
Green vegetables	0.3	580
Milk	1.0	20 000
Fish	1.5	2 900
Cheese	3.0	2 900
Butter	4.0	3 900

[a] Costs of foodstuffs in the USSR are based on Ref. [24].

the cost of alternative food supplies may have been much higher in the month after the accident than currently, although this seems unlikely given the current food shortages. In addition, it is counterproductive to apply less restrictive countermeasures for a short term problem while applying countermeasures based on pessimistic (i.e. cautious) assumptions for the long term problem. If consideration is given to the very long period that radiocaesium will remain in the environment, the costs of applying very restrictive protective measures for extended periods may be excessive and at the expense of achieving greater health improvements elsewhere for the same monetary resource. The allocation of particular weight to factors of a sociopolitical nature in the optimization process would, however, be expected to resolve many of those apparent anomalies which arise from a constrained analysis of the monetary cost of dose reductions.

Additionally, this cost-benefit approach is very simplistic and does not take into account the benefits of agrotechnical methods in achieving dose reductions at costs less than those that arise from food restrictions. These techniques could lead to the justification of lower intervention levels (see box). However, in the absence of more detailed data on the costs of these protective measures, it is not possible to comment further on the intervention levels. A more rigorous evaluation of the costs and efficacy of foodstuff countermeasures is, however, a matter deserving greater attention than it apparently has received in the interest of developing a balanced and cost effective approach to this problem.

4.4.3. Other Factors

Countermeasures for reducing ingestion doses from contaminated foodstuffs include a number of agricultural and industrial techniques as supplements or alternatives to the withdrawal or loss of food with activity above the control levels. The agricultural and processing countermeasures that have been used extensively to date in the affected areas are described in more detail in Part C. As mentioned above, the simplistic arguments developed (Eq. (1)) for indicating 'optimal' levels for restrictions are not adequate for considering the cost per unit of dose averted of each of these various countermeasures. Additional arguments involving justification as well as optimization can be used (see Section 4.4.3.1). However, without detailed information on the costs of the agricultural/industrial techniques, together with their effectiveness at reducing caesium levels in food, it is impossible to arrive at any quantification of the problem. However, certain qualitative statements can be made.

It may well be justified to carry out agro-industrial countermeasures at levels below those derived from Eq. (1). Clearly, if a countermeasure has very little associated cost but significantly reduces even these small doses, then it may well be justified to invoke it. On the other hand, if a technique has an associated cost that is greater than or equal to the market cost of the products, the technique can never be justified on economic grounds (though there may be sociopolitical reasons for invoking such a protective measure). When evaluating the cost per unit of dose averted for these techniques it should be borne in mind that for some of the measures described in Part C the costs appear only once when the action is taken (e.g. removal of soil surface and deep ploughing) and can be written off over the period of time the measure is expected to last and for which total doses are saved (i.e. over many years). For other techniques (e.g. removal of animals to uncontaminated pasture before slaughter, feeding uncontaminated fodder) the costs will continue to arise in the future.

While these factors might tend to reduce the intervention levels, there are (at least) two major factors that would tend to increase them. First, there are currently considerable problems in the USSR in providing adequate food supplies. Many foodstuffs are rationed and there are widespread shortages. Clearly the cost of providing alternative food supplies is high, despite fixed prices. Additionally, there are considerable negative social implications in adopting very low intervention levels, as they can lead to changes in the lifestyles of some people; in particular, it can give rise to feelings that life is no longer viable in those areas where they cannot produce and consume their own food.

4.4.3.1. Cost-Benefit Analysis of Agro-Industrial Countermeasures for Food

When considering a strategy of countermeasures, including agro-industrial measures (such as food processing, addition of chemicals to soil, ploughing, etc.), one technique that may be used to identify the optimum is cost-benefit analysis. In principle, this involves identifying the options available, assigning some measure of the overall cost to each option, taking into account potential radiological harm, financial costs and allowances for other costs, and then identifying the option which gives rise to the least overall cost. When a series of countermeasures may be taken that are not independent of each other, this may not be a trivial exercise. However, for the sake of illustration, an extension of the simple equation given in the main text is provided here for the case where there is one agro-industrial measure available other than merely restricting the foodstuff.

Consider, then, three options: (1) no action, for which the costs may be expressed as:

$$C\alpha H$$

where

- C is the contamination in the foodstuff (Bq/kg),
- α is the cost of unit collective dose (roubles/man-sievert),
- H is the dose per unit intake (Sv/Bq).

(2) Restricting the food, where the costs may be taken as those of providing alternative food, B (roubles/kg); and (3) taking an agro-industrial countermeasure, where the total cost may be expressed as:

$$P + C\alpha H/f$$

where

- P is the cost of the countermeasure per unit mass of the final product (roubles/kg),
- f is the effectiveness of the countermeasure (the ratio of the dose without countermeasure to that with the measure).

It can be shown that the agro-industrial countermeasure is justified if $f(B - P) > B$, i.e.:

$$\frac{P}{B} < \frac{f-1}{f}$$

If this condition is true, then it can be shown that the countermeasure should be invoked between contamination levels of

$$\frac{P}{\alpha H}\,\frac{f}{(f-1)} \quad \text{and} \quad \frac{f}{\alpha H}\,(B - P)$$

These results are illustrated in Figs 4–6. Figure 4 shows the 'break-even' point for the countermeasure as a function of its effectiveness. Thus, for an effectiveness of 5, the countermeasure is justified if its cost per kg is less than 0.8 of the cost of the foodstuff. Figure 5 then shows the dependence of the optimal control levels on the cost of the countermeasure (for f = 5). Thus, where the cost

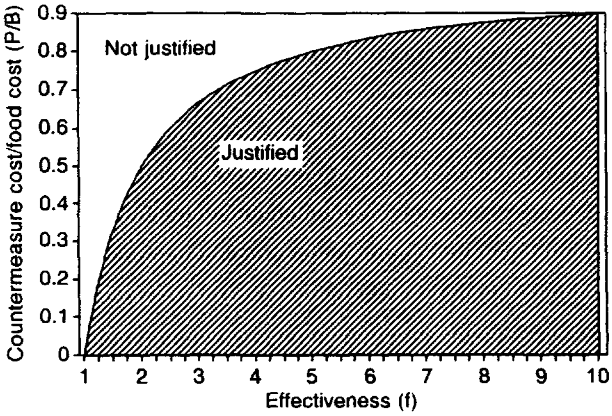


FIG. 4. Break even point for an agricultural countermeasure.

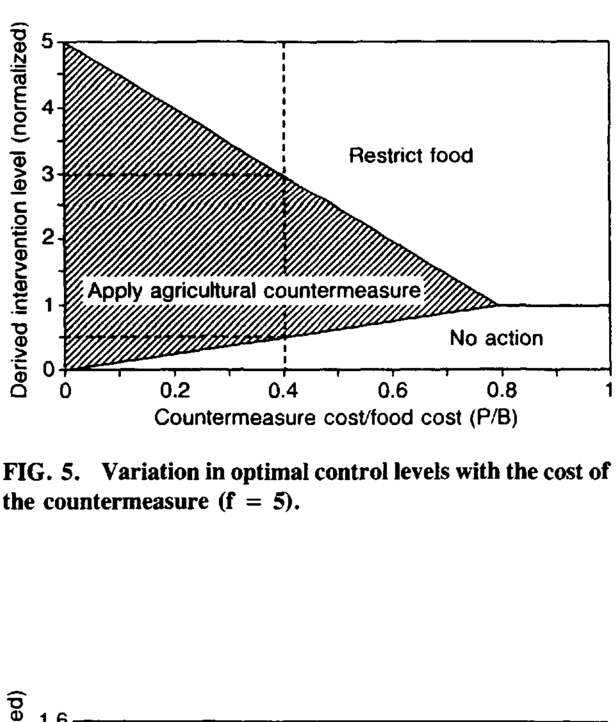


FIG. 5. Variation in optimal control levels with the cost of the countermeasure (f = 5).

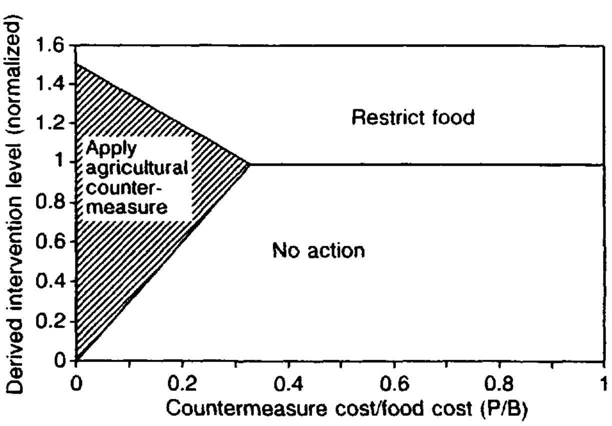


FIG. 6. Variation in optimal control levels with the cost of the countermeasure (f = 1.5).

of the measure per kg is 0.4 of the cost of the final food product, the control level for introducing the countermeasure is 0.5 of that of the B/αH value. The countermeasure should be used for food contaminated up to a value of 3 times the B/αH value, above which the food should be restricted and simply replaced with an alternative supply. Figure 6 shows the same situation for f = 1.5. In both cases, it can be seen that the derived intervention level can be set lower than the simple B/αH value if the countermeasure is relatively cheap.

4.4.4. Practical Implementation

It is difficult, if not impossible, to comment further on the effectiveness or otherwise of the techniques currently in use to reduce caesium levels in foodstuffs because of the absence of detailed cost information. However, a joint FAO/IAEA fact finding mission (see Part A) considered whether there were any accepted techniques that had not been, but might be, used in the USSR. Several conclusions that emerged from this fact-finding mission.

First, an impressive strategy involving many different techniques for controlling the activity content in food is used in the USSR. These techniques are described in more detail in Part C. However, while these measures have brought down the caesium levels in much of the food to below the current criteria in use, one technique that has been used successfully in Scandinavia has not been utilized. This is the administration of 'caesium binders' to grazing animals. This method is described in more detail in Part B. Again, in the absence of detailed cost information, it is difficult to give quantitative advice. However, currently in order to produce milk and meat below the intervention levels in the more contaminated regions, milk has to be processed into butter and animals have to be fed 'clean' feed for 1.5–2 months before slaughter or moved to uncontaminated land. This procedure has substantial associated economic costs and, moreover, social costs for the private farmers that should not be underestimated, since it disrupts their traditional farming methods (these farmers usually produce milk and meat to support and feed themselves and their families).

The Scandinavian experience (with reindeer grazing on relatively highly contaminated lichen) has shown that the use of caesium binders can reduce the levels of caesium in milk and meat without the need for milk processing or special feeding of animals, with subsequent large economic savings and, moreover, minimal disruption to traditional farming methods. The IAEA has been and is continuing to assist the Governments of the three Republics in further studies of these methods and their potential future application (see Part A).

A second measure, which is hardly an agro-industrial technique, but which can significantly reduce doses, is to provide simple, reliable dietary advice to the population. Such advice could include, for example, recommendations on how frequently wild fruits/berries and mushrooms, or game, etc., could be consumed, or possibly recommendations on simple methods for washing, preparing and cooking food in such a way that caesium levels can be significantly reduced (e.g. the parboiling of mushrooms reduces caesium levels by a factor of about 5 from the raw foodstuff). A study in Norway [22] has estimated the cost of implementing such advice per unit of dose averted and has shown that it is extremely cost effective (US $59/man·Sv). It may be that there are measures based on information that could yet be extremely cost effective in reducing doses in the affected areas, and this should be a subject for further consideration.

Another area that might warrant further study is the cost effectiveness of providing in vivo gamma spectrometric measurement, since, as noted in Part B, there is the potential for overestimation of the caesium content in live animals because the simple dose rate meters register a contribution from ^{40}K (typically 100 Bq/kg, but quite variable). Although correction factors can be applied, because of the variability between animals individual cattle can be kept longer than necessary on valuable 'clean' feed. Better instrumentation would improve the situation, and is already being provided, but this should be examined carefully on a cost-benefit basis.

4.4.5. Summary of Food Restrictions

The basis on which the Soviet intervention levels have been derived are not wholly consistent with the IAEA indicative guidance. In particular, the Soviet dose criteria apply to diet as a whole, whereas the IAEA criteria apply separately to each of six main categories of food. Moreover, the Soviet criteria apply to the most exposed, as opposed to the IAEA criteria, which apply to the average individual in the affected group.

Making allowance for the differences in formulation between the respective criteria, the intervention levels adopted in the USSR are at the lower bound of the range suggested by the IAEA. This would not be expected, given the scale of the accident, the extent over which restrictions were needed and the difficulties with food supply in the USSR. The fact that a few individuals exceed the policy level should not be seen as a failure of the policy. Rather, the policy criterion should be the *average* practice and not the extreme outliers. Otherwise, a considerable imbalance will result towards lower actual values that are not justified.

The costs of restricting foodstuffs were, in many cases, disproportionate to the doses averted. Moreover, in establishing the intervention levels, insufficient attention appears to have been given to the negative implications of food restrictions, in particular those that may result from deficiencies and/or substantive changes in dietary intake. A better balance could have been reached between doses averted and the costs and other disadvantages of food restrictions. Higher intervention levels could readily have been justified under the circumstances.

4.5. Relocation

4.5.1. Criteria and Their Underlying Principles

The criteria adopted for relocation following the Chernobyl accident are compared with the IAEA guidance in Table 17 [25]. The most striking feature in the table is the variety of different quantities (dose in a year, dose in a lifetime and contamination density) used to express the criteria. These differences preclude direct comparisons between the various criteria. Even those criteria that ostensibly are expressed in the same terms (i.e. the Soviet criteria for 1986 to 1989 and the IAEA

TABLE 17. Comparison of Intervention Levels for Relocation

Year	Intervention levels	
	USSR [6, 8–10]	IAEA [2]
1986	100 mSv/a	
1987	30 mSv/a	
1988	25 mSv/a	
1989	25 mSv/a	About a few to a hundred mSv in a year[a, b]
1990	350 mSv[c] 40 Ci/km^2 (1480 kBq/m^2)[d] 15 Ci/km^2 (555 kBq/m^2)[d]	

[a] One to a few tens of μSv/h if expressed in terms of a dose rate.

[b] In previous international guidance, a range of 50–500 mSv/a was proposed [4, 17].

[c] A lifetime dose limit of 350 mSv was initially proposed, but was later superseded by criteria expressed in terms of contamination density (see Sections 3.5.2 and 3.5.3).

[d] The criterion of 40 Ci/km^2 (1480 kBq/m^2) ($^{137}Cs/^{134}Cs$) applies generally and the 15 Ci/km^2 (555 kBq/m^2) level applies to families with young or sick children and pregnant women. In the BSSR, a generally applicable criterion of 15 Ci/km^2 (555 kBq/m^2) has been adopted [25].

TABLE 18. Summary of the Major Features of Each Criterion

Criterion	Quantity to express criterion	Pathways of exposure to be included	Individual to whom criterion is applied	Method of dose estimation
		USSR		
1986–1989	Dose in a year	All[a]	Critical group	Conservative
1990	Lifetime dose (1986–2056)	All[b]	Critical group	Conservative
1990	Concentration of deposited Cs	NA[c]	NA[c]	NA[c]
		IAEA		
	Dose in a year (or dose rate)	Those pathways specifically affected by relocation[d]	Average individual in the group relocated	Realistic

[a] All exposure pathways are taken into account for the purposes of comparison with the quantitative criterion. However, the criteria are subdivided into two components, one for comparison with the exposure via ingestion, and the second for other exposure pathways. Half of the annual dose was attributed to the ingestion dose in 1986 and one third in the subsequent years. No account was to be taken of protective measures in estimating the dose to be compared with the criterion for the other exposure pathways.

[b] All exposure pathways are to be taken into account and, for the purposes of calculating doses for comparison with the criterion, it is assumed that no protective measures are taken from 1990 onwards. However, account was to be taken of measures taken in the period 1986–1989.

[c] Not applicable.

[d] Generally, only external exposure from deposited material and internal exposure from the inhalation of resuspended material. In some cases relocation may also lead to a reduction in doses from the ingestion of foodstuffs.

indicative guidance, all of which are expressed in terms of dose in a year) are, on closer analysis, different. Each of the criteria needs to be transformed on a common basis into the same quantity to enable proper comparison between them. The dose averted by relocation is the most appropriate quantity for this purpose as it is a measure of the benefits achieved by relocation.

Before transforming the various criteria into directly comparable terms, it is important first to identify all of the detailed differences between them, in particular those which are not immediately apparent in Table 17.

The importance of ensuring that 'like is being compared with like' when evaluating different criteria cannot be overstated. The comparison of 'unlike' or 'incomparable' quantities, whether knowingly or not, has contributed needlessly to disagreements and misunderstandings between various groups in the USSR. Moreover, these misunderstandings make the achievement of a consensus on relocation policy in the USSR difficult. The more significant differences among the criteria and their methods of application are summarized in Table 18.

The substantive differences between the respective criteria and between their methods of application preclude the possibility of making simple direct comparisons between them. Most of the differences are germane to the conceptual basis and principles of intervention and they warrant further discussion before the respective criteria are transformed into a form in which they can all be compared fairly.

4.5.1.1. The Dosimetric Quantity Used to Express Intervention Levels for Relocation

No clear consensus has yet emerged internationally on the most appropriate quantity to use for expressing the intervention levels of dose for relocation. What is absolutely clear, however, is that when making judgements on relocation or on any other protective measure it is the dose averted that has to be balanced against the costs and any other disadvantages of taking the measure.

Consequently, criteria expressed in any other terms can only be surrogates for the dose averted. It may, therefore, appear surprising that none of the quantities in Table 18, and in particular in the international guidance, are expressed in such terms. The background to and reasons for this must be examined.

There are considerable, if not insuperable, difficulties associated with the formulation of fairly precise, yet generally applicable, quantitative guidance on relocation in terms of averted dose or indeed any other quantity. The quantity dose rate (note that this is not the same as dose in a year) offers the greatest potential in this context, but only in such idealized circumstances as to make it of limited practical value[2]. Judgements on the optimum level of averted dose at which relocation should be implemented would, in general, depend on the period over which the dose was averted and for which the relocation was foreseen. For example, different judgements could be expected where relocation periods of several months and tens of years, respectively, were required to avert the same level of dose. Thus, if meaningful and helpful quantitative guidance is to be given in terms of averted dose (or indeed any other quantity), it must be associated with some specified period of relocation or with a particular type of accident scenario and thus temporal pattern of exposure. Otherwise, the range of values in any generally applicable guidance could, of necessity, be unhelpfully large in order to accommodate the diverse situations of potential interest. The absence of such qualification is partially responsible for the wide range of values given in the IAEA quantitative guidance (see Table 17).

Although the dose averted, suitably qualified, is the most relevant quantity for judging the benefits of relocation (and, to the extent practicable, it is the ideal quantity for expressing the criterion), this does not preclude the use of other quantities. Quantities such as annual dose, average annual dose over a fixed period, level of contamination, etc., can, if used judiciously, act as adequate surrogates for the dose averted. Intervention criteria expressed in such terms, however, can never alone be sufficient for making well balanced judgements on relocation. Additional information on the dose profile over the anticipated period of relocation would be needed (i.e. in order to compare the dose averted and the associated costs). The relationship between such quantities and the dose averted will vary considerably with the circumstances of the accident and nature of the contamination, with obvious implications for criteria expressed in these terms. Such criteria would be in accord with the principles of intervention only if their origins took account of the dose averted as a result of their use.

However, there are disadvantages, both technical and in terms of how they are perceived, in using quantities other than dose averted for expressing the criterion. First, other quantities are merely surrogates for the actual quantity of interest and their use will, in general, introduce additional uncertainty and imprecision. Second, the use of surrogate quantities will inevitably distract attention from the central issue, the dose that can be averted by the protective measure, and may lead to misinterpretation of the role and significance of such quantities. Other disadvantages are specific to the particular quantity and these are considered later when the merits and disadvantages of each of the criteria in Table 17 are evaluated.

One final and particularly important point needs to be made regarding the need for care and precision in the use of dose quantities. The use of loose terminology and inadequate qualification of the quantities used has been and continues to be a source of much confusion and unnecessary disagreement in discussions of criteria, etc., in the USSR. For example, doses estimated realistically and conservatively are often erroneously compared without qualification. Similarly, invalid comparisons are made between doses evaluated with and without the influence of protective measures taken into account and between lifetime doses evaluated over different time periods. These aspects need to be given more careful attention than in the past with a view to minimizing unnecessary misunderstandings and avoiding the attendant difficulties.

4.5.1.2. *Exposure Pathways to Be Included and the Relevance of Past Doses*

In accordance with the underlying principles, only those pathways and doses that may be influenced by the protective measure should be taken into account in judging whether it should be implemented and, if so, at what level. For relocation these pathways will, in general, be limited to external exposure from deposited material and internal exposure from inhalation of material resuspended in the atmosphere. Where appropriate, the residual dose from ingestion following the application of food restrictions could also be included insofar as it is reduced by relocation. Similarly, no account should be taken of doses received in the past as these cannot be affected by protective measures taken in the future. The inclusion of past exposures and pathways unaffected by the protective measure (or for which the exposures could be reduced more effectively by other measures that were

[2] The merits of dose rate as a quantity for formulating generic guidance on relocation are limited to the rather idealized situation where inputs, other than the costs of the measure and the reductions in dose achieved, are not relevant to decisions on relocation. Its applicability, moreover, is limited to those cases where the costs of relocation can be assumed to be directly proportional to the number of and the time for which people are relocated and where those relocated would return to the affected areas once the dose rate had fallen below the intervention level.

simpler, less costly and less socially disruptive) is wrong in principle and in practice.

Notwithstanding their irrelevance for decisions on intervention, past doses may need to be included when making decisions on other matters in the aftermath of an accident. For example, they would be particularly relevant when determining the need for long term medical care and surveillance of those affected by the accident and for the payment of compensation.

4.5.1.3. *Application of the Criteria*

Differences are evident in Table 18 in the critical group chosen for application of the criteria and in the degree of realism adopted in the dose assessment. The guidance developed internationally on these issues is clear. The criteria should, in general, be applied to an average member of the critical group affected by the protective measure and the estimate of dose should be as realistic as possible. The adoption of conservative approaches in either the choice of critical group or the dose assessment will inevitably result in action being taken that is both suboptimal and contrary to the principles and purposes of intervention. The adoption of a conservative approach is often defended both in the USSR and elsewhere as being beneficial to those affected because action will be taken at lower doses than intended and this is in people's best interests. This view, however, is misguided and ignores the negative features of the protective measure itself, which may be considerable. If the intervention criterion has been properly evaluated as being the best under the prevailing circumstances, the subsequent inclusion of pessimism or optimism in any aspect of its application can only be detrimental and in conflict with the principles and objectives of intervention.

4.5.1.4. *Comparison of the Criteria on a Common Basis*

In order to make a proper and fair comparison between the various criteria in Table 18, they have all been transformed in terms of the dose that would be averted as a result of their application to the specific circumstances following the Chernobyl accident (subject to the assumption that there is no subsequent return to the affected areas). These averted doses are compared in Table 19 and they have been evaluated as realistically as possible. In each case the dose averted from external radiation from deposited material is given, together with an approximate estimate of the total dose averted. The latter includes the residual ingestion dose that remains after food restrictions and which could, in principle, be averted to some extent by relocation. The actual reduction in this dose would depend on where people were relocated, the subsequent agricultural practice in the area from which they were relocated, food distribution patterns, etc. The simplifying assumption has been made that agriculture in areas from which people have been relocated ceases completely and that doses from the ingestion of radionuclides are averted (i.e. food totally free of contamination is consumed following relocation). This assumption is likely to overestimate the actual ingestion dose that would be averted.

Several comments need to be made on the methods used to estimate the averted doses. The most realistic methods that the Institute of Biophysics (IoB) was able to recommend in November 1990 [26] were used, taking due account of the actual methods used when applying the respective criteria. These more realistic methods lead to doses that are a factor of 1.7 times lower than those previously calculated by the IoB for general dose assessment purposes and for the purposes of comparison with the criteria. This correction factor only takes account of the proven conservatism in the estimates (i.e. from comparison of estimates and measurements in the years following the accident). Further conservatism may still exist in the estimation of lifetime doses because of uncertainties in the rate at which the dose will decline in the future. The possibility that the averted doses given in Table 19 are overestimates cannot, therefore, be precluded. The doses from food consumption were estimated on the basis of the average relationship between dose and contamination density [26], while recognizing that there are considerable variations between settlements depending on the soil characteristics and the agricultural practice. The residual food dose (i.e. that remaining after the application of agricultural measures and foodstuff restrictions) assumed to be averted by relocation was evaluated as the sum, over the following 70 years, of the predicted dose in each year subject to a maximum dose averted of 2 mSv/a; the latter is typical of the current maximum annual dose with food restrictions and other agricultural measures in place [27]. These assumptions are likely to lead to an overestimate in the ingestion doses averted. The dose averted corresponding to the 350 mSv lifetime dose criterion was evaluated subject to the assumption that the maximum dose in the affected settlements in the period 1986–1989 was 70 mSv (evaluated using the conservative methods used by IoB in applying the criterion).

It is evident from Table 19 that, with one exception, the averted doses associated with the Soviet criteria all fall within the range of the IAEA numerical guidance. However, this is hardly surprising given the very large range of values spanned by the IAEA guidance in order to accommodate diverse situations of potential interest. It is notable, however, that the averted doses are all close to the lower bound of the IAEA range of values. The averted dose for the criterion of 15 Ci/km^2 (555 kBq/m^2) (used in the All-Union State Programme for the selective relocation of particular groups in the

TABLE 19. Realistic Estimates of the Dose Averted as a Result of the Respective Criteria

	Criterion	Estimated lifetime dose averted from external radiation[a] (mSv)	Estimated lifetime dose averted from external radiation and residual ingestion dose[a, b] (mSv)
		USSR	
1986	100 mSv/a[c]		
1987	30 mSv/a[c]	~140	<240
1988	25 mSv/a[c]	~130	<230
1989	25 mSv/a[c]	~150	<260
1990	350 mSv/lifetime[d]	~ 60	<130
1990	40 Ci/km^2 (1480 kBq/m^2)[e]	~ 80	<160
	15 Ci/km^2 (555 kBq/m^2)[f]	~ 30	< 80
		IAEA	
	A few to a hundred mSv in a year	~50 to ~1700[g]	~120 to ~1800

[a] The period over which the lifetime dose is averted is taken as being 70 years, beginning from the year in which the criterion applies. In the case of the IAEA criterion, the dose averted has been estimated for a 70 year period beginning in 1990. The assumption is made that there is no subsequent return to the affected settlements after relocation, i.e. relocation is permanent.

[b] The ingestion dose averted by relocation can only be estimated approximately, as much would depend on where people are relocated, subsequent agricultural practices in the relocated area, food distribution practices, etc. The assumption is made that, after relocation, doses from ingestion are reduced to zero. This assumption will overestimate the actual reduction in dose achieved.

[c] Half of the criterion in 1987 and one third in 1988 and 1989 were allocated to exposure via ingestion and the remaining fractions to other exposure pathways.

[d] Applies to a lifetime dose over the period 1986–2056 (see Section 3.5.2).

[e] Applies generally (see Section 3.5.3).

[f] Applies to particular subgroups in the population, but has been adopted for general application in the BSSR (see Section 3.5.3).

[g] The values corresponding to the IAEA criterion, expressed as dose in a year, would vary with the circumstances of the accident and the nature of the contamination. The values quoted are for contamination which is typical of the Chernobyl accident.

population judged to be at greater risk, and as a general criterion in the BSSR) is the only one which lies below the range of IAEA values. Given the scale of the Chernobyl accident and the qualifications that accompany the IAEA quantitative guidance, levels somewhat nearer the middle or upper part of the range would have been expected.

The external doses that could be averted by relocation for the criteria used in the period 1987–1989 are approximately 140 mSv; for the 350 mSv lifetime dose limit and the 40 Ci/km^2 (1480 kBq/m^2) criterion the doses that could be averted are about a factor of 2 lower. The residual ingestion doses that could, in principle, also be averted by relocation would, at most, be of a comparable magnitude; they could be substantially less depending on the subsequent agricultural and food distribution practices adopted. The criteria used during 1987–1989 all lead to comparable savings in averted dose; for the post-1990 criteria the dose averted is about a factor of 2 lower. Such a change is not necessarily inconsistent with the underlying principles of intervention but, to be justified, it should be associated with a change in the factors entering into the balance in the intervening period (e.g. resource constraints, public attitudes, etc.). These aspects are explored further in Section 4.5.5 and Annex 3.

The doses that could be averted by relocation are, in general, modest in relation to the monetary and social costs of this protective measure. Indeed, for the post-1990 criteria, the external dose that could be averted is small in comparison with the average levels of natural background radiation that would be received over the same period. The health significance of these doses and the economic cost and social per unit dose averted for measures taken to avoid them are dealt with further in Sections 4.5.3 and 4.5.4, respectively. Consideration is given later to the influence of social factors.

4.5.2. Merits and Disadvantages of the Respective Criteria

The merits and disadvantages of each type of criterion used in the USSR are summarized in the context of international guidance on intervention.

4.5.2.1. Dose in a Year (1986–1989)

If the quantity 'dose in a year' is used as a surrogate for the dose averted, this is consistent with the principles of intervention. Despite its extensive use for the purposes of formulating criteria for relocation (the current IAEA guidance [2] is expressed in these terms), there are negative aspects to its use. Conceptually, there are no compelling reasons for choosing one year as the time period of reference in preference to any other period. Indeed, there may be strong arguments to the contrary. Familiarity, and the use of this period for the purposes of expressing many other quantities, may have been instrumental in its choice. The latter, however, is responsible for the main problem with this quantity, i.e. the possibility of misinterpreting it. This arises because direct comparison, however inappropriate, can readily be made with annual dose limits and erroneous conclusions can be drawn. This in turn can lead to confusion, misunderstanding and, ultimately, a loss of trust in the whole system of intervention. Although this point may appear academic, its importance should not be underestimated within the context of establishing criteria capable of gaining broad acceptability. The possibility of making invalid comparisons and the misunderstandings that result are not the sole preserve of the general public.

Over and above the potential difficulties in using this quantity, there are, in addition, deficiencies in how it has been applied, in particular in the conservative estimation of doses for comparison with the criterion and in applying it to the exposure of the critical group, as opposed to the average individual, among those affected by the protective measure. The use of conservative dose estimates is wrong conceptually and may lead to the unnecessary relocation of people (i.e. those who would actually receive doses less than the criterion). The belief that such a conservative approach is in the best interests of those affected, while well intentioned, is misplaced. It appears not to recognize the major social and possible health costs of relocation, nor the additional anxiety resulting from leading people to believe that they would receive doses far in excess of those that would occur in practice.

4.5.2.2. Lifetime Dose Limit of 350 mSv

In principle a lifetime dose limit is, despite the inevitable confusion with dose limits, an ideal surrogate for dose averted in those cases where relocation is intended to be permanent or at least of a very long duration. Where relocation is likely to be temporary, however, it offers no particular advantages over other quantities where dose is integrated over a fixed period of time. Two criticisms can be offered of the way in which the criterion was applied, the second of which also leads to difficulties with some aspects of its conceptual basis. First, conservative methods of dose estimation were used for making comparisons with the criterion; the implications of this have already been set out. Second, the dose arising during the period 1986–1989 was included in the dose to be compared with the criterion; as has been previously discussed, this is inconsistent with the principles underlying intervention and can have no conceptual justification. The inclusion of past doses may, however, be appropriate for purposes other than for decisions on intervention, for example in compensating those affected by the accident or in determining the need for long term health care and surveillance measures.

The reasons for past doses being included appear to be connected with the conceptual basis used to establish the criterion (see Section 3.4.2). This basis, however, appears to be fundamentally flawed and, moreover, is not in accordance with the principles underlying intervention. It is based on the premise that below this level of dose, it will not be possible statistically to observe an increase in radiation induced health effects in the exposed population. Irrespective of the accuracy of this premise, the occurrence of health effects at these levels of dose is not precluded. Indeed, the scientific consensus at this time is that for health planning purposes, it would be prudent to assume that such effects would occur at a level that can be estimated based on the risk coefficients given in recent international reviews [3, 28].

Two additional factors have lessened the acceptability of this potentially useful criterion. The first factor is that the criterion is concerned solely with relocation as a protective measure, with no explicit consideration given to the relative merits of other simpler and possibly more cost effective measures in establishing a coherent intervention policy. Relocation was to be implemented if the dose from all pathways, taking no account of any other protective measures taken after 1989, exceeded the criterion. In those settlements where the criterion was not exceeded, no further protective measures were to be taken. This approach is subject to at least two criticisms:

(1) decisions on food restrictions are largely independent of those for relocation, and their continued use and worth should have been evaluated separately for those settlements not being relocated; and (2) in determining whether relocation should be undertaken and what dose saving would accrue, proper account should have been taken of the large potential dose savings that could be achieved at a far lower financial and social cost by the continued use of food restrictions.

The second factor concerns interpretation of the criterion in terms of the annual dose limit for members of the public. Many, both within and outside the USSR, have interpreted the criterion as having its origins in the product of an annual dose limit of 5 mSv per annum and a lifetime of 70 years. It is claimed by those who developed the criterion that such considerations played no role in its development. Notwithstanding this, the numerical equivalence has been the source of much unnecessary confusion and misunderstanding, some of which still persist. This misunderstanding has led some to propose a reduction in the criterion to 70 mSv, with the reduction in the annual dose limit recommended by the ICRP from 5 to 1 mSv given as the justification for this change. Such proposals are unfounded and inconsistent with the principles of intervention (see Section 2). They show a complete lack of understanding of the role and purpose of dose limits and of their irrelevance in establishing intervention levels. Disagreements on this topic among scientists in the USSR would appear to have contributed significantly to the loss of confidence by the people and their political representatives in the system of intervention being proposed and to anxiety in the population. Those who have misrepresented the role of dose limits in the context of intervention are undoubtedly, to a large extent, responsible for this unfortunate situation. This confusion has not helped those affected by the accident. An important lesson for the future can be learned from this experience. Numerical values for criteria should be chosen, insofar as is practicable, to preclude the possibility of their being confused with dose limits, even if this means that some compromise in their scientific basis must be made.

4.5.2.3. Contamination Levels

The use of contamination levels, if derived as a surrogate for averted dose, is in accordance with the principles of intervention. It has the considerable practical advantage of being the primary parameter from which environmental measurements have been made and for which maps are available. It is also more readily understood by the layman than dose. Its main deficiency is that its relationship with dose (especially that via ingestion) may vary by up to two orders of magnitude, depending upon soil characteristics and agricultural practices. At best, therefore, it can only be a fairly crude measure of dose and of doses potentially averted. Ideally, any criterion expressed in this way should, therefore, be qualified where necessary so that allowances can be made for those situations where the relationship between dose and contamination level departs significantly from the average. The absence of such qualification from the current relocation criterion is a significant omission which should be rectified.

4.5.3. Levels of Individual Risk Associated with the Criteria

Before examining the cost per unit of dose averted associated with the various relocation criteria, it is important first to put into perspective the levels of individual risk that would result from continuing to live in the affected areas. Realistic estimates of the level of dose that could be averted by relocation at the various criteria are given in Table 19; in the absence of relocation these would be the estimated additional doses to which people would be exposed.

Estimates of the annual increase in the risk of death, as a function of age, for individuals born in 1990 and continuing to live in settlements where the lifetime dose takes particular values are given in Table 20. Estimates are also given of the resulting average loss of life expectancy and the annual average increase in risk (averaged over an assumed lifetime of 70 years) for such individuals. The increases in risk and loss of life expectancy would be lower for individuals born at other times. For the purposes of comparison, data on the annual death rate from all causes in the USSR, averaged over males and females, are also given in Table 20. The basis on which all of these risks have been derived is set out in Annex 2.

The following scenario illustrates the way in which information in Table 20 can be used in making decisions involving a relocation strategy. For a relocation criterion of 40 Ci/km^2 (1480 kBq/m^2), an upper estimate of the lifetime dose that could be averted is about 160 mSv (see Table 19). The corresponding average loss of life expectancy would be about 50 days and the annual increase in risk of death, averaged over a lifetime, would be about 1 in 10 000 per annum. As indicated previously, lower risks would be experienced by those born in years other than 1990. These additional risks, while not trivial, are small in comparison with the levels of risk unavoidably encountered in everyday life. The magnitudes of these risks, in themselves, fall far below what many would consider necessary to justify the major social cost and inconvenience of relocation. Indeed, the risk to health of relocation itself (notwithstanding the major social problems it brings) may exceed the radiation risk averted. The loss of life expectancy as a result of relocation is a matter warranting more detailed examination and quantification; its implications can then

TABLE 20. Additional Risk Resulting from Continued Living in the Affected Settlements

Age (a)	Annual death rate per 10^5 people (a^{-1})[a]	Annual increase in the probability of death (per 10^5 people) who continue to live in settlements where the lifetime dose (1990–2060) would equal the specified value[b]		
		37 mSv	87 mSv	210 mSv
1	230	0	0	0
10	51	1	2.5	6
20	100	4	9	21
30	180	8	18	41
40	320	15	35	83
50	750	39	90	220
60	1600	110	250	600
70	3700	250	580	1400
80	9800	450	1000	2500
Average loss of life expectancy (days)[c]		3	29	70
Annual average increase in risk of death from living in contaminated settlements per 10^5 people (a^{-1})[d]		3.1	7.2	17

Note: Values are quoted in general to two significant figures.

[a] Annual death rates from all causes in the USSR averaged over males and females (assuming 10^5 people are alive at each age).

[b] Annual increase in probability of death for people born in 1990 who continue to live in settlements with lifetime doses as specified. The distribution in time of the doses is that predicted for the contaminated areas (see Section 4.5.4).

[c] Average loss of life expectancy for someone born in 1990; lower risks would be experienced by others born at different times.

[d] Annual increase in risk of death for someone born in 1990, averaged over an assumed lifetime of 70 years; lower risks would be experienced by others born at different times.

be properly appreciated and communicated to those who may be affected, thus ensuring that personal decisions on relocation were made on a more informed basis. For other relocation criteria expressed in terms of dose or contamination level, the corresponding levels of risk or loss of life expectancy can be estimated by appropriate scaling.

4.5.4. Cost–Benefit Analysis of Relocation

The cost of relocation and the radiation doses averted by its introduction are the two important factors to be considered in making balanced judgements on the most appropriate level at which to implement this protective measure. They are, of course, not the only factors that need to be taken into account: in some cases they may not even be the most important, particularly if social and political factors are given prominence. Notwithstanding the potential importance of other factors, there is merit in first undertaking a partial or constrained analysis of the balance or interplay between these two inputs alone, i.e. the costs of, and doses averted by, relocation. There are two main purposes of this analysis. First, it provides estimates of the monetary resources that would need to be expended on relocation in order to avert unit doses or unit health effect, thus providing a basis for comparison with expenditures elsewhere in the economy to improve health. Second, it enables the optimum level for introducing relocation to be determined, at least in those cases where cost and averted radiation risk are the only considerations. This provides a baseline against which the influence of including other factors of a more sociopolitical nature can subsequently be judged. The influence of these other factors is evaluated in Section 4.5.5.

For simplicity, the analysis has been limited to consideration of permanent relocation, i.e. there is no intention at the time relocation occurs for subsequent return to the affected area. This, in fact, closely resembles the actual situation, although inevitably there will be some who wish to return to these areas even if at present there is no intent to do so. In these circumstances, the dose averted by relocation is the residual lifetime dose that would otherwise have been received. In the more general case, due account would need to be taken of the duration of relocation (which would be determined by the level of dose at which return might occur) in determining the optimum intervention policy.

4.5.4.1. Scope and Content of the Analysis

The scope and content of the analysis were specified in order to satisfy two main objectives: first, to enable estimates to be made of the cost per unit of dose averted on the assumption of the relocation of a number of individual settlements having different radiological, economic and social characteristics; second, to estimate for each Republic and/or at the All-Union level the cost per unit of dose averted associated with relocation as a function of the level of dose or contamination at which it was to be introduced.

There were compelling reasons for carrying out the analysis both for individual settlements and on the larger scale of the Republics or at the All-Union level. Any practicable policy for relocation must be applicable to at least a whole Republic and preferably at an All-Union level and, therefore, it should be evaluated on this scale. In addition, however, it is important to investigate whether policies developed on a broader basis remain applicable when applied to individual settlements or whether they need to be qualified or supplemented to account for local factors. Significant differences are to be expected between the average cost per unit of dose averted for relocating a large number of settlements within a Republic as a whole and that for individual settlements because of variability in their radiological, economic and social characteristics.

Notwithstanding the importance of undertaking the analysis in these two distinct parts, it did not prove possible in practice. Within the requisite time-scale it was not possible to obtain the data required on the specific radiological, economic and social conditions in selected settlements. Consequently, it was not possible to test the 'robustness' or validity of the conclusions

TABLE 21. Basic Radiological Data Used in the Cost-Benefit Analysis

Contamination level of caesium (Ci/km^2)	Annual (1990) individual effective dose (mSv)[a]	Individual lifetime effective dose (mSv)[a]	Number of people in the dose range	Lifetime collective effective dose (man·Sv)[a, b]
5–10	2.2–3.7	37–62	411 800	20 400
10–15	3.7–5.1	62–87	87 200	6 500
15–20	5.1–6.6	87–111	117 900	11 700
20–25	6.6–8.1	111–136	28 100	3 500
25–30	8.1–9.6	136–161	24 900	3 700
30–35	9.6–11.0	161–186	15 700	2 700
35–40	11.0–12.5	186–210	5 300	1 050
40–60	12.5–18.4	210–309	10 400	2 700
60–80	18.4–24.3	309–408	3 400	1 200
>80	>24.3	>408	900	4 000
Total			705 600	54 000

[a] All doses are estimated on the assumption that no protective measures are taken.

[b] Collective dose in each contamination range is estimated as the product of the number of people and the mean lifetime individual dose between 1990 and 2060.

reached from the analysis carried out on a macroscale at the Republic or All-Union level. This omission, over which the Project had no control, is a major deficiency in the current analysis and it should be rectified as soon as is practicable. The unavailability of these data had similar implications for the evaluation of sociopolitical factors (see Section 4.5.5). Contrary to the original intent, this evaluation could also only be carried out on the scale of a Republic or at the All-Union level, with all of the attendant limitations.

4.5.4.2. *Basic Data Used in the Analysis*

The basic data and other assumptions used in the analysis are given in Annex 2, together with comprehensive results of the cost–benefit analysis. Only a summary of the main data used and the assumptions made is given here. To the extent possible, the USSR was requested to provide data that were realistic, thus avoiding the introduction of unwanted bias into the analysis. Consequently, some of the data (in particular the dosimetric data) used in the analysis differ from those reported elsewhere; departures from realism may still persist for some of the data and where these may be significant they are identified. Data were available for the All-Union level and for each of the three Republics. The analysis was, however, confined to the All-Union level. A cursory analysis of the data indicated that few additional insights could be gained by carrying out separate analyses for each of the individual Republics, in particular in the context of the very broad nature of any conclusions that could be reached in the absence of an analysis on a settlement by settlement basis.

4.5.4.3. *Radiological Data*

The basic radiological data are summarized in Table 21. The distribution of the population as a function of the contamination level of caesium was taken from Ref. [29] and the relationships between doses and contamination levels from Ref. [26]. These relationships were judged by the Institute of Biophysics to be the most realistic that could be derived at present. They contain a correction factor of 1.7 compared with their earlier dose estimates, which had intentionally been conservative. This correction factor only takes account of the proven conservatism of the estimates (i.e. from comparison of estimates and measurements in the years following the accident). Further conservatism may still exist in the estimation of lifetime doses because of uncertainty over the rate at which the dose will decline in the future. This aspect is currently receiving further investigation in the USSR and the possibility of a further downward revision in the predicted lifetime doses cannot be precluded.

The relationships used are set out fully in Annex 2 and for two of the quantities, the annual dose in 1990 and the lifetime dose between 1990 and 2060, below.

(1) *Assuming no protective measures are taken* [26]

— Annual doses in 1990:

$$H_{a,ext} = 0.11C \text{ mSv/a}$$

$$H_{a,int} = 0.734 + 0.184C \quad [\text{mSv/a}]$$

— Lifetime doses from 1990 to 2060:

$$H_{l,ext} = 1.87C \text{ mSv}$$

$$H_{l,int} = 12.34 + 3.08C \quad [\text{mSv}]$$

(2) *Assuming that food restrictions are applied* [27]

— Annual dose in 1990:

$$H_{a,int} = -0.17 + 0.95 \log_{10}C \quad [\text{mSv/a}]$$

where C is the contamination level of caesium in Ci/km^2 and the subscripts 'int' and 'ext' refer to internal and external radiation and 'a' and 'l' to annual and lifetime doses, respectively.

Several cautionary remarks need to be made on these relationships. It must be recognized, first, that they are somewhat idealized and only applicable on average. For internal doses, in particular, it would be inappropriate to use them to estimate doses in individual settlements where the soil characteristics or agricultural practices deviate greatly from the average. This is one of the factors dictating the need for a supplementary cost–benefit analysis for a representative range of individual settlements. The other point is that the annual dose from internal radiation in 1990, assuming food restrictions are applied, is assumed in this analysis to remain the same in all subsequent years while the restrictions remain in force (unless of course the predicted dose without protective measures is lower). While this is likely to be a reasonable assumption for the early part of the 1990s, it is likely thereafter to result in an increasing overestimate of the ingestion dose, at least while food restrictions remain in force.

4.5.4.4. *Economic Data*

The basic data on the costs of protective measures have been derived from the All-Union State and Republican Programme for the Rectification of the Consequences of the Chernobyl Accident, 1990–1992 [9].

This Programme contains costs, divided into many categories, for those who are being relocated and for a variety of measures being taken to provide improved living conditions for those remaining in the affected areas. From these data, average costs per person for relocation and for providing improved living conditions were derived. These costs are summarized below and the basis of their derivation is given in Annex 2. The costs have been subdivided into two components, comprising a fixed 'baseline' cost necessary for the introduction of the protective measure, or fixed costs, together with an annual component depending on the period the measures remain in force.

Relocation: 42 000 roubles per person.

Improved living conditions: 4300 roubles per person, plus an annual cost of 1250 roubles per person (or 1430 roubles per person for those in areas with a contamination level in excess of 15 Ci/km^2 (555 kBq/m^2)) for each year the protective measures remain in force.

Because of some ambiguity regarding the exact categorization of the various costs and the fundamental premise that the costs can be assumed to be directly proportional to the number of people affected, the above estimates should only be used to provide a very approximate estimate of the overall costs of different protective measures (apart of course from the strategy from which they were derived, i.e. the current 1990–1992 Programme [9]). Moreover, the costs are only appropriate when used as an average over all affected settlements. It would be inappropriate to use them to examine the cost per unit of dose averted for the relocation of any individual settlement.

4.5.4.5. *Strategies for Protective Measures Evaluated*

The cost per unit of dose averted by relocation has been estimated as a function of the level at which it is assumed to be introduced. The level of caesium contamination has been used in the analysis as the criterion for relocation, but solely as a matter of convenience. Lifetime dose, annual dose in 1990, or other quantities could, according to preference, equally have been used. Transformations in terms of other quantities can readily be made on the basis of the information presented in Table 21.

The estimate of the cost per unit of dose averted of introducing relocation at different levels is given within the general framework of the 1990–1992 All-Union State Programme [9]. It is assumed throughout the analysis that the level of contamination (or associated level of dose) above which improved living conditions are provided remains fixed and the only variable is the level at which relocation is introduced. In addition, it is assumed that the evaluation is made prior to the implementation of the Programme. Different results would be obtained if the evaluation were to be carried out now (i.e. after the current Programme has been partially implemented). This is because some of the costs of providing improved living conditions are 'one time' costs which neither could be retrieved, nor would continue to be useful, if a decision were subsequently made to alter the relocation policy. The sensitivity of the results to the time at which the analysis is performed has been investigated.

The cost per unit of dose averted of undertaking relocation at different levels of dose or contamination will also vary with the period over which provision continues to be made for improved living conditions. In the absence of precise information on the scale of the post-1992 Programme, only indicative estimates can be made. Three hypothetical scenarios have been postulated solely for the purposes of examining the significance of this parameter:

— Beyond 1992 no further provision is made for improved living conditions.
— The existing provisions for improved living conditions remain in force for a period of five years (i.e. until 1995).
— The existing provisions for improved living conditions remain in force for a period of ten years (i.e. until the year 2000).

The choice of these values has no significance (nor should it be accorded any) in relation to the period over which measures aimed at improving living conditions may remain in force in the affected regions.

The marginal cost per unit of dose averted, as a function of the contamination level (in the range of 5 to 80 Ci/km^2 (185–2960 kBq/m^2)), was estimated for each of the three scenarios. In addition, a large number of sensitivity analyses were undertaken to investigate the influence of some of the key parameters. Consideration is limited here to two of the more important parameters, the costs of relocation and of providing improved living conditions.

4.5.4.6. *Results*

Base Case

The variation in the marginal cost per unit of dose averted of introducing relocation at different contamination levels is summarized here in Table 22 and illustrated in Fig. 2–10 in Annex 2 of this Part; values are given for each of the periods for which the measures for improving living conditions are assumed to continue.

The average cost per unit of dose averted for each of the protective measures strategy is also given in

TABLE 22. Variation in Average and Marginal Costs per Unit of Dose Averted as a Function of the Relocation Criterion and the Period for Which Measures to Improve Living Conditions Are Assumed to Continue[a, b]

Period for which measures to improve living conditions continue	3 years		5 years		10 years	
Criterion for relocation (in Ci/km^2 (kBq/m^2) of caesium)[b]	Cost per unit of dose averted (million roubles/man-sievert)					
	Average	Marginal	Average	Marginal	Average	Marginal
5 (185)	0.55	0.75	0.55	0.72	0.55	0.62
10 (370)	0.45	0.50	0.47	0.48	0.53	0.41
15 (555)	0.44	0.37	0.47	0.35	0.54	0.29
20 (740)	0.48	0.30	0.54	0.28	0.66	0.24
25 (925)	0.52	0.25	0.58	0.23	0.72	0.20
30 (1110)	0.61	0.21	0.67	0.20	0.81	0.17
35 (1295)	0.71	0.19	0.78	0.18	0.92	0.15
40 (1480)	0.78	0.14	0.83	0.14	0.96	0.12
60 (2220)	1.06	0.10	1.06	0.099	1.13	0.085
80 (2960)	1.29	0.081	1.22	0.078	1.23	0.067
α	1.40	—	1.29	—	1.27	—

[a] Costs were estimated for the baseline assumptions with regard to the cost of relocation and providing improved living conditions. The average cost per unit of dose averted is the sum of the costs of providing improved living conditions for those settlements contaminated above 5 Ci/km^2 (185 kBq/m^2) and of relocating those above the specified criterion divided by the collective effective dose averted as a consequence of these measures. The marginal cost per unit dose averted was estimated as the increase in cost as a result of adopting a lower relocation criterion divided by the associated increase in the collective dose averted.

[b] Criteria can be transformed into other quantities using data given in Table 21.

Table 22. It can be seen to be very high and a cost in excess of one million roubles/man-sievert averted is associated with providing improved living conditions in some areas. This is a consequence of many of the more costly measures (e.g. compensation) taken to provide improved living conditions which have little or no bearing on the resulting radiation doses. The only measures that achieve major reductions in dose are those to provide 'clean food' and other agrotechnical measures to reduce foodstuff contamination. These costs, however, make up but a small fraction of the total monetary resources being directed towards improving living conditions.

The marginal cost per unit of dose averted of relocation at different contamination levels varies with the period for which measures to improve living conditions are assumed to remain in force. This is because relocation, compared with improving living conditions, becomes a relatively less expensive option the longer the latter remain in force. For a ten year period the marginal cost per unit of dose averted of relocating at 40 Ci/km^2 (1480 kBq/m^2) is about 0.1 million roubles/man-sievert. This increases by approximately twofold for contamination levels of about 20 Ci/km^2 (740 kBq/m^2). For lower contamination levels, the cost per unit of dose averted increases rapidly (i.e. relocation rapidly becomes less cost effective).

Sensitivity to the Costs of Relocation and of Providing Improved Living Conditions

Two of the more sensitive and uncertain parameters in the analysis are the costs of relocation and of providing improved living conditions. The costs of relocation in the All-Union State Programme would appear to be applicable only to people relocated to newly constructed settlements where a completely new infrastructure has to be provided. Somewhat lower costs would be associated with relocation to existing settlements where only marginal additions to the existing infrastructure may be needed. Given this potential uncertainty, the sensitivity of the cost per unit of dose averted to the cost of relocation has been examined. 'One-off' costs per person of 20 000 and 30 000 roubles were assumed in addition to the base case of 43 000 roubles. The results are summarized here in Table 23 and in Figs 2–5 and 2–6 in Annex 2 of this Part for two periods (three and ten years) over which the provisions for improved living conditions are assumed to remain in force.

A reduction in the cost of relocation has a significant influence on the marginal cost per unit of dose averted by relocation. The effect is more pronounced in the case where measures to improve living conditions are assumed to continue for a period of ten years as opposed to three years (i.e. assumed to cease post-1992). Assuming measures for improved living conditions for ten years, there is about a twofold reduction in the marginal cost per unit of dose averted for a reduction in the relocation cost from 42 000 to 30 000 roubles. Marginal costs per unit of dose averted of about 60 000 roubles/man-sievert are then associated with a criterion of 40 Ci/km^2 (1480 kBq/m^2) and about 100 000 roubles/man-sievert with a level of about 20 Ci/km^2 (740 kBq/m^2). The effect is more dramatic for a twofold reduction in the cost of relocation to 20 000 roubles/person, with the marginal costs decreasing, typically, by more than a factor of ten. Marginal costs of about 7000 roubles/man-sievert are associated with relocation at 40 Ci/km^2 (1480 kBq/m^2) and about 50 000 roubles/man-sievert for a level as low as 10 Ci/km^2 (370 kBq/m^2). The reason for these large decreases is that the costs of relocation and improved living conditions are then very similar. Consequently, the additional doses averted by relocation, although modest, are then achieved at only a relatively small additional cost. Put simply, where the costs of relocation and of improved living conditions are comparable, relocation is likely to be the preferred protective measure (assuming cost and radiation health risk are the only inputs into the decision) as it would lead to much greater savings in dose for essentially the same cost. Consideration of factors other than risk and cost may of course alter this view.

Uncertainties are also associated with the costs of providing improved living conditions and with how the values used here were derived from the All-Union State

TABLE 23. Sensitivity of the Marginal Cost per Unit of Dose Averted by Relocation to the Relocation Cost

Cost per person of relocation (roubles)	43 000		30 000		20 000	
Criterion for relocation (in Ci/km^2 (kBq/m^2) of caesium)[b]	**Marginal cost[a] per unit of dose averated (million roubles/man-sievert)** *Period over which measures to improve living conditions continue (years)*					
	3	10	3	10	3	10
5 (185)	0.75	0.59	0.48	0.30	0.26	0.073
10 (370)	0.50	0.39	0.32	0.20	0.17	0.049
15 (555)	0.37	0.28	0.23	0.13	0.12	0.016
20 (740)	0.30	0.22	0.19	0.11	0.10	0.013
25 (925)	0.25	0.19	0.16	0.091	0.083	0.011
30 (1110)	0.21	0.16	0.13	0.078	0.072	0.010
35 (1295)	0.19	0.14	0.12	0.069	0.063	0.008
40 (1480)	0.14	0.11	0.090	0.053	0.048	0.006
60 (2220)	1.10	0.081	0.065	0.039	0.035	0.005
80 (2960)	0.081	0.064	0.051	0.031	0.027	0.004

[a] Marginal costs are estimated for the baseline assumption with regard to the costs of providing improved living conditions.
[b] Criteria can be transformed into other quantities using data given in Table 21.

TABLE 24. Sensitivity of the Marginal Cost per Unit of Dose Averted by Relocation to the Cost of Providing Improved Living Conditions[a, b]

Costs of improved living conditions	Baseline costs[c]		Baseline costs multiplied by 2		Baseline costs divided by 2	
	Marginal cost per unit of dose averted (million roubles/man-sievert)					
Criterion for relocation (in Ci/km^2 (kBq/m^2) of caesium)[b]	*Period over which measures to improve living conditions continue (years)*					
	3	10	3	10	3	10
5 (185)	0.75	0.59	0.57	0.20	0.83	0.78
10 (370)	0.50	0.39	0.38	0.13	0.56	0.52
15 (555)	0.37	0.28	0.27	0.059	0.42	0.39
20 (740)	0.30	0.22	0.22	0.048	0.33	0.31
25 (925)	0.25	0.19	0.18	0.040	0.28	0.26
30 (1110)	0.21	0.16	0.16	0.035	0.24	0.23
35 (1295)	0.19	0.14	0.14	0.030	0.21	0.20
40 (1480)	0.14	0.11	0.11	0.023	0.16	0.15
60 (2220)	0.10	0.081	0.077	0.017	0.12	0.11
80 (2960)	0.081	0.064	0.060	0.014	0.091	0.089

[a] Marginal costs are estimated for the baseline assumption with regard to the costs of relocation.

[b] Criteria can be transformed into other quantities using data given in Table 21.

[c] Baseline costs for improved living conditions are a 'one off' cost per person of 4300 roubles plus an annual cost per person of 1250 roubles (<15 Ci/km^2 (<555 kBq/m^2)) and 1430 roubles (>15 Ci/km^2 (>555 kBq/m^2)).

Programme. The sensitivity of the results was therefore analysed for improved living costs at a factor of 2 higher and lower than the baseline values. The results are given here in Table 24 and in Figs 2–7 and 2–8 in Annex 2 of this Part, again for two periods for which measures for improved living are assumed to continue.

Lower costs for providing improved living conditions lead to increases in the values for the marginal cost per unit of dose averted by relocation (and vice versa). This is a consequence of the same dose being averted by relocation in all cases, but at a higher relative cost when the cost of providing improved living conditions is lower. Typically (assuming measures to improve living conditions continue for a ten year period), an increase in the costs of improved living conditions by a factor of 2 would decrease the marginal cost per unit of dose averted by a factor of about 5 in areas with ^{137}Cs ground contamination levels in excess of 15 Ci/km^2 (555 kBq/m^2). For a decrease in costs of a factor of 2 the cost per unit of dose averted would increase by about 30%. Somewhat lower sensitivity to the cost of providing improved living conditions results if it is assumed that these provisions cease beyond 1992.

What is particularly evident from the results in Tables 22-24 and Figs 2-7 to 2-9 (in Annex 2) is that the cost per unit of dose averted by relocation is very sensitive to the costs of relocation and of providing improved living conditions and also to the period for which the latter are assumed to continue. The confidence that can be attached to the values currently assigned to these costs and periods will strongly influence judgements on the optimal choice of relocation level, at least those judgements exercised on cost-benefit grounds alone. The reliability of the cost estimates and the period over which measures to improve living conditions are likely to continue are, therefore, matters that warrant closer scrutiny.

Cost-Benefit Analysis of the Situation Following the Implementation of the 1990-1992 All-Union State Programme

The previous estimates of the marginal cost per unit of dose averted as a function of the contamination level at which relocation is implemented are only relevant to the situation prior to implementation of the Programme.

TABLE 25. Comparison of the Marginal Cost per Unit of Dose Averted by Relocation for the Situation prior to and after Implementaton of the 1990–1992 All-Union State Programme

Relocation criterion (in Ci/km^2 (kBq/m^2))[b]	Marginal cost[a] per unit of dose averted (million roubles/man-sievert)	
	Before	After
5 (185)	0.62	0.79
10 (370)	0.41	0.53
15 (555)	0.29	0.38
20 (740)	0.24	0.31
25 (925)	0.20	0.26
30 (1110)	0.17	0.22
35 (1295)	0.15	0.20
40 (1480)	0.12	0.15
60 (2220)	0.085	0.11
80 (2960)	0.067	0.087

[a] Marginal costs are estimated using baseline values for the costs of relocation and for improving living conditions; the latter are assumed to continue for ten years.

[b] Criteria can be transformed into other quantities using data given in Table 21.

Different outcomes would result once the Programme had begun to be implemented because some of the costs of providing improved living conditions are 'one-off' costs and cannot be recovered once spent; in these cases, relocation, as an alternative to continuing to provide improved living conditions, would be less cost effective, i.e. it would lead to higher values for the marginal cost per unit of dose averted.

The magnitude of the increase can be seen from Table 25, where the cost per unit of dose averted is compared for an analysis of the situation before implementation of the current Programme and at its end (i.e. at the end of 1992). In both cases, the costs of relocation and of improved living conditions were the same as the baseline values used previously and the measures for improved living conditions were assumed to continue for a period of ten years. The marginal cost per unit of dose averted by relocation increases by about 20–30% for an analysis undertaken of the situation following, as opposed to before, the implementation of the current All-Union State Programme. Although this increase is not large, it does indicate that if relocation is to be introduced it should be undertaken as soon as practical circumstances permit. Otherwise, significant 'one-off' investments on improving living conditions in areas from which the population will subsequently be relocated will, at least partially, be wasted.

Sensitivity of the Cost per Unit of Dose Averted by Relocation to the Relationship Between Internal Dose and the Surface Contamination of Caesium

All of the above estimates of the cost per unit of dose averted by relocation were evaluated on the basis of average relationships between the contamination density of caesium on the ground and the dose. Significant variation can occur in this relationship, in particular in the internal dose, depending on soil conditions and agricultural practices. Information [30] on a number of settlements in one particular region showed that the ratio between the internal dose and the external dose (without countermeasures) varied from about unity to about 15. It is interesting to examine the extent to which such a variation might alter the cost per unit of dose averted that has been estimated on the basis of the average relationship between dose and contamination density. The variation in the marginal cost per unit of dose averted by relocation is shown in Table 26 for a range of contamination densities and for several assumed values for the ratio of the internal to external dose. For simplicity, the marginal costs per unit of dose averted have been evaluated subject to the assumption that no provision is made for improved living conditions.

It is evident from Table 26 that the marginal cost is sensitive to the ratio of the internal to external dose and, more particularly, to the relationship between the internal dose and contamination density. For the range of ratios analysed, the marginal cost per unit of dose averted varies by a factor within a range between about five to ten, the exact value depending on the contamination density. This potentially large variation is a clear demonstration of the need for any relocation policy to take due account of the local circumstances, in particular where these vary markedly from the average. Clearly, given such variation, what is judged to be 'optimal' on the basis of average values of parameters may or may not be 'optimal' when proper account is taken of local conditions. This analysis also reinforces earlier observations as to limitations of contamination level as a quantity for use as a criterion for relocation.

The analysis above has only examined the influence of local factors in so far as they affect doses and, therefore, needs further qualification. Significant variation may also occur in the financial and social costs of different protective measures between settlements and it is important that these aspects are taken into account, together with dosimetric variations. As indicated at the

TABLE 26. Sensitivity of the Marginal Cost per Unit of Dose Averted by Relocation to the Relationship between Total Dose and Contamination Density

Relocation criterion (in Ci/km^2 (kBq/m^2) of caesium)[b]	Marginal cost[a] per unit of dose averted (million roubles/man-sievert)			
	Ratio between the internal and external dose for the designated contamination density, R			
	R = 1	R = average	R = 4	R = 15
5 (185)	2.3	1.14	0.90	0.28
15 (555)	0.75	0.49	0.30	0.19
40 (1480)	0.28	0.20	0.11	0.05

[a] Marginal cost of relocation is evaluated subject to the simplifying assumption that no provision is made for improved living conditions.

[b] Criteria can be transformed into other quantities using data given in Table 21.

outset, it was considered an important part of this evaluation to investigate the 'robustness' of the analysis conducted on the basis of average data by carrying out an analysis for selected settlements. This was not, however, possible because the requisite data could not be provided in time. The limited results presented above, even taking account of only dosimetric aspects, indicate the importance of such an analysis in order to explore the extent to which any policy developed on a generic basis would need to be qualified by consideration of local circumstances.

Evaluation of the Marginal Cost per Unit of Dose Averted by Relocation

Judgements on what constitutes the optimum intervention level for relocation (assuming that the only inputs to the balance are the costs of its implementation and the doses that it averts) are dependent on the value assigned to the cost per unit of dose averted. Various values have been attributed to this cost in different countries and for different circumstances and some of these are summarized in Table 27 [31–35].

A variety of methods have been used for estimating the costs of the man-sievert, including, among others, the willingness to pay to avoid risk and considerations of human capital. No broad consensus exists on the best approach to use. However, the so-called 'human capital approach' has perhaps received the greatest use, both in radiation protection and in the allocation of resources to improve safety in other areas. It is at the origin of many values for the cost of the man-sievert included in Table 27. In Annex 2 estimates are made, using the human capital approach, of the cost of the man-sievert for use in the USSR. The methodology adopted is broadly that used in Ref. [33]. A baseline cost of about 5000 roubles/man-sievert has been estimated as being appropriate for exposures arising at small levels of individual dose. From Tables 24 and 25 it can be seen that, in general, the costs per man-sievert averted are far in excess of this baseline value. Only if the cost of relocation is assumed to be significantly less than that adopted in the All-Union State Programme do the marginal costs of relocation even approach this value.

Increases in this baseline cost would be appropriate for exposures to higher levels of dose in order to accommodate the greater avoidance of higher levels of individual risk. Notwithstanding the clear recognition that account must be taken of risk aversion in practical decision making, no consensus exists on how this could best be done. Inevitably the degree of aversion to any risk will be influenced by many considerations and not just by the level of risk itself. The source of the risk and broader attitudes towards it will be influential. In the absence of a consensus in this area, and given the variability in the degree of risk aversion exhibited to different sources of risk and in different countries, it is not possible to make a definitive assessment of this aspect. Instead, a sensitivity analysis has been performed to illustrate its potential significance for decisions on relocation. The way in which risk aversion has been included in the analysis is set out in Annex 2 and the degree of aversion examined was chosen to encompass a fairly wide range of those which have been suggested or used elsewhere. However, this choice should not be taken to imply that other degrees of risk aversion are inappropriate. What is appropriate can only be determined by the particular circumstances under investigation.

When risk aversion is taken into account, the cost assigned to unit collective dose increases by an amount depending on the levels of dose encountered and the

TABLE 27. Estimates of the Cost to be Assigned to Unit Collective Dose

	Cost per unit of dose (currency/man-sievert)	
	(local currency)	(US $)
USNRC[a]	US $100 000	100 000
NRPB[b]	UK £5000	~10 000
CEPN[c, d]	F.Fr.10 000	~ 1 800
	F.Fr.30 000	~ 5 400
Nordic[e]	US $20 000	20 000
IAEA[f]	US $3000	3 000

[a] United States Nuclear Regulatory Commission. Proposed for use in judging the cost effectiveness of measures to reduce effluent discharges from LWRs — account only to be taken of collective dose arising within 50 miles (80 km) of the discharge location in its use (i.e. in general, only a small fraction of the total collective dose) [31].

[b] United Kingdom National Radiological Protection Board. Based on human capital considerations. The baseline value is tabulated and is intended for application to small individual doses; for higher doses the value is to be increased by a variable multiplier, the magnitude of which depends on the level of dose [32].

[c] Centre d'étude sur l'évaluation de la protection dans le domaine nucléaire. Based on human capital considerations. The baseline value of F.Fr.10 000 is for application to small individual doses [33].

[d] Value applied to individual doses that are a significant fraction of dose limits [33].

[e] Recommendations from the four Nordic Institutes of Radiation Hygiene [34].

[f] The value recommended as the minimum to use for effluent discharges resulting in transboundary exposures at low levels of dose [35].

degree of risk aversion assumed. For the largest degree of risk aversion analysed in Annex 2, the cost assigned to unit dose increases to about 100 000 roubles/man-sievert for doses associated with intervention at about 100 Ci/km^2 (3700 kBq/m^2). This decreases to about 30 000 and 10 000 roubles/man-sievert for intervention levels of 40 and 10 Ci/km^2 (1480–370 kBq/m^2), respectively. From a comparison of these values with the marginal costs estimated in Tables 24 and 25, it is evident that, based on the costs of protective measures given in the All-Union State Programme, relocation would only be justified (subject to the constraints and limitations of this analysis) for contamination levels in excess of about 80 Ci/km^2 (2960 kBq/m^2).

Relocation could be justified at lower contamination levels if the costs of relocation and of providing improved living conditions differed significantly from those used in the All-Union State Programme. If the cost of relocation were reduced to 30 000 roubles/person, the level at which relocation would be justified would decrease to about 60 Ci/km^2 (2220 kBq/m^2); this would decrease further to about 20 Ci/km^2 (740 kBq/m^2) if a cost of 20 000 roubles per person were assumed. These results further indicate the importance of reliable estimates for the costs of protective measures. The reliability of the cost data for protective measures used in the analysis warrants more careful examination, though this is beyond the scope of the present study.

In summary, the cost–benefit analysis has shown that further relocation of the population still living in contaminated settlements could not be justified (subject to the costs of, and risk reduction by, relocation being the sole factors involved in the decision). In the same context, there can be no justification for the adoption of a more restrictive criterion than that currently adopted of 40 Ci/km^2 (1480 kBq/m^2). On the other hand, fairly convincing theoretical economic arguments could be made in support of a relaxation in this criterion. Even if allowance is made for risk aversion, the situation does not change unless the costs of relocation and of providing improved living conditions differ significantly from the values given in the All-Union State Programme [9]. Relocation at lower levels could only be justified if the actual degree of risk aversion far exceeds that set out in Annex 2 and which has been examined here. This cannot be precluded given the unprecedented scale of the Chernobyl accident and the many and diverse pressures on those directly affected by the accident, their representatives and the various authorities responsible for ameliorating the situation. These aspects are examined in more detail in the following section.

The results of the cost–benefit analysis should be further qualified in that they are applicable only on average. For settlements where the dosimetric, social and economic characteristics deviated greatly from the average, different conclusions may be reached. Additional analyses for individual settlements are needed in order to determine the 'robustness' of the results of the present analysis.

4.5.5. Elicitation and Evaluation of Other Factors Relevant to Decisions on Relocation

4.5.5.1. Introduction

Following a nuclear accident with off-site consequences, the main objectives are dose limitation and dose reduction. In the process of setting the criteria for the protective measures, the decision maker will have to contend with economic and political constraints in implementing the recovery plans and on the acceptability and credibility of the priorities and criteria for recovery [36, 37].

From the outset it was appreciated in planning the evaluation of the protective measures adopted within the USSR that it would not be adequate to concentrate on the radiological protection aspects alone. Social and political factors inter alia would also drive the decision making. Accordingly, the Project description, as approved by the International Advisory Committee, included the use of multiattribute decision aiding techniques to investigate and include these factors. As the Project evolved, the specification of the manner in which these techniques were to be used was progressively clarified until it was decided to hold four Decision Conferences, one each in the BSSR, the RSFSR and the UkrSSR, and one at the All-Union level. The purposes of these Decision Conferences were:

— To enable some of the decision problems related to the Chernobyl accident to be structured efficiently, thus clarifying and elucidating issues.
— To summarize for the International Chernobyl Project the key socioeconomic and political factors that, together with the physical, radiological and medical evidence, influence the relocation and protective measures taken in the Republics.
— To illustrate the use and potential benefits of formal decision analysis methods and the techniques of decision conferencing for the resolution of complex issues.

Subsequently, a fifth Decision Conference was held at which representatives from the earlier Conferences met to build a summary model that represented the main issues and concerns. A detailed description of the Decision Conferences is given in Annex 3.

4.5.5.2. General Conclusions of the Decision Conferences

The objectives set for the Decision Conferences were all broadly met. With the use of decision analytical techniques, the decision problem on relocation was structured to be efficient; this enabled all of the important issues to be clarified and elucidated. The Conferences achieved a considerable consensus in terms of the structure of the decision model, on the evaluation of criteria to be adopted and on the general form of relocation strategies that should be considered.

The application of the model provided the Project with valuable insights into the relative importance attached in the USSR to the various factors relevant to the development of a relocation policy. In addition, it demonstrated the potential benefits of formal decision analysis methods and the techniques of decision conferencing for the resolution of complex issues. The public acceptability of the policy, in particular, and the stress it might generate in the affected population were identified as two of the more important considerations. The costs of its implementation and the reduction in risk it achieved were, in comparison, considered to be of secondary importance. The current lack of trust and the considerable misinformation and rumours circulating among the population were identified as the main reasons for attaching particular importance to gaining public acceptability for any future policy. The much greater weight attached to public acceptability and stress, compared with cost and radiation risk reduction, are responsible for the very large costs per unit of dose averted that have been estimated for the current relocation policy (see Section 4.5.4).

The scope of this part of the Project involved mainly the elicitation and clarification of those factors (additional to risk reduction and cost) that were judged by the USSR to be germane to decisions on relocation, and to gain some insights on the relative importance attached to them. No attempt was made under the Project to evaluate these judgements. This was outside the scope of the study and a proper evaluation would have demanded resources well in excess of those available. Moreover, such judgements are properly the responsibility of the Soviet authorities which are best placed to understand and balance the many often conflicting views and expectations of those affected. What is evident, however, from the albeit limited visits by the Project team to affected settlements, and from the many discussions with authorities at various levels, is that the need to secure public acceptance of, and confidence in, any future policy is the key to restoring calm and a return to some degree of normality in the affected areas.

4.5.6. Summary of Relocation

The establishment of criteria for the relocation of people following a large nuclear accident is very complex and involves consideration of many factors of both a radiological and social nature. The IAEA and the ICRP have recommended fundamental principles that should underlie the establishment of relocation criteria. Experience in the practical application of these principles was, however, very limited prior to the Chernobyl accident. Moreover, the scale of this event raised new issues which had not been dealt with previously. Inevitably, in these circumstances, an evolutionary approach was adopted in the USSR to the development and practical implementation of relocation criteria. The conclusions reached in this evaluation (in particular those emerging from a direct comparison of the Soviet criteria with the current international guidance) should, therefore, be viewed in the context of an evolving situation both internationally and in the USSR.

4.5.6.1. *Conceptual Basis and Terminology*

The bases on which the criteria for relocation were derived by the authorities are not wholly consistent with the principles currently recommended internationally. However, this does not necessarily imply that the quantitative criteria adopted are inappropriate. In addition, there were conceptual misunderstandings and terminological problems among the parties concerned (including central and local authorities) that contributed to many of the present problems. The more important points are set out below.

(a) The use of imprecise terminology and the misunderstanding and/or misrepresentaion of some fundamental radiological protection concepts and principles on the part of both the scientific community and others have been a source of much confusion and disagreement in the USSR. These, taken together with the considerable delays in developing policy and effectively communicating it, have been largely responsible for the failure to reach a broad consensus on relocation policy. Moreover, they have contributed to a loss of confidence on the part of the affected population in the measures being taken in their interest.

(b) One of the more important misunderstandings or misrepresentations has been confusion over, and lack of recognition of, the very different origins and purposes of the dose limits recommended internationally for controlling planned increases in radiation exposure and those of the dose levels at which intervention is prompted to decrease existing radiation exposures. Dose limits per se are not the appropriate levels at which to intervene following an accident. The dose averted by relocation is the relevant quantity for judging the radiological benefits of relocation and, where practicable, this quantity should be used as the basis for expressing quantitative criteria.

It is not evident that considerations of averted dose were at the origin of all of the criteria that have been proposed by the authorities. Criteria may also be formulated in terms of other more useful derived quantities that are surrogates for averted dose (e.g. contamination level, annual dose, lifetime dose, dose rate, etc.). A number of these have been used in the USSR, each having merits and disadvantages. In particular, surface contamination is not generally applicable for dose estimates because there is a strong dependence of dose estimates on local soil conditions and food consumption habits.

It is not evident that due account was taken by the authorities of the many negative aspects of relocation in formulating the relocation policy. There are indications from studies in other areas that mass relocation of people leads to a reduction in average life expectancy (through increased stress and changes in lifestyle) and a reduced quality of life in the new habitat.

In applying a lifetime dose criterion for relocation, it is inappropriate to take account of past doses. Intervention may reduce the risk of adverse health effects in proportion to the dose averted, but it can have no influence on doses already received before the intervention. For dose ranges below the threshold for deterministic effects, it is conceptually unsound and in contradiction to the principles for intervention to take past doses into account. There are, however, circumstances in which the total dose to be received, past and projected, may be the relevant quantity, for example in judging the need for an extension of any long term medical follow-up or care of those exposed as a result of the accident.

The conservative approach (i.e. overestimates) adopted in the estimation of doses to people living in the contaminated areas of concern on the grounds that this was in their best interests was inappropriate in principle and contradictory to the fundamental objectives of intervention. It had two important negative consequences: first, the radiological consequences of continuing to live in contaminated areas were overstated and this contributed to additional and unnecessary fear and anxiety in the population; second, and more important, some people will be needlessly relocated.

4.5.6.2. *Criteria and their Application*

The average levels of individual lifetime dose that could potentially be averted by relocation, prompted either by the 350 mSv or the 40 Ci/km^2 (1480 kBq/m^2) criterion, are of the same order as or less than the doses due to the average natural background radiation.

It is not clear that the modest nature of the doses that could be averted by relocation, and their assumed risks, are fully appreciated by either the population of the contaminated areas of concern or by many of those people advocating a more stringent regime. The extra incremental risk of about 1 in 10 000 per year on average to which an individual remaining in a contaminated area would be exposed would be marginal in comparison with risks experienced in everyday life and in itself would not justify such a radical measure as relocation.

On considerations of cost and risk reduction alone there can be little if any justification for the adoption of more restrictive relocation criteria than those currently adopted in the All-Union State Programme (i.e. 40 Ci/km^2 (1480 kBq/m^2)). Indeed, a reasonable case could be made for a relaxation in the policy, i.e. for an increase in the intervention levels.

A much larger number of people than those living in settlements with contamination levels in excess of 40 Ci/km^2 (1480 kBq/m^2) are to be relocated. The doses averted by the relocation of these people will be significantly less than the modest values already indicated. The implications of this are that more restrictive criteria are being adopted in practice.

Many factors, other than those of cost and risk reduction, have had an important and possibly overriding influence on relocation policy. The need to restore public confidence, which has been seriously eroded for many reasons over the past five years, to reduce anxiety and to gain broad acceptance for the policy were identified to be particularly important. In ongoing reappraisals by the authorities of the relocation policy, these factors are being assigned much greater weight than factors that are concerned strictly with radiological protection, with consequential implications for the policy. The relative importance to be attached to the various factors is, however, a matter for the relevant authorities.

Future changes in relocation policy will inevitably be constrained by past actions. Notwithstanding the merits of and technical justification for a change in policy, acceptance of major changes would be difficult to achieve, particularly where these involved a relaxation in the criterion previously adopted. A relaxation in the current relocation policy (i.e. higher intervention level) would almost certainly be counterproductive given the very difficult social conditions in the contaminated areas of concern. However, there can be no justification on radiological protection grounds for the adoption of a more restrictive policy if consideration is limited to the costs and risk reduction achieved. This should be strongly resisted unless there are overriding considerations of a social nature.

References

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Revised Guidance on the Principles for Establishing Intervention Levels for the Protection of the Public in the Event of a Nuclear Accident or Radiological Emergency, IAEA-TECDOC-473, Vienna (1988).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection Principles for Sources not Under Control: Their Application to Accidents, IAEA, Vienna (in preparation).

[3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Pergamon Press, Oxford and New York (1991).

[4] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Protection of the Public in the Event of Major Radiation Accidents: Principles for Planning, ICRP Publication 40, Pergamon Press, Oxford and New York (1984).

[5] LINGE, I.I., Statement on intervention levels on dose and derived intervention levels for foodstuffs, Institute of Biophysics, Moscow, 21 January 1991.

[6] IL'IN, L.A., Policy of the USSR National Commission on Radiation Protection on the Substantiation of Temporary Annual Dose Limits for Public Exposure due to the Chernobyl Accident, submitted by the USSR delegation to the 38th session of UNSCEAR, 1989.

[7] KONDRUSEV, A.I., Dose limits for the public for 1988 and 1989 pursuant to the accident at the Chernobyl nuclear power plant, 18 July 1988 (translated from Russian).

[8] IL'IN, L.A., Statement on the lifetime dose limit concept, Institute of Biophysics, Moscow, 21 November 1990.

[9] SUPREME SOVIET OF THE USSR, All-Union State and Republican Programme for the Rectification of the Consequences of the Chernobyl Accident, 1990–1992, Moscow, 1990 (in Russian).

[10] MINISTRY OF HEALTH OF THE USSR, Rep. SP-AES-79, Moscow (1979) (in Russian).

[11] ZAICHENKO, A.I., Temporary permissible radioactive contamination levels for various items, 7 May 1986 (translated from Russian).

[12] ZAICHENKO, A.I., Temporary permissible radioactive contamination levels for soil, roads, and the external and internal surfaces of buildings after decontamination work, 12 June 1986 (translated from Russian).

[13] ZAICHENKO, A.I., Temporary permissible radioactive iodine content (^{131}I) in drinking water and food products during accident cleanup operations, 6 May 1986 (translated from Russian).

[14] ZAICHENKO, A.I., Temporary permissible levels for radioactive substances contained in food products, drinking water and medical herbs, 30 May 1986 (translated from Russian).

[15] PEPENKOV, V.S., ZAICHENKO, A.I., Temporary permissible levels for radioactive substances contained in fruit and vegetables preserves, 19 September 1986 (translated from Russian).

[16] ZAICHENKO, A.I., Temporary permissible levels for total content of the radionuclides caesium-134 and caesium-137 in food products and drinking water (VDU-88), 15 December 1987 (translated from Russian).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Principles for Establishing Intervention Levels for the Protection of the Public in the Event of a Nuclear Accident or Radiological Emergency, Safety Series No. 72, IAEA, Vienna (1985).

[18] BULDAKOV, L.A., Statement on intervention levels of doses for evacuation and thyroid blocking, Institute of Biophysics, Moscow, 3 January 1991.

[19] COMMISSION OF THE EUROPEAN COMMUNITIES, Derived Reference Levels as a Basis for the Control of Foodstuffs following a Nuclear Accident. A Recommendation from the Group of Experts, CEC, Brussels (1986).

[20] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, Joint FAO/WHO Food Standards Programme, Codex Alimentarius Commission,

Proposed FAO/WHO Levels for Radionuclide Contamination of Food in International Trade, Rep. CX/FAC 89/17, FAO, Rome (1989).

[21] AVERIN, V., Institute of Agricultural Radiology, Gomel, BSSR, personal communication, 1990.

[22] STRAND, P., et al., "Measures introduced in Norway after the Chernobyl accident: A cost-benefit analysis", Environmental Contamination Following a Major Nuclear Accident (Proc. Symp. Vienna, 1989), Vol. 2, IAEA, Vienna (1990) 192.

[23] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Limits for Intakes of Radionuclides by Workers, ICRP Publication 30, Pergamon Press, Oxford (1979).

[24] DEMIN, V., personal communication, November 1990.

[25] BURIAK, V., personal communication, October 1990.

[26] LINGE, I.I., personal communication, October 1990.

[27] LINGE, I.I., et al., "Statistical features of irradiation following the Chernobyl accident", Statistics of Human Exposure to Ionising Radiation (Proc. CEC Workshop Oxford, 1990) (in preparation).

[28] UNITED NATIONS, Sources, Effects and Risks of Ionizing Radiation (Report to the General Assembly), Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), UN, New York (1988).

[29] LINGE, I.I., Dose related distribution of population from contaminated areas (>5 Ci/km^2 of ^{137}Cs), Institute of Biophysics, USSR Ministry of Health, Moscow (1990).

[30] LINGE, I.I., personal communication, November 1990.

[31] UNITED STATES NUCLEAR REGULATORY COMMISSION, Code of Federal Regulations 10 CFR 20, Appendix I, Guidance on the Reduction of Effluents from Light Water Reactors, USNRC, Washington, DC (1975).

[32] ROBB, J.D., WRIXON, A.D., Revised Estimates of the Monetary Value of Collective Dose, Rep. NRPB-M157, National Radiological Protection Board, Chilton, UK (1989).

[33] LOMBARD, J., Proposition for Reference Values for the Cost of the Man Sievert, Rep. CEPN-175, Centre d'étude sur l'évaluation de la protection dans le domaine nucléaire, Fontenay-aux-Roses (1990).

[34] Statement from the Heads of the Nordic Institutes of Radiation Hygiene, Stockholm, 26 January 1987.

[35] INTERNATIONAL ATOMIC ENERGY AGENCY, Assigning a Value to Transboundary Radiation Exposure, Safety Series No. 67, IAEA, Vienna (1985).

[36] INTERNATIONAL ATOMIC ENERGY AGENCY, Techniques and Decision Making in the Assessment of Off-Site Consequences of an Accident in a Nuclear Facility, Safety Series No. 86, IAEA, Vienna (1987).

[37] INTERNATIONAL ATOMIC ENERGY AGENCY, Principles and Techniques for Post-Accident Assessment and Recovery in a Contaminated Environment of a Nuclear Facility, Safety Series No. 97, IAEA, Vienna (1989).

Part G

Annex 1

International Principles for Intervention Following a Radiological Accident

This Annex is largely an extract from a draft IAEA publication [1] which sets out principles for the protection of workers and of the public in the event of a radiological accident. Consideration is limited here to those aspects relevant to the protection of the public.

1-1. Introduction

In most situations in which there is a need to consider controls over people's exposure to radiation, control can be applied to the source of the radiation. This is clearly the case for all medical exposures, as it is for all normal exposures as a result of industrial processes utilizing sources of radioactivity. For control of exposures of members of the public in these situations, it is sufficient to control the source, and no restrictions or modifications to people's actions are needed other than restriction of access to sites. Control of exposures to workers will usually require a combination of physical controls applied to the source and management control applied to the worker but still closely related to the source.

There are, however, a small number of situations in which the source of exposure is not susceptible to control, usually because the radioactive materials are already dispersed in the environment or are in the course of dispersion. Control of the source was either never possible or has been temporarily lost. The two most easily identifiable examples of such situations are exposures resulting from the natural occurrence of radionuclides in the environment and exposures resulting from the release of radionuclides following a nuclear accident. Even though after a nuclear accident control over the primary source will probably be regained fairly quickly, the radioactive materials already dispersed into the environment still constitute an uncontrolled secondary source.

The pre-existing or uncontrolled sources of exposure fall into two quite distinct groups: those which already exist at the time when control procedures are being considered and those which may arise in the future. Pre-existing sources have their origins in radioactive materials or radiation present in the environment naturally or as a result of earlier human actions. Examples of the former include ^{40}K in foods and thus in people's bodies, cosmic radiation, radon and radioactive minerals in the ground. The latter include the results of human uses of both natural and artificial radioactive materials, examples of which are fallout from the testing of nuclear weapons, radioactive wastes previously discharged to the environment, past accidental releases to the environment and spoil from mining operations. Control of the exposures from any of these sources requires decisions on the situations as they exist at the time, with no possibility of influencing the original cause. It is not possible to make any detailed predictions of sources which may arise in the future, but it seems likely that the basic principles derived here cover a sufficiently wide range of possibilities that they should apply to these also.

The common denominator in situations involving pre-existing or uncontrolled sources is that exposure to radiation can only be reduced by intervention in ways that require restrictions or modifications to people's habits, or at least the redeployment of resources. Thus, in setting out these basic principles, it has seemed helpful at the conceptual level to treat all these situations in a unified manner, even though the more detailed considerations leading to recommendations for ways of deriving intervention levels, and the levels themselves, are more conveniently handled separately for each type of situation.

1-2. Basic Principles of Dose Limitation

1-2.1. Normal Operating Conditions

The full system of dose limitation recommended by the International Commission on Radiological Protection (ICRP) in its Publication No. 26 [2] and incorporated into the International Atomic Energy Agency's Basic Safety Standards for Radiation Protection, 1982 Edition [3] applies to exposures resulting from controlled radiation sources under normal operating conditions.

The most effective way of controlling exposure is by controlling the source itself. For this case the ICRP recommends that the introduction of the practice of which the source is a part should be justified. This means that the introduction of the practice should do more good than harm (the justification of the practice). The ICRP then recommends, as additional requirements, that control of the source should be adjusted until the exposures resulting from the practice are as low as is reasonably achievable, economic and social factors being taken into account (the optimization of protection). Furthermore, to avoid excessive risk to individuals, the sum of doses to individual members of the public from a specified group of practices or to individual workers from their occupational exposures should be less than the appropriate limit (the limitation of dose to individuals).

1–2.2. Intervention Situations

In order to apply the system of dose limitation to pre-existing or uncontrolled sources, the relative importance and applicability of the three basic principles has to be reconsidered. Justification should be applied to the countermeasures, forming a programme of intervention, in the sense that the intervention should only be made if it does more good than harm. Optimization then dictates that the form and scale of the intervention should be decided so as to maximize the net benefit. The dose limits for normal conditions relate to a group of practices specified to exclude the pre-existing or uncontrolled sources and hence are inapplicable.

1–3. Principles for Intervention

The basic principles of the system of dose limitation for controlled sources can, with some changes of emphasis, be extended to intervention situations. The one component that cannot be applied is the dose limit for exposure of members of the public to controlled anthropogenic industrial sources. It is already widely understood, and must be emphasized, that this dose limit is of circumscribed applicability; for example, it is not intended to apply to the exposure of members of the public to medical irradiation as patients. Equally, it is not intended to apply to exposures resulting from natural radiation or uncontrolled sources.

The applicable principles for intervention have been set out by the ICRP in the context of nuclear accidents in its Publication No. 40 [4] and in the context of natural sources in its Publication No. 39 [5]. The principles, restated in a sufficiently broad fashion to cover all relevant situations, but concentrating on interventions affecting members of the public, are:

(1) The intervention should be justified in the sense that introduction of the protective measure should achieve more good than harm.
(2) The level at which the intervention is introduced and the level at which it is later withdrawn should be optimized so that they will produce the maximum net benefit.
(3) All possible efforts should be made to prevent serious deterministic health effects by restricting doses to individuals to levels below the threshold for such effects.

In some instances of high dose rates or prolonged exposures, in addition to attempting to prevent deterministic effects, the risk of stochastic effects to individuals may be a significant factor in the decision making process. Authorities may then wish to keep the risks to individuals of such effects below levels that they consider undesirable. The basis for such levels would be different from that of dose limits derived under normal conditions.

The first two principles each require consideration of the benefit that would be achieved by the intervention and the harm, in its broadest sense, that would also result from it. They therefore require the use of the procedures for reaching decisions of the type described in ICRP Publication No. 37 [6] and Publication No. 55 [7]. As noted in these publications and clarified in Fig. 1–1, the inputs to these justification and optimization studies include factors that are related to radiological protection, whereas the final decisions may also depend on other factors, probably of a political nature. Radiological protection factors are defined as those which are related to the level of protection achieved. Thus they include those factors describing the dose distribution averted and those describing the costs and other disadvantages incurred in averting the doses. The 'decision aiding' techniques available for use in carrying out the type of analysis indicated in Fig. 1–1 have been described in detail in ICRP Publication No. 55 [7]. All these techniques have as their primary objective to clarify, for the people who have to decide on the intervention, the various factors, to quantify them if this is reasonable and necessary, and to systematize the trade-offs between the various factors.

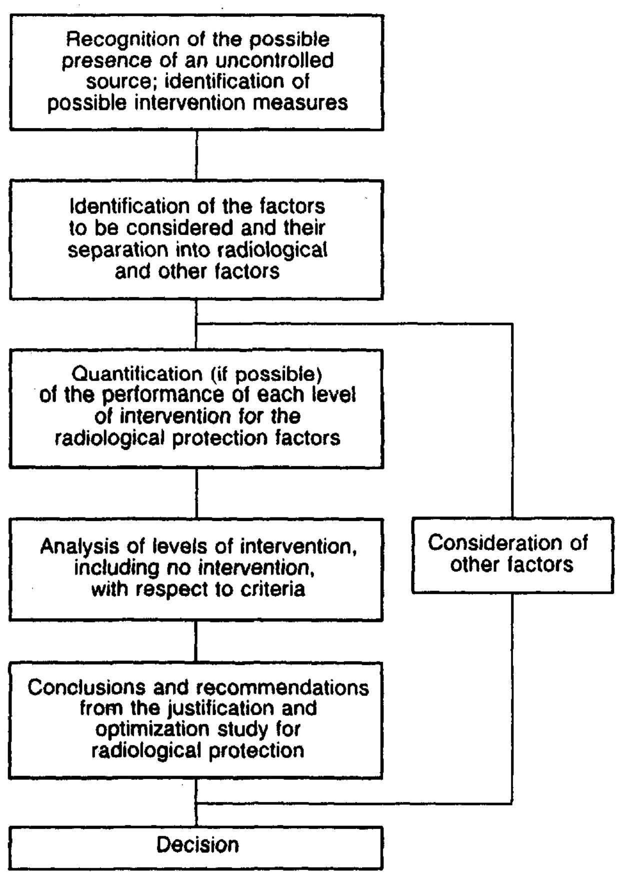


FIG. 1–1. Structured approach to decision making for intervention.

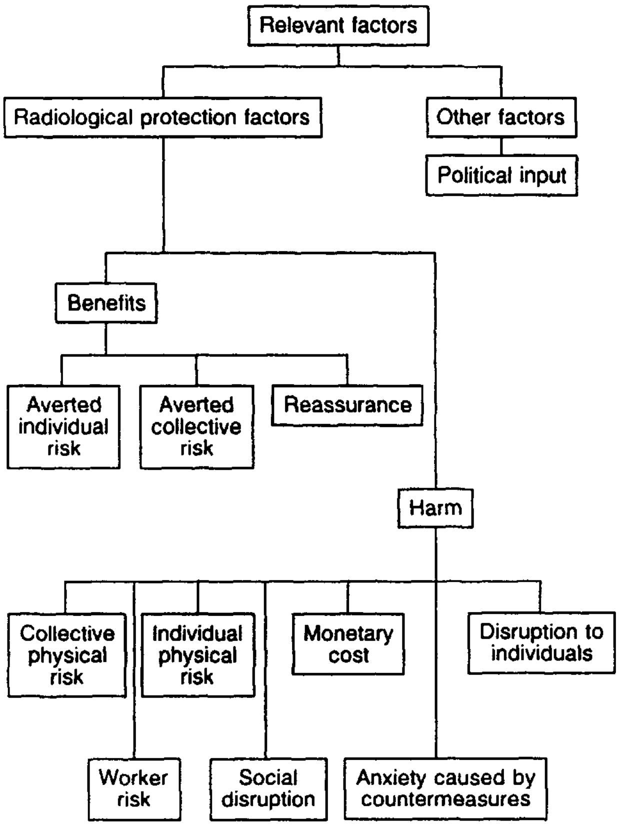


FIG. 1–2. Factors relevant to decisions on the level of introduction of an early countermeasure.

One of the most general decision aiding systems that is capable of accepting input data of both a quantitative and a qualitative nature is multiattribute utility analysis. If this were to be applied to the decision on an intervention measure such as evacuation, then the structure of the inputs to the analysis would be as shown in Fig. 1–2. Some of the factors shown are clearly radiological protection factors as defined earlier and are more or less quantifiable; these are the averted individual and collective risks for the members of the public, the individual and collective physical risks to the public caused by the countermeasure, the individual and collective risks to the workers in carrying out the countermeasure, and the monetary cost of the countermeasure. The less quantifiable factors, including the reassurance provided by the implementation of the countermeasure, and its counterpart, the anxiety caused by its implementation, and the individual and social disruption resulting, are also shown in the figure as radiological protection factors. Although this assignment is less obvious, the factors fulfil the criterion of being related to the level of protection achieved. The political input, however, is not deemed to be a radiological protection factor.

The factors have been divided in Fig. 1–2 into those describing benefits from the countermeasure and those describing harm. In analysing the inputs to the decision, it is necessary to decide on the relative importance of each factor. These judgements have to be applied irrespective of the decision aiding technique used and, as shown in ICRP Publication No. 55 [7], the resultant decision is the same provided that the database is the same and the judgements are consistent. If multiattribute utility analysis is the technique used, then all the radiological protection factors can be directly included in the analysis by deriving or assigning utility functions to them, and the trade-off judgements are expressed as scaling constants. If cost–benefit analysis is the technique, then those factors convertible into financial equivalents can be included in the quantitative analysis, but the other radiological protection factors have to be introduced in a qualitative manner before reaching the output of the radiological analysis shown in Fig. 1–1.

In carrying out the justification and optimization procedures, it will be necessary to decide the boundaries of the various inputs shown in Fig. 1–2. In the case of the radiation doses to be averted, this is reasonably clear, but even for these a decision has to be made whether to treat the entire irradiated population as a whole or whether to separate out sections which are substantially different, either because of different doses received or different susceptibility to harm. The practicality of such proposed separations should be taken into account in making the decision.

In the case of the harm associated with the intervention, the physical risk and disruption will often be associated with the same population to whom the intervention is applied, as will the social trauma, although this is likely also to affect families and friends, who may be physically distant. The economic costs, however, may be borne primarily by those affected by the intervention in some situations or primarily by a completely different section of the population in others. The decision on how much of this economic cost is appropriate for inclusion in the optimization cannot be made in general terms, but in carrying out each particular optimization the decision should be made and clearly stated.

Although the two principles of justification and optimization are stated separately and are indeed conceptually separate, it is necessary to consider them together when reaching a decision. For a given scenario there will be a range of intervention levels that would be justified, i.e. would do more good than harm. The optimum level will fall within that range. For other scenarios the range of optimized levels may differ, as will the optimum. From an analysis of many scenarios it will be possible to derive a range of optimum intervention levels that are somewhat broader than they would be if levels were being established for a more constrained set of circumstances such as are likely to be of concern in practice. It is in this sense that ranges of intervention levels can be derived, but derivation of such a range would not preclude the exclusion of the optimum from the range if the particular scenario at the time was also outside the scope of those levels used in advance to generate the range. It must also be emphasized that when a range is generated, it is not automatically optimum, in the absence of other information, to choose the minimum of the range for intervention action.

Since all the intervention actions are designed to keep doses below the deterministic threshold, the harm associated with the radiation dose averted by one intervention is unaffected by other interventions. Each type of intervention action can therefore be evaluated independently from the standpoint of justification and optimization. Although the third principle should be applied to the total dose to individuals resulting from the sum of the residual doses after all the interventions have been made, this is unlikely to be a practical concern in most situations.

1–4. Discussion of Some Important Issues Relevant to Intervention

The purpose of intervention is to put potentially exposed individuals into a better position (ideally the best) in the sense that lower overall risks are achieved at a 'reasonable' cost in financial and social terms. While this objective is both clear and conceptually simple, the practical determination of what constitutes the most appropriate type and level of intervention in any particular circumstances is more complex. This choice requires a balance to be achieved between a variety of competing attributes, as shown in Fig. 1-2 (e.g. risks of radiation exposure, risks consequent upon intervention, direct and indirect costs of intervention, public anxiety) whose magnitudes may vary with the accident characteristics and whose relative importance may be susceptible to political and social value judgements. There are inherent difficulties in reducing some of the relevant attributes to a common scale; however, this is not novel, and is a problem commonly encountered in decision making in many social and economic spheres. Because of the potential importance of political and social factors, there is, inevitably, much scope for differing outcomes; such differences should not be unexpected or surprising. Notwithstanding these difficulties, it is evident that, for intervention to achieve its objectives, these issues need to be addressed explicitly and a proper balance, however qualitative, achieved.

As noted earlier, various decision aiding techniques are available to assist judgements in such complex areas (e.g. cost–benefit analysis, multiattribute analysis). None has such compelling advantages as to recommend its universal application and much would depend on the problem being investigated. Cost–benefit analysis is one of the simpler and more readily understood techniques and, for this reason alone, is used here to illustrate a number of the more important issues in making decisions on intervention.

The problem can be conceptualized in cost–benefit terms but based on the structure of Fig. 1-2 as follows, where the benefit is expressed as:

$$B = (Y_0 - Y_1) + B_c - X - R - A \qquad (1)$$

where:

- B is the net benefit achieved by the protective measure;
- Y_0 is the cost equivalent of the radiation detriment if the protective measure is not taken;
- Y_1 is the cost equivalent of the remaining radiation detriment if the protective measure is carried out;
- B_c is the cost equivalent of the reassurance benefit from the protective measure;
- X is the monetary cost of implementing the protective measure;
- R is the cost equivalent of the risks introduced by the protective measure itself;
- A is the cost equivalent of the anxiety and disruption caused by the protective measure.

It is evident from this equation that intervention would be justified whenever the value of B was positive and that the optimum would be achieved when B was a maximum provided that the terms are defined broadly enough to encompass all the radiological protection factors shown in Fig. 1-2. The sole constraint in this process is that intervention should ideally be introduced at levels of individual dose below those at which serious deterministic health effects occur; the sole exception to this generalization is if such intervention would, in practice, make the situation worse.

In practice it is difficult to quantify, in monetary cost, all the terms of Eq. (1) and value judgements, similar to those in most social and economic decisions, would often need to be made. The equation, however, provides a conceptual framework for such judgements.

A number of the important issues and difficulties associated with the development of guidance on intervention can be illustrated by reference to the various terms in Eq. (1). With regard to the harm attributable to the health impact, both direct effects (e.g. cancer) represented by the term $(Y_0 - Y_1)$ and indirect effects attributable to the radiation exposure (e.g. anxiety), represented as part of the term A, may need to be taken into account. The assessment of the health impact encounters all of the difficulties inherent in the valuation of changes in the quality and expectation of life; although complex, this is again a common, indeed essential, process that has to be carried out, intuitively or explicitly. Similar considerations arise in the evaluation of the physical risks introduced by the countermeasure itself and represented by the term R. The overall harm resulting from the intervention will comprise several components as shown in Fig. 1-2 and represented in

Eq. (1) by the terms S, R and A, which are more or less easily quantifiable. The evaluation of the monetary components comprised in the term X (e.g. the direct monetary cost of evacuation or relocation, compensation for restricted foodstuffs, cost of food disposal) is relatively straightforward, but the other factors comprised in the term A, present greater difficulty. The equation omits the factors, other than the radiological protection factors, shown in Fig. 1-2, such as the political and social perception of the need to intervene, or the desire for harmonization of intervention regionally or internationally.

The relative importance of the various terms in Eq. (1) will depend on the type of intervention envisaged. For intervention in cases in which the dominant considerations are the risks due to radiation exposure and the physical risks due to the intervention itself, the balance reduces to a relatively simple comparison, or trade-off, between the alternative risks. If the risks are to the same individuals, the balance is further simplified because considerations of equity do not then arise. The balancing process becomes much more complex if the dominant terms are the risks due to radiation exposure and the overall harm (both quantifiable and qualitative) of the intervention. Not only is the process more complex, it is also subject to differing outcomes depending on the value judgements of importance attached to the various components contributing to the harm. These value judgements are introduced into the cost–benefit formulation as the conversion multipliers needed to bring all the terms to cost (e.g. $ per man-sievert); in the multiattribute formulation they are explicit as the scaling constants [7]. An additional complication that must be recognized is that the risks are often borne by those people potentially exposed whereas, in many cases, the costs will be distributed across a much larger regional or national population. In such cases wider considerations of factors other than radiological protection, such as sociopolitical attitudes and the optimal allocation of national resources, may play a significant role in establishing the appropriate balance.

Despite the broad international accord on the principles and objectives of intervention, differences are to be expected in their practical expression. These will result from differences in the weighting of the various terms in Eq. (1). The most important source of difference, however, will result from the weight given to factors of a non-radiological, sociopolitical, and inevitably less tangible nature. For example, there may be pressure to introduce intervention in response to a perceived risk by the public, even where the actual level of risk and the cost of averting it would not, in itself, justify the intervention; similarly, there may be pressures to maintain doses beneath existing dose limits or some other prescribed limits developed for a totally different purpose, despite its being wrong in principle and possibly counterproductive. The existence of overall constraints may act as a further reason for differences. For example, there will be bounds to the resources a society may be willing, or even able, to commit to intervention; on the other hand, if the costs of intervention are small, or trivial on a per caput basis, there may be a tendency, or even social pressure, to intervene at a lower level than would otherwise be indicated. Different weighting of the more quantifiable factors in Eq. (1) may also contribute to differences in selected intervention levels; in general, however, they will be of secondary importance in comparison with the other potential sources of difference identified.

The establishment of intervention levels is thus a complex process whose complexity is compounded by sociopolitical considerations. Recognition of the complex interplay between the many factors is the first step to understanding the diversity of intervention levels that have been adopted in the past and to working towards the possible future reconciliation of levels. In view of the potential importance of sociopolitical factors, differences are to be expected between the levels established in different countries, even where they have all been developed in accordance with the same basic radiological protection principles or objectives. These differences should not be seen as surprising; rather it should be recognized that they are almost inevitable. More attention does need to be given in the future, however, to making the decision process in establishing intervention levels more 'transparent' along the lines shown in Fig. 1-1. The origins of differences in proposed levels, which often arise for very legitimate reasons, will then be evident; this will be a considerable aid both to the understanding and ultimately to the acceptance of any levels proposed.

Thus it is to be expected that any authority acting alone within one country might arrive at levels different from those derived elsewhere. It must be recognized, however, that in practice national authorities do not act in a vacuum, and the effect of actions taken in other countries can be a powerful influence on sociopolitical considerations. In the case of interventions affecting the national population, national authorities sometimes find that a high degree of public reassurance can be gained by setting levels equal to those of their neighbours. This can lead to a spontaneous harmonization of levels which is seen by some as desirable for reducing public anxiety. In some cases, however, there may be social and political pressures to introduce levels lower than those of other countries, with the intention of increasing public confidence locally; this can lead to a spiralling effect which ultimately only reduces confidence, and so should be resisted. This is particularly important in the special case of intervention to restrict the movement of food in international trade, when it is superficially easy for individual countries to set very low levels when their own produce is uncontaminated and their food supplies

TABLE 1-1. Indicative Guidance on Intervention Levels[a]

Protective measure	Quantity[b]	Effective dose	Thyroid equivalent dose
Sheltering	External dose plus committed dose from intakes in the first 24 h (mSv)	About a few to a few tens of mSv	
Administration of stable iodine	Committed doses from intakes in the first 24 h (mSv)		About a few tens to a few hundreds of mSv
Evacuation	External dose plus committed doses from intakes in the first 24 h (mSv)	About ten to a few hundred mSv	
Relocation[c]	External dose plus committed doses from intakes over a year (mSv)	About a few to a hundred mSv[d]	
Food controls[e]	Committed doses from intakes in a year (mSv)	About one to a few tens of mSv	

[a] This quantitative guidance is indicative only. The ranges of values should not be adopted for application without first analysing carefully their appropriateness to the particular circumstances of interest.

[b] This is the quantity to be compared with the intervention level. In principle it is the dose averted that is to be compared but in practice this can often be equated with the projected dose.

[c] A somewhat wider range of levels is quoted for relocation compared with the other protective measures. This is intended to reflect the greater sensitivity of this measure to the magnitude of an accident.

[d] In some cases, this criterion can also be expressed in terms of dose rate. In these circumstances the indicative guidance for dose rate is in the range of one to a few tens of μSv/h.

[e] This applies separately to each of the following categories of foodstuffs: dairy products, meats, vegetables, grain, fruit, drinking water and beverages.

are secure. Justification and optimization can only be carried out meaningfully in terms of the wider international community, and considerable progress has been made in this direction by bodies such as the Codex Alimentarius Commission.

1–5. Indicative Guidance on Intervention Levels

The characteristics of accident sequences postulated for a nuclear installation, the local environmental conditions and national or regional considerations may all influence the choice of intervention levels. After an optimization based on radiological protection factors has been carried out, it may also be necessary to take into account other factors, such as those dictated by the prevailing political climate as described in Section 1-3. Thus, there will be several inputs to the decision making process, each carrying its own relative weight. Considerable care is needed when introducing these non-radiological factors to ensure that they do not appear more than once in the justification or optimization process. Clearly, to be most appropriate, intervention levels should be developed specific to the circumstances of interest. This need for specificity and the potential variability of intervention levels depending on the prevailing circumstances inhibit the degree to which quantitative guidance can be established that will be broadly (internationally) applicable.

Notwithstanding these qualifications, it is possible to provide indicative guidance in this area that may be used as an aid to national authorities in establishing their own particular levels. Such guidance is given in Table 1-1 for the five major protective measures: sheltering, issue of stable iodine, evacuation, relocation and food restrictions. For each protective measure a range of intervention levels is given. The indicative nature of the guidance must be emphasized and it must not be taken to preclude intervention levels outside the specified ranges. Where committed dose is referred to, this is the integral of the dose rate to the appropriate organs and tissues for 50 years after intake.

Two main considerations have influenced the choice of levels in Table 1-1; first, the levels that have been proposed for use and adopted in Member States, and secondly, the levels that emerge from application of the albeit simplified and constrained optimization techniques. Moreover, the levels have been selected to provide a high degree of assurance that intervention levels developed for a wide range of different but particular circumstances will fall within the quoted ranges. Of necessity, therefore, the ranges are somewhat broader than they would be if levels were being established for a more constrained set of circumstances such as are likely to be of concern in practice. One additional qualification needs to be made with regard to the ranges of levels in Table 1-1. It would be erroneous to select arbitrarily values from the bottom of the range in preference to others on the grounds that this is cautious and would therefore lead to the best outcome. In the absence of other information, levels within the middle of the ranges are likely to be more representative of the optimum.

This guidance is intended to be helpful to those with responsibility for establishing intervention levels; however, it would be counterproductive if the levels were adopted directly without having undertaken a proper analysis of the appropriateness of the guidance to the particular circumstances of interest. This can be exemplified by reference to the indicative guidance given for food intervention. Although the guidance is considered broadly appropriate for most circumstances, in particular where food production exceeds demand, it may be totally inappropriate in the context of famine or food shortages.

It is worth emphasizing that the doses given in Table 1-1 are those that would be averted by implementation of the countermeasure. They thus correspond to the term $(Y_0 - Y_1)$ in Eq. (1). It will be the case for some countermeasures, especially evacuation in the pre-release phase, that Y_0 will be effectively zero; nonetheless in principle it is the averted dose that should be considered.

1–6. Derived Intervention Levels

Intervention levels, such as those given in Table 1-1, are generally specified in terms of averted dose. In practice, however, the results of environmental measurements made immediately following an accidental release of radioactive material will be expressed in terms of levels and concentrations (e.g. Gy/h, Bq/m^3, Bq/m^2). To enable these measurements to be interpreted in terms of intervention levels of dose, it is convenient to calculate in advance derived intervention levels that correspond, under specified conditions, to intervention levels. These derived intervention levels are expressed in the same quantities and units as the environmental measurements [8].

In the release phase and immediately after it, the derived intervention levels should relate to the protective measures of sheltering and evacuation and to the administration of stable iodine for thyroid blocking. Thus they will tend to be expressed as external dose rates from the plume or ground deposition activities per unit area of the ground and time integral of atmosphere air concentrations, and so on. Each derived intervention level would correspond to the intervention level under specified assumptions, particularly the duration of exposure.

During the release phase, if it is prolonged, and in the post-release phase, additional derived levels will be needed for the introduction of protective measures relating to the food-chain. These will be specified in such terms as radioactivity levels in given foodstuffs (e.g. for radioiodine in milk in Bq/L; for green vegetables in Bq/kg) and may relate to peak concentrations or averages over specified periods of time. The relationships between the derived intervention level and the intervention level of dose are even more 'dependent' on the assumptions made in the context of foodstuffs, particularly the assumed duration or time integral of concentration and the quantities consumed by individuals. If the derived level relates to a foodstuff not directly consumed by man (e.g. pasture), then a further set of models and assumptions also has to be taken into account.

Guidance on the calculation of derived intervention levels is outside the scope of this report. However, as part of its programme of Safety Series publications, the IAEA has published Safety Series No. 81 [8], which gives procedures for such calculations.

1–7. Planning of Intervention Levels

The basic principles set out in this Annex which underlie decisions on intervention imply that the level at which a given protective measure is introduced may vary with the prevailing circumstances. Therefore, in establishing a practical scheme for intervention, flexibility must be maintained; it would be wrong to establish an intervention level that is intended to be applied irrespective of the circumstances. However, this need for flexibility should not be used as an argument against establishing intervention levels in advance, on the grounds that the optimization process could be carried out on the day. Such an approach would almost certainly be counterproductive, given the other pressures likely to be encountered in an accident situation. There is, therefore, an important role for planning in the establishment of intervention levels or ranges of intervention levels for different protective measures. The importance of such planning in ensuring the timely and effective introduction of protective measures in an accident cannot be overstated.

Intervention levels can be established for a wide spectrum of possible accident scenarios with the aid of simple cost-benefit analysis or other decision making techniques. These analyses should indicate the sensitivity of the intervention level to the significant variables and enable a range of levels and relevant protective measures appropriate to different circumstances to be selected, thereby providing a degree of flexibility whilst retaining sensible constraints. The appropriate level at which intervention action should be implemented would then be selected according to the actual circumstances should an accident occur.

References for Annex 1

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection Principles for Sources Not under Control: Their Application to Accidents, IAEA, Vienna, in preparation.

[2] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Recommendations of the International Commission on Radiological Protection, ICRP Publication No. 26, Pergamon Press, Oxford and New York (1977).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Basic Safety Standards for Radiation Protection, 1982 Edition, Safety Series No. 9, IAEA, Vienna (1982).

[4] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Protection of the Public in the Event of Major Radiation Accidents: Principles for Planning, ICRP Publication No. 40, Pergamon Press, Oxford and New York (1984).

[5] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Principles for Limiting Exposure of the Public to Natural Sources of Radiation, ICRP Publication No. 39, Pergamon Press, Oxford and New York (1984).

[6] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Cost-Benefit Analysis in the Optimization of Radiation Protection, ICRP Publication No. 37, Pergamon Press, Oxford and New York (1983).

[7] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Optimization and Decision-Making in Radiological Protection, ICRP Publication No. 55, Pergamon Press, Oxford and New York (1989).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Derived Intervention Levels for Application in Controlling Radiation Doses to the Public in the Event of a Nuclear Accident or Radiological Emergency, Safety Series No. 81, IAEA, Vienna (1986).

Part G

Annex 2

Countermeasures to Be Taken after 1990 to Ensure Safe Living Conditions for the Population Affected by the Chernobyl Accident

2-1. Introduction

This Annex presents a first estimate of the cost and averted collective exposure of the potential relocation of the population from the affected territories of the BSSR, the RSFSR and the UkrSSR, to improve their living conditions following the Chernobyl accident. It is an input to the evaluation of the radiological consequences of the Chernobyl accident in the USSR. The general objective was to assess "the concept which the USSR has evolved to enable the population to live safely in areas affected by radioactive contamination following the Chernobyl accident, and an evaluation of the effectiveness of the steps taken in these areas to safeguard the health of the population". Specifically, this work is aimed at evaluating protective measures from 1990 onwards.

When the Project was initiated a 350 mSv lifetime dose was proposed as a reference value for relocating populations living in contaminated areas. This proposal has been the subject of much argument between various groups in the USSR. Following the inception of the Project, in April 1990, the Supreme Soviet of the USSR adopted the "State All-Union and Republican Programme for Urgent Measures for Rectification of the Consequences of the Chernobyl Accident for 1990–1992". This three year programme proposed a wide spectrum of measures to improve the living conditions of the population in the contaminated areas outside the exclusion zone established just after the accident in 1986. Among these measures provision of 'clean food' and relocation of settlements appear the most straightforward means of reducing individual and collective radiation exposures.

At the time the present study started some settlements had already been relocated, but there was a strong ongoing debate on the opportunity of further relocations below the criteria stated in the Programme. In this respect the work presented here is a first attempt to evaluate the accuracy of the proposed countermeasures with respect to radiological protection criteria, as well as the opportunity of evaluating the effects of implementing more stringent actions.

From a close analysis of the situation prevailing in the three Republics, it is evident that the debate about protective measures cannot be reduced to a simple comparison between the resources to be spent and their potential beneficial impact in terms of the reduction in collective exposure achieved. A large fraction of the money already spent (or to be spent in the next few years) on improving living conditions will achieve little or no reduction in dose. In fact, most of the resources already allocated (or to be allocated) needs to be seen as direct or indirect compensation for those who may have been affected by the accident, mainly from the psychological point of view, in order to improve the public acceptability of the situation.

Thus, the present evaluation, which provides quantitative estimates of the costs and efficacy of measures that could be taken to improve living conditions, addresses only one input to the decisions on the optimum choice of protective measures to mitigate the consequences of the Chernobyl accident. (For a broader perspective involving issues such as public acceptability, stress to the population, see Annex 3 to Part G.)

2-2. Methodology

2-2.1. Background

The dosimetric and economic data on which the present evaluation is based were collected during three missions to Moscow, Minsk and Kiev that took place between July and October, 1990. Although a large number of data were gathered during these missions, they were, strictly speaking, only useful for a detailed analysis at the All-Union and/or Republic level; there were insufficient data to carry out an evaluation for a range of individual settlements as had originally been planned.

For decision making in a public health context, it is obvious that the effectiveness of possible protective measures should first be evaluated at the Republic or All-Union level, to verify their practibility both in terms of economic and social impacts. However, as individual settlements are likely to have different radiological, economic and social characteristics, it is also of great importance to estimate the effectiveness at a local level, to ensure that the general policy remains adequate.

Because there were insufficient representative data at a local level, the evaluation presented in this report is focused mainly on the All-Union level; the differences between Republic and All-Union levels were not sufficient to justify a separate evaluation. The effects of differences at the local level have been analysed in a

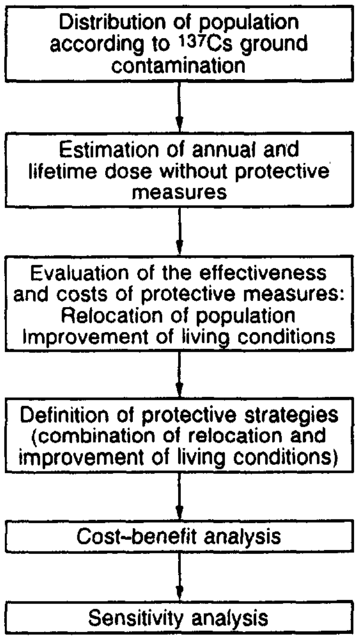


FIG. 2-1. Basic structure of the model to evaluate protective measures.

sensitivity analysis based on some specific data for settlements in the Mogilev region; however, this analysis was limited to the effect of differences between settlements on the resulting dose per unit of soil contamination.

A very general and simplified modelling approach has been adopted in the evaluation. This was judged appropriate in the context of the available data, the broad assumptions that had to be made in their use, and the need to accommodate a variety of proposed intervention criteria (e.g. the level of caesium ground contamination, the average annual dose, the lifetime dose).

Because of the many simplifications and assumptions adopted in the model, the results have to be interpreted carefully and considered only as indicative estimates of the cost and effectiveness of the protective measures envisaged.

2-2.2. General Structure of the Model

The different steps of the model are presented in Fig. 2-1. The starting point is the distribution of the population according to the level of ^{137}Cs ground contamination. The first step of the model is to equate the various levels of contamination with the exposure of individuals living in such locations, particularly the mean individual dose in 1990, and the lifetime dose during the 1990-2060 period. The second step is related to the evaluation of the cost and the efficacy (defined as the dose averted) of the relocation of the population and the improvement of living conditions (ILC) for those staying in the contaminated areas. The third step is the definition of 'strategies' to be evaluated. These are defined by different extents of relocation, the improved living criterion remaining fixed throughout. The fourth

TABLE 2-1. Distribution of the Soviet Population as a Function of the Level of ^{137}Cs Ground Contamination in 1990

Ci/km^2 of ^{137}Cs	kBq/m^2 of ^{137}Cs	Number of people	Percentage in the range	Cumulative percentage
5–10	185–370	411 800	58.4	58.4
10–15	370–555	87 200	12.3	70.7
15–20	555–740	117 900	16.7	87.4
20–25	740–925	28 100	4	91.4
25–30	925–1110	24 900	3.5	94.9
30–35	1110–1295	15 700	2.2	97.1
35–40	1295–1480	5 300	0.8	97.9
40–60	1480–2220	10 400	1.5	99.4
60–80	2220–2960	3 400	0.5	99.9
>80	>2960	900	0.1	100
Total		705 600		

step presents the analysis of the cost per unit dose averted for the alternative relocation strategies. In order to put the various results into perspective, a set of monetary values is proposed for the unit of collective dose. The final step is devoted to sensitivity analyses, which enable the robustness of the results to be evaluated.

2-3. Distribution of Population According to Ground Contamination

The basic input to the model is the distribution of the population living in the affected areas as a function of the level of ground contamination expressed in Ci/km^2 of ^{137}Cs [1]. This information was only provided for zones under control, i.e. for levels above 5 Ci/km^2 (185 kBq/m^2). The corresponding total population is about 705 600 people for the three Republics (the BSSR, the RSFSR and the UkrSSR) and is considered to be representative of those living in these areas at the beginning of 1990. Table 2-1 presents the distribution of the population as a function of the level of ground contamination in 1990. Of course, this distribution will change with time because of the decay of the ^{137}Cs contamination and population movements.

The evaluation is thus only concerned with the 'control' and 'strict control' zones, as defined by the Soviet authorities (i.e. populations living in areas with a surface ^{137}Cs contamination above 5 Ci/km^2 (185 kBq/m^2) and 15 Ci/km^2 (555 kBq/m^2), respectively). The ^{137}Cs ground contamination level is not homogeneous and was influenced by the meteorological conditions prevailing during the Chernobyl accident in 1986.

The distribution of the population on a Republic by Republic basis is given in Table 2-2 [2-5]. Some differences are apparent between the data in Tables 2-1 and 2-2; these are mainly due to the estimates having been made at different times, during which the relocation of people continued. The evaluation made in this report is for the whole population affected in the three Republics.

2-4. Estimation of Annual and Lifetime Doses without Protective Measures

The doses corresponding to a given contamination level have been derived from a generic dosimetric model developed at the Institute of Biophysics in Moscow. The model is based on simple expressions, which are used to derive the external and internal doses in a given year, t, as a function of the surface ^{137}Cs contamination, when no restrictions exist.

2-4.1. Dosimetric Model

The internal and external effective dose equivalents for a given year are given by the following formulas:

External dose

$$H_{a,ext}(t) = \frac{0.28}{k} C \left(0.7e^{-0.3t} + 0.3e^{-0.024t}\right) \quad [\text{mSv/a}]$$

where t = 0 for the year 1988, C is the surface ^{137}Cs concentration (Ci/km^2), and k is the correction factor taking into account the conservatism in the initial model developed by the Institute of Biophysics.

Internal dose

$$H_{a,int}(t) = \frac{1}{k} (0.28C + 1.1232) \times \left(e^{-0.05t} + 0.43e^{-0.35t}\right) \quad [\text{mSv/a}]$$

The reference value suggested for k by the Institute of Biophysics is 1.7. This value is consistent with calculations performed at the All-Union Centre for Radiation Medicine of the Academy of Medical Sciences of the USSR in Kiev [6], as well as with independent estimates

TABLE 2-2. Distribution of the Population in the Three Republics as a Function of the Ground ^{137}Cs Concentration Levels

Ci/km^2	kBq/m^2	RSFSR	UkrSSR	BSSR	All-Union
5-15	185-555	113 100	147 000	267 000	527 100
15-40	555-1480	80 900	22 400	105 000	208 300
>40	>1480	4 600	2 600	9 400	16 600
Total		198 600	172 000	381 400	752 000

TABLE 2-3. Average Relationships between Surface Contamination, Annual Dose (for 1990) and Lifetime Dose (1990-2060)[a]

Surface contamination by ^{137}Cs		Annual effective dose equivalent in 1990 (mSv)	Lifetime effective dose equivalent (1990-2060) (mSv)
(Ci/km^2)	(kBq/m^2)		
5-10	185-370	2.2-3.7	37-62
10-15	370-555	3.7-5.1	62-87
15-20	555-740	5.1-6.6	87-111
20-25	740-925	6.6-8.1	111-136
25-30	925-1110	8.1-9.6	136-161
30-35	1110-1295	9.6-11	161-186
35-40	1295-1480	11-12.5	186-210
40-60	1480-2220	12.5-18.4	210-309
60-80	2220-2960	18.4-24.3	309-408
>80	>2960	>24.3	>408

[a] Doses are estimated in the absence of any protective measures.

performed by the dose assessment task group within the Project. It should be noted that the 1.7 correction factor only takes account of known conservatisms based on measurements up to 1990. The potential exists for an additional conservatism in the assumed environmental half-life of ^{137}Cs, which could lead to an even higher value of k. The estimation of the lifetime effective dose equivalent from the two equations above is given by the following expressions:

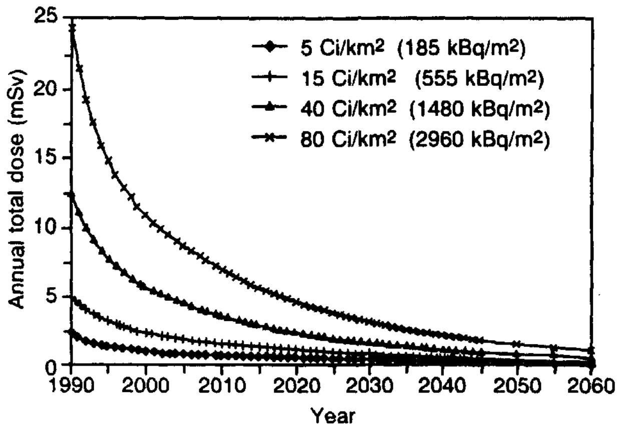


FIG. 2-2. Variation of annual dose with time. Doses are estimated in the absence of any protective measures.

Lifetime effective dose equivalent from 1990 to 2060

$$H_{l,ext} = \frac{3.18}{k} C \quad [mSv]$$

$$H_{l,int} = \frac{1}{k} (21 + 5.24C) \quad [mSv]$$

$$H_{l,total} = \frac{1}{k} (21 + 8.42C) \quad [mSv]$$

These expressions are only valid for the purpose of estimating average dose per unit contamination; in particular, the internal dose per unit contamination may vary greatly with the soil characteristics and agricultural practice employed. For dose assessments for particular settlements, different methods of estimation should be used to take account of local circumstances. In general, internal doses are more closely correlated with milk contamination than ground contamination.

A limited sensitivity analysis has been undertaken for selected settlements. The internal dose differs significantly from the average value obtained from the above expression.

TABLE 2–4. Evolution of Mean Individual Annual Dose over the 1990–2060 Period for a Ground ^{137}Cs Contamination of 40 Ci/km^2 (1480 kBq/m^2) in 1990

Year	t	External dose	Internal dose	Total (mSv)	Percentage	Cumulative percentage
1990	2	4.41	8.07	12.48	5.93	5.93
1991	3	3.71	7.30	11.02	5.23	11.17
1992	4	3.18	6.68	9.87	4.69	15.86
1993	5	2.78	6.17	8.95	4.25	20.11
1994	6	2.47	5.74	8.21	3.90	24.01
1995	7	2.24	5.37	7.60	3.61	27.63
1996	8	2.05	5.04	7.09	3.37	31.00
1997	9	1.90	4.75	6.65	3.16	34.16
1998	10	1.78	4.49	6.27	2.98	37.14
1999	11	1.69	4.25	5.93	2.82	39.96
2000	12	1.61	4.02	5.63	2.68	42.63
2001	13	1.54	3.82	5.36	2.54	45.18
2002	14	1.48	3.62	5.10	2.42	47.60
2003	15	1.43	3.44	4.87	2.31	49.92
2004	16	1.38	3.27	4.65	2.21	52.13
2005	17	1.34	3.11	4.45	2.11	54.24
2006	18	1.30	2.95	4.26	2.02	56.26
2007	19	1.27	2.81	4.07	1.94	58.20
2008	20	1.23	2.67	3.90	1.85	60.05
2009	21	1.20	2.54	3.74	1.78	61.83
2010	22	1.17	2.41	3.59	1.70	63.53
2011	23	1.14	2.30	3.44	1.63	65.17
2012	24	1.11	2.18	3.30	1.57	66.74
2013	25	1.09	2.08	3.16	1.50	68.24
2014	26	1.06	1.98	3.04	1.44	69.68
2015	27	1.04	1.88	2.91	1.38	71.07
2016	28	1.01	1.79	2.80	1.33	72.40
2017	29	0.99	1.70	2.69	1.28	73.67
2018	30	0.96	1.62	2.58	1.23	74.90
2019	31	0.94	1.54	2.48	1.18	76.07
2020	32	0.92	1.46	2.38	1.13	77.21
2021	33	0.90	1.39	2.29	1.09	78.29
2022	34	0.87	1.32	2.20	1.04	79.34
2023	35	0.85	1.26	2.11	1.00	80.34
2024	36	0.83	1.20	2.03	0.97	81.31
2025	37	0.81	1.14	1.95	0.93	82.23
2026	38	0.79	1.08	1.88	0.89	83.13

TABLE 2–4. (cont.)

Year	t	External dose	Internal dose	Total (mSv)	Percentage	Cumulative percentage
2027	39	0.78	1.03	1.81	0.86	83.98
2028	40	0.76	0.98	1.74	0.83	84.81
2029	41	0.74	0.93	1.67	0.79	85.60
2030	42	0.72	0.89	1.61	0.76	86.37
2031	43	0.70	0.84	1.55	0.74	87.10
2032	44	0.69	0.80	1.49	0.71	87.81
2033	45	0.67	0.76	1.43	0.68	88.49
2034	46	0.66	0.73	1.38	0.66	89.15
2035	47	0.64	0.69	1.33	0.63	89.78
2036	48	0.62	0.66	1.28	0.61	90.39
2037	49	0.61	0.63	1.24	0.59	90.98
2038	50	0.60	0.59	1.19	0.57	91.55
2039	51	0.58	0.57	1.15	0.55	92.09
2040	52	0.57	0.54	1.11	0.53	92.62
2041	53	0.55	0.51	1.07	0.51	93.12
2042	54	0.54	0.49	1.03	0.49	93.61
2043	55	0.53	0.46	0.99	0.47	94.08
2044	56	0.52	0.44	0.96	0.45	94.54
2045	57	0.50	0.42	0.92	0.44	94.97
2046	58	0.49	0.40	0.89	0.42	95.40
2047	59	0.48	0.38	0.86	0.41	95.81
2048	60	0.47	0.36	0.83	0.39	96.20
2049	61	0.46	0.34	0.80	0.38	96.58
2050	62	0.45	0.33	0.77	0.37	96.95
2051	63	0.44	0.31	0.75	0.35	97.30
2052	64	0.43	0.30	0.72	0.34	97.64
2053	65	0.42	0.28	0.70	0.33	97.97
2054	66	0.41	0.27	0.67	0.32	98.29
2055	67	0.40	0.25	0.65	0.31	98.60
2056	68	0.39	0.24	0.63	0.30	98.90
2057	69	0.38	0.23	0.61	0.29	99.19
2058	70	0.37	0.22	0.59	0.28	99.47
2059	71	0.36	0.21	0.57	0.27	99.74
2060	72	0.35	0.20	0.55	0.26	100.00
Total		74.75	135.71	210.45		

TABLE 2-5. Percentage of the Lifetime Effective Dose Equivalent Delivered in Given Periods[a]

Period	Percentage of lifetime dose
1990-1994	20
1995-1999	16
2000-2004	12
2005-2009	10
2010-2014	8
2015-2019	6
2020-2024	6
2025-2029	4
2030-2039	7
2040-2060	7

[a] Doses in the absence of any protective measures are estimated.

2-4.2. Relationships between Surface Contamination, Mean Annual Dose and Lifetime Dose

On the basis of the equations presented above, the average relationships between dose and contamination level are given in Table 2-3.

2-4.3. Variation of Annual Dose with Time

Figure 2-2 presents the temporal variation of dose for the 1990-2060 period for various levels of contamination (5, 15, 40 and 80 Ci/km^2) (185, 555, 1480 and 2960 kBq/m^2).

As an example, Table 2-4 presents the evolution of the mean individual dose over the 1990-2060 period for a ground ^{137}Cs contamination of 40 Ci/km^2 (1480 kBq/m^2).

The percentage of the lifetime dose delivered in given periods is indicated in Table 2-5.

TABLE 2-6. Distribution of the Lifetime (1990-2060) Collective Dose as a Function of Surface Contamination[a]

Range of contamination		Population	Percentage	Lifetime effective collective dose equivalent (man·Sv)
(Ci/km^2)	(kBq/m^2)			
5-10	185-370	411 800	58.4	20 370
10-15	370-555	87 200	12.4	6 472
15-20	555-740	117 900	16.7	11 668
20-25	740-925	28 100	4	3 476
25-30	925-1110	24 900	3.5	3 698
30-35	1110-1295	15 700	2.2	2 719
35-40	1295-1480	5 300	0.7	1 049
40-60	1480-2220	10 400	1.5	2 702
60-80	2220-2960	3 400	0.5	1 220
>80	>2960	900	0.1	412
Total		705 600	100	53 786

[a] Doses are estimated in the absence of any protective measures.

2-4.4. Collective Dose

In the absence of any protective measures, the total collective dose for the 1990–2060 period, for people living in the control and strict control zones, is estimated to be about 54 000 man·Sv. This collective dose has been calculated using the distribution of population within the control and strict control zones [1] and on the assumption that the size of the population and its age structure will remain constant over the whole period. The distribution of the collective dose as a function of the level of surface contamination is given in Table 2–6.

2-5. Cost and Effectiveness of Countermeasures

A large set of measures can be envisaged to reduce the level of exposure in the 'controlled areas', e.g. restrictions on contaminated foodstuffs, technical measures in the field of agriculture, either to decontaminate soils or to protect the population by means of adequate shielding when possible, etc. [7].

In the required time-scale it was not possible to obtain adequate data on the cost and efficacy of the various detailed measures in order to evaluate them in terms of dose reduction. In their absence, the model only considered protective measures in two broad categories:

- relocation of the population, and
- improvement of living conditions.

The improvement of living conditions (ILC) includes the whole spectrum of measures taken in the three Republics for the population remaining in the affected areas, including the provision of clean food.

2-5.1. Effectiveness

2-5.1.1. Improvement of Living Conditions

Of the many measures taken to improve the living conditions, only a few have a significant effect on the doses received; the provision of clean food is perhaps the most important in this respect. In the model it is assumed that this is the only protective measure which reduces the dose, and no account is taken of the effect on the dose of a decrease in surface contamination associated with specific decontamination measures.

The time for which measures to improve the living conditions will continue is not fixed. The State All-Union and Republican Programme was initially planned for a three year period (1990–1992), and its continuation beyond this time, and in what form, is a matter to be determined in the future. In the absence of specific data on this, the basic assumption was made that these measures would continue only for the duration of the current State Programme; the sensitivity of the results to the measures continuing for five and ten years was, however, also evaluated.

The effectiveness of agricultural protective measures on the internal dose has been evaluated by Linge et al. [8]. Figure 2-3 shows internal doses for 1989 plotted against the level of soil surface contamination by ^{137}Cs. Based on dosimetric data from observations in a number of settlements in 1989, the relationship between a given concentration level and the internal dose for 1989 is given by:

$$\text{Internal dose in 1989} = -0.17 + 0.95 \log_{10} C$$

where C is the surface ^{137}Cs contamination (Ci/km^2).

Because of uncertainties in the rate at which future doses will decrease, it was cautiously assumed that the internal dose observed in 1989, with agricultural restrictions in place, will remain the same for each year during which measures to improve the living conditions continue (unless in the absence of protective measures the dose would have been less).

2-5.1.2. Relocation

Relocation is assumed to be totally effective; the dose is considered to be zero as soon as the population has left

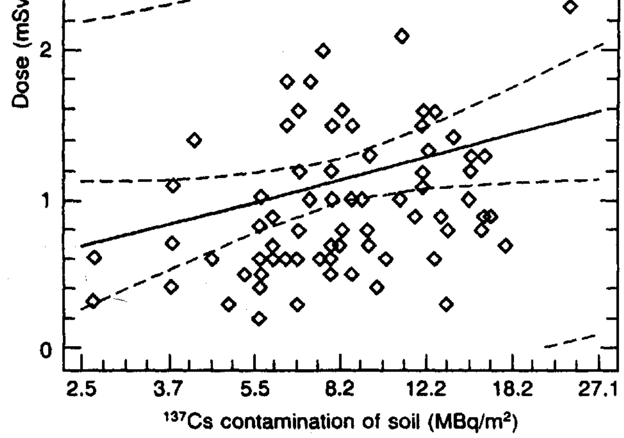


FIG. 2-3. Variation of internal doses with level of soil surface contamination by ^{137}Cs for a number of settlements in 1989. *[Source: Ref. [8]]*

TABLE 2-7. Number of People to be Relocated according to the State All-Union and Republican Programme

	Number of people to be relocated
BSSR	93 700
RSFSR	84 200
UkrSSR	40 600
All-Union	218 900

the contaminated area. This implies that the population is relocated to regions where the natural background irradiation is not significantly different, and no contaminated food is consumed. Two further aspects have to be considered. First, for social and economic reasons, the relocation of a given settlement or a set of settlements may necessitate the additional relocation of neighbouring settlements where these are economically dependent on those relocated. Secondly, there may be many people in each Republic who wish to be relocated, even when the level of contamination is below the criterion. (On the basis of these considerations, a coefficient of relocation has been introduced when performing the sensitivity analysis).

Table 2-7 presents the number of people to be relocated in the State All-Union and Republican Programme, where the criteria for relocation are:

- all people living in areas with a ^{137}Cs contamination of more than 40 Ci/km^2 (1480 kBq/m^2)
- all families with pregnant women or children under 12 years old in areas with a ^{137}Cs contamination greater than 15 Ci/km^2 (555 kBq/m^2).

The total number of people to be relocated (218 900) is much larger than the corresponding population for which the criteria are applicable. (According to Table 2-1, 206 600 persons are living in areas with more than 15 Ci/km^2 (555 kBq/m^2)).

2-5.2. Costs

All costs used in the model are taken from the State All-Union and Republican Programme, which combines the data provided by the three Republics [2]. (Cost structures of the All-Union, BSSR, RSFSR and UkrSSR programmes are presented in Table 2-8.) The cost data in the various programmes were extrapolated from early 1980s data, without correction for the recent economic changes in the USSR. Two categories of costs can be distinguished: 'one off' costs, and annual costs. These costs are summarized in Table 2-9 for the protective measures, relocation and ILC. In addition, there is a third category of costs which are likely to be incurred, irrespective of whether people are relocated or have their living conditions improved. These can therefore be assumed to be independent of the protective measures taken.

Our categorization of the various costs is slightly different from that presented in the programme. The purpose of this was to improve the delineation between the costs that can be related to providing improved living conditions and those which are related to the relocation. Some of the costs can be considered independent of whether measures are taken to improve living conditions or the population is relocated (i.e. independent of the protective strategy).

On the basis of these assumptions the costs per capita of relocation and improvement of living conditions are shown in Table 2-10.

2-6. Protection Strategies

The current State All-Union and Republican Programme is based on the following criteria for providing ILC and relocation:

- ILC for the population living in areas where the ground contamination is above 5 Ci/km^2 (185 kBq/m^2);
- relocation for the population living in areas where the ground contamination is above 40 Ci/km^2 (1480 kBq/m^2).

The key issue is to evaluate the cost and dose reduction achieved by varying the criterion for relocation. The two basic protective measures have been combined into strategies which fit within the generic conceptual framework below:

No restriction	Protective measures to improve living conditions	Relocation

Level A   Level B

The value of 5 Ci/km^2 (185 kBq/m^2) has been adopted in the model for Level A as it is the level currently adopted in the State Programme. This corresponds to the boundary of the 'controlled area'. Expressed in terms of annual dose in 1990 or lifetime dose, this contamination level corresponds to:

—average annual effective dose equivalent in 1990
= 2.2 mSv/a

—average lifetime effective dose equivalent (1990–2060)
= 37 mSv

TABLE 2-8. Basic Cost Structure of the All-Union, BSSR, RSFSR and UkrSSR Programmes, 1990–1992

	Million roubles	Percentage
All-Union Programme		
Relocation of population	9 250.6	70.1
Compensation of population	2 228.0	16.1
Improvement of local situation	1 307.4	7.6
Medical care	419.6	1.9
Environmental monitoring	139.8	0.7
Agricultural losses	226.3	1.6
Research	518.3	2.0
Information of public	6.8	0.0
Subtotal	14 096.8	
Construction of 'gazoduc'	1 202.0	
Total	15 298.8	
BSSR Programme		
Relocation of population	4050.3	70.1
Compensation of population	929.2	16.1
Improvement of local situation	438.4	7.6
Medical care	110.7	1.9
Environmental monitoring	40.7	0.7
Agricultural losses	92.4	1.6
Research	116.4	2.0
Information of public	0.9	0.0
Total	5779.0	
RSFSR Programme		
Relocation of population	3353.2	73.5
Compensation of population	367.3	8.1
Improvement of local situation	233.9	5.1
Medical care	209.5	4.6
Environmental monitoring	42.2	0.9
Agricultural losses	54.9	1.2
Research	295.1	6.5
Information of public	5.1	0.1
Total	4561.2	
UkrSSR Programme		
Relocation of population	1847.1	51.2
Compensation of population	931.5	25.8
Improvement of local situation	483.1	13.4
Medical care	99.4	2.8
Environmental monitoring	56.9	1.6
Agricultural losses	79.0	2.2
Research	106.8	3.0
Information of public	0.9	0.0
Total	3604.7	

TABLE 2-9. Estimated Costs Derived from the State All-Union and Republican Programme [3]
(only for settlements with a contamination of over 5 Ci/km² (185 kBq/m²)) for the 1990–1992 period)

Measure		Costs (Million roubles)
I. 'One off' costs		
1. *Relocation:* (Number of people: 218 900)		
Construction of new houses, shops, etc.		8 167
Compensation for transfer		1 083.6
	Subtotal	9 250.6
2. *ILC:* (Number of people: 581 100)[a]		
Improvement of social conditions		800
Agricultural and industrial forestry measures		355.4
Creation of plants for production of clean food		152
Construction of 'gazoduc'[b]		1 202
	Subtotal	2 509.4
3. *Independent*[c]:		
Construction of research establishments		46.4
Materials for scientific and medical organizations		84.9
Building of sanatoriums		122.5
	Subtotal	253.8
	Total 'one off' costs	12 013.8
II. Annual costs		
1. *ILC:* (Number of people: 581 100)		
Environmental monitoring		139.8
Subsidies for agriculture and forestry		226.3
Compensation:		
15 roubles/month[d]		313.8
Other compensation[e] (kindergarten, cost-free food, additional holidays, increase of retirement pensions, premium for experts)		1 496.7
Information service		6.8
	Subtotal	2 183.4
2. *Independent costs*[c]:		
Operation of research establishments		387
Special medical care		297.1
	Subtotal	684.1
	Total variable costs	2 867.5

[a] Number of people for improvement of living conditions = number of people in areas with over 5 Ci/km² (185 kBq/m²) (in the report = 800 000) minus the number of relocations.

[b] Without further information, it is assumed that there is a linear relationship between the construction cost of the gas pipeline system ('gazoduc') and the number of people affected.

[c] It is assumed that these costs would be incurred irrespective of whether a population is relocated or measures are taken to improve living conditions.

[d] This cost is estimated on the basis of 15 roubles per person per month for 581 100 persons.

[e] Due to a lack of detailed information on the number of people affected by these measures, it is assumed that all these costs are related to the population in areas with over 5 Ci/km² (185 kBq/m²), who will still be in the area after 1992.

TABLE 2-10. Cost per Capita Used in the Model

	Cost per person (roubles)
Relocation	42 260
ILC:	
'One off' costs	4 320
Annual costs	
< 15 Ci/km^2 (555 kBq/m^2)[a]	1 250
> 15 Ci/km^2 (555 kBq/m^2)	1 430

[a] This distinction is introduced to take into account the two levels of compensation. It is assumed that for over 15 Ci/km^2 (555 kBq/m^2), the compensation is 30 roubles/month per person, whereas for between 5 and 15 Ci/km^2 (185 and 555 kBq/m^2) it is only 15 roubles/month per person.

assuming no protective measures are taken. Altogether, 11 strategies have been evaluated with the model (Table 2-11), in which different values have been assumed for Level B, the level above which it is assumed that relocation is implemented.

Table 2-12 presents the number of people to be relocated, or for whom living conditions will be improved, for each strategy.

2-7. Cost-Benefit Analysis

Strictly speaking, the evaluation of the various strategies is based on a differential cost-benefit analysis [9], here called cost-benefit analysis for simplification. The baseline analysis has been conducted under the following assumptions:

(a) The measures for improvement of living conditions, especially the provision of clean food, are only intended to last three years: 1990–1992. For the remaining years, no special measures have been specified, and the collective exposure in this period represents 84% of the total. This last assumption will underestimate the effectiveness of the agricultural measures implemented during the first three years, as these will continue to have some impact even in the absence of further restrictions on foodstuffs. Furthermore, extension of the protective measures or implementation of new measures after 1992 are matters to be decided in the future.

(b) The costs of all the measures are assumed to be incurred in the year 1990.

2-7.1. Results

Table 2-13 presents the cost and residual collective dose associated with each strategy. The results of the cost-benefit analysis are summarized in Table 2-14.

TABLE 2-11. Definition of Strategies

Strategy	Criteria for improvement of living conditions (Level A)	Criteria for relocation (Level B)
S1 (5)	—	5 Ci/km^2 (185 kBq/m^2)
S2 (10)	5 Ci/km^2 (185 kBq/m^2)	10 Ci/km^2 (370 kBq/m^2)
S3 (15)	5 Ci/km^2 (185 kBq/m^2)	15 Ci/km^2 (555 kBq/m^2)
S4 (20)	5 Ci/km^2 (185 kBq/m^2)	20 Ci/km^2 (740 kBq/m^2)
S5 (25)	5 Ci/km^2 (185 kBq/m^2)	25 Ci/km^2 (925 kBq/m^2)
S6 (30)	5 Ci/km^2 (185 kBq/m^2)	30 Ci/km^2 (1110 kBq/m^2)
S7 (35)	5 Ci/km^2 (185 kBq/m^2)	35 Ci/km^2 (1295 kBq/m^2)
S8 (40)	5 Ci/km^2 (185 kBq/m^2)	40 Ci/km^2 (1480 kBq/m^2)
S9 (60)	5 Ci/km^2 (185 kBq/m^2)	60 Ci/km^2 (2220 kBq/m^2)
S10 (80)	5 Ci/km^2 (185 kBq/m^2)	80 Ci/km^2 (2960 kBq/m^2)
S11 (—)	5 Ci/km^2 (185 kBq/m^2)	No relocation

TABLE 2–12. Number of People to Be Relocated or Subject to Improved Living Conditions for the Different Strategies

Strategy	Number of persons	
	ILC	Relocation
S1	0	705 600
S2	411 800	293 800
S3	499 000	206 600
S4	616 900	88 700
S5	645 000	60 600
S6	669 900	35 700
S7	685 600	20 000
S8	690 900	14 700
S9	701 300	4 300
S10	704 700	900
S11	705 600	0

The results are expressed in terms of marginal cost of unit of collective effective dose equivalent averted. Taking, for example, the strategy S6, the marginal cost per man-sievert averted represents the increment of cost to relocate the population and to improve living conditions from strategy S7 to S6 (i.e. 7007 − 6479 = 528 million roubles) divided by the corresponding collective dose averted (i.e. 44 718 − 42 221 = 2497 man·Sv).

2–7.2. Reference Values of the Man-Sievert

To make judgements on the marginal costs per unit dose averted by the various strategies, it is necessary to introduce a reference value for the cost of the man-sievert. The 'theoretical' optimum level of ground contamination for relocation, assuming that the cost of implementing the corresponding strategy and the associated collective dose are the only two factors to be considered, will be determined by the value assigned to this quantity.

A large range of values have been proposed within the radiation protection community for the cost of the man-sievert. In addition to the diversity of values proposed for different circumstances (public or occupational exposures, very low or medium doses, etc.), it is recognized that a large variety of methods can be used to derive such values and no broad consensus exists on the best approach [10]. However, the so-called human capital approach has been extensively used by practitioners, and most of the values proposed, either by national or international organizations, are directly or indirectly related to it. In the absence of generally accepted values for the cost of the man-sievert in the USSR, the human capital approach, combined with considerations of individual risk aversion, is judged as the most defensible means of generating reference values. The methodology of coping with risk aversion is not yet well established. No reference values have been agreed upon to express the degree of aversion according to an increase of risk, and no consensus exists on how this might vary with the particular situation. The model adopted for deriving reference monetary values of the man-sievert for use in this evaluation is described in detail below.

It is clear that without taking other considerations such as aversion into account, it is extremely difficult to justify any strategies for relocation. The baseline value for exposure arising at low levels of individual dose is found to be 5000 roubles per man-sievert. This value is far below the lowest marginal cost of about 80 000 roubles associated with strategy S10.

TABLE 2–13. Cost and Collective Dose Associated with the Different Strategies

Strategy	Cost (million roubles)	Residual collective effective dose equivalent 1990–2060 (man-sievert)
S1	29 819	0
S2	15 739	18 852
S3	12 758	24 842
S4	8 791	35 618
S5	7 845	38 821
S6	7 007	42 221
S7	6 479	44 718
S8	6 300	45 679
S9	5 950	48 150
S10	5 836	49 262
S11	5 806	49 637

TABLE 2-14. Collective Dose Averted and Marginal Cost of the Unit of Collective Dose Averted for the Different Strategies

Strategy	Collective effective dose equivalent averted (1990–2060) (man-sievert)	Marginal cost per unit collective dose averted (roubles/man-sievert)
S1	53 786	746 857
S2	34 934	497 694
S3	28 944	368 165
S4	18 168	295 185
S5	14 964	246 465
S6	11 565	211 604
S7	9 068	185 413
S8	8 106	141 650
S9	5 636	102 868
S10	4 523	80 778
S11	4 148	—

Model for the monetary valuation of the unit of collective dose

The baseline monetary value of the man-sievert (a_{ref}) is derived from the following formula:

$$a_{ref} = \frac{\text{annual gross national product}}{\text{population}} \times \text{LLE/Sv}$$

where LLE/Sv is the loss of life expectancy associated with one sievert. On the basis of the risk coefficient recently proposed by ICRP [11], the value is 0.95 year:

$$[(5 \times 10^{-2} \text{ (fatal cancer/man-sievert)} \times 15 \text{ years}) + (1 \times 10^{-2} \text{ (genetic effect/man-sievert)} \times 20 \text{ years})]$$

On the basis of the annual gross national product (GNP) and the total population for the USSR in 1987 — 866 billion roubles and 289 million inhabitants, respectively — the baseline monetary value of the man-sievert is 2850 roubles. A rounded figure of 5000 roubles per man-sievert can be adopted to take into account the cost of medical care related to the potential health effects, the possible evolution of the economic situation (increase of GNP, inflation) as well as uncertainties in the various parameters.

The degree of aversion according to the exposure level is integrated into the monetary value of the man-sievert, using the following simple model:

$$\alpha_i = \alpha_{ref} (d_i/d_0)^a$$

where α_i is the monetary value of unit collective dose for level of exposure i, α_{ref} is the reference monetary

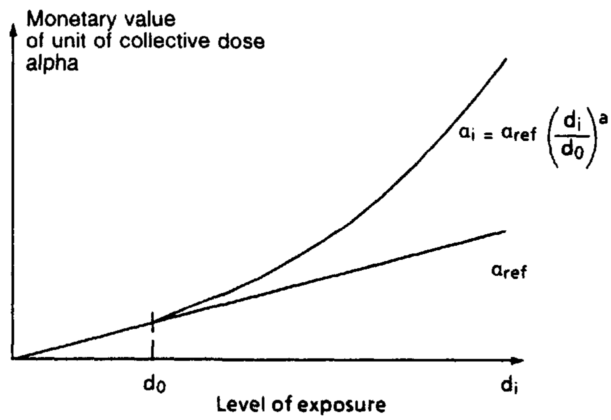


FIG. 2-4. Schematic representation of the impact of introducing a risk aversion factor into the monetary valuation of the man-sievert.

TABLE 2-15. Reference Values of the Man-Sievert according to the Level of Exposure

Ci/km^2	kBq/m^2	Reference monetary values of the man-sievert (roubles/man-sievert) according to the risk aversion coefficient[a]	
		a = 1.2	a = 1.5
5	185	5 200	5 250
10	370	6 300	6 800
15	555	7 750	9 100
20	740	9 500	11 950
25	925	11 450	15 250
30	1110	13 550	19 000
35	1295	15 700	23 050
40	1480	18 000	27 450
60	2220	27 950	47 900
80	2960	38 800	72 250
100	3700	50 200	99 750

[a] With ILC.

value of unit collective dose for exposure arising at levels of individual dose lower than d_0, d_0 is the upper band of the range of individual dose for which a_{ref} is applicable, d_i is the level of individual dose ($d_i > d_0$), and a is the exponent representing the degree of aversion.

Figure 2–4 is a schematic representation of the impact of introducing a risk aversion factor into the monetary valuation of the man-sievert.

As presented, the model is adapted for a situation where the levels of individual exposure are constant. In the case of the lifetime exposure associated with an accidental situation, the individual dose decreases over the years. To take into account this decrease, the individual doses are weighted over the years according to the following formula:

$$\alpha_i = \alpha_{ref} \frac{\sum_{t=0}^{70} \left(\frac{d_{it}}{d_0}\right)^a}{71}$$

The values for d_0 and a remain a matter of debate and different figures have been proposed so far by various authors. For the purpose of the analysis, a value of 1 mSv for the annual individual dose has been selected on the grounds that this figure has been proposed by international organizations as a no-action level for intervention in case of a nuclear accident (see, for example, Ref. [12]). For the risk aversion coefficient a, values of 1.2 [13] and 1.5 [14] have been applied to reflect the uncertainty attached to this key parameter.

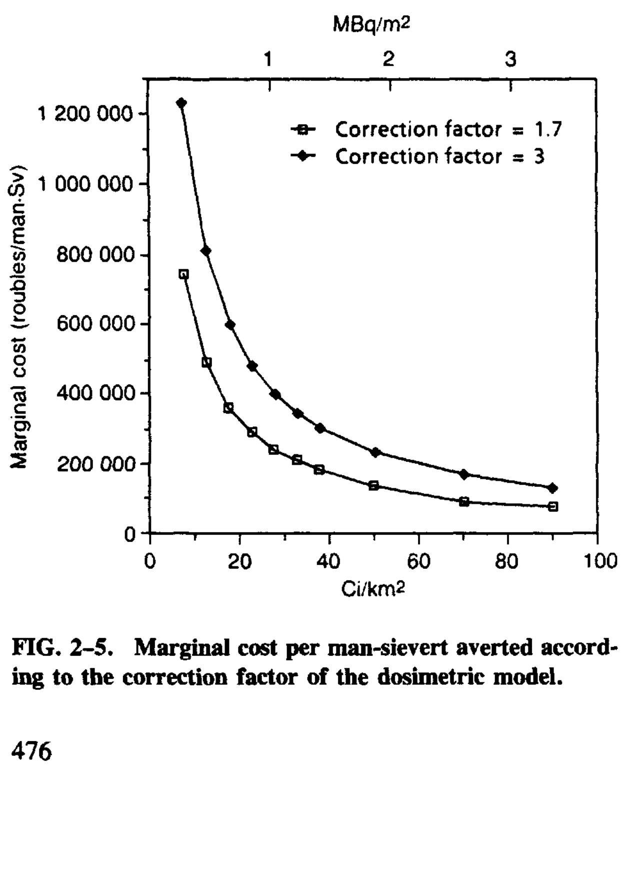


FIG. 2-5. Marginal cost per man-sievert averted according to the correction factor of the dosimetric model.

Table 2–15 presents the final reference values obtained with the model, for various levels of ground contamination and different values of the risk aversion coefficient with a reference baseline alpha value of 5000 roubles.

Taking some measures of risk aversion into consideration, which is quite compatible with the attitude of the population living in the contaminated areas and is reflected in the position of many representatives of the various Republic authorities, it would be possible to justify relocation. The final conclusion clearly depends upon the attitude towards aversion. With an upper value of 1.5 for the risk aversion coefficient, relocation of the population above 80 Ci/km^2 (2960 kBq/m^2) would be justified. This resuit is based on the assumption that measures for ILC are taken.

2–8. Sensitivity Analysis

As mentioned in the previous sections, the strategies have been evaluated subject to major assumptions concerning both the dosimetric and economic parameters used in the model. It was therefore important to perform a sensitivity analysis to evaluate the robustness of the results with respect to these assumptions. Dosimetric and economic evaluations have been performed for a three year (1990–1992) duration of the measures concerning the improvement of living conditions, and a correction factor (conservatism of the model) of 1.7.

2–8.1. Conservatism of the Model

Figure 2–5 presents the effect of varying the correction factor to take into account the conservatism of the initial dosimetric model. As expected, the marginal cost per unit dose averted of the different measures is directly linked to this parameter. This indicates the importance of ensuring that the doses are estimated as realistically as possible, if sound judgements are to be made in establishing optimum intervention policies.

2–8.2. Economic Parameters

For the economic valuation, the basic assumptions are:

Relocation cost/person	42 260 roubles
Improvement of living conditions	
'one off' cost/person	4 320 roubles
annual cost/person	
< 15 Ci/km^2 (555 kBq/m^2)	1 250 roubles
> 15 Ci/km^2 (555 kBq/m^2)	1 430 roubles
Coefficient of relocation	1

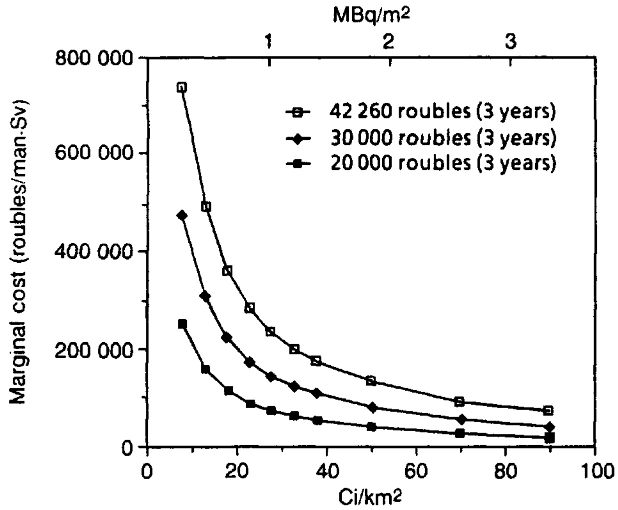


FIG. 2-6. Marginal cost per man-sievert averted according to the cost of relocation (ILC: 3 years).

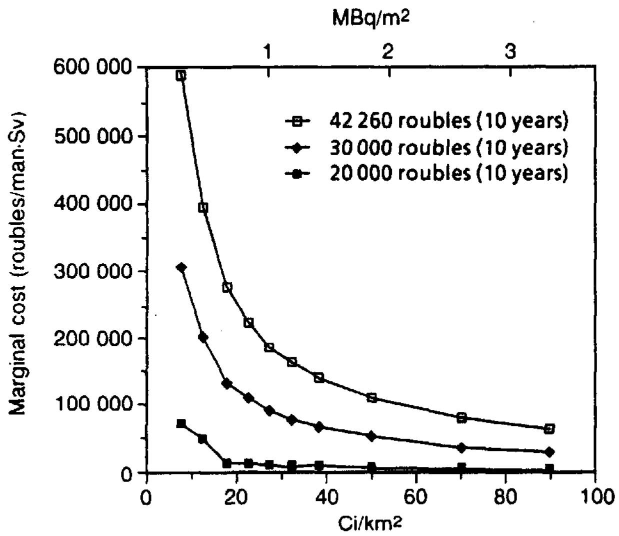


FIG. 2-7. Marginal cost per man-sievert averted according to the cost of relocation (ILC: 10 years).

Simple analyses show great differences in the marginal cost of the unit of collective dose averted, depending on the assumed costs for relocation and improvement of living conditions. Figures 2-6 and 2-7 present the variation in marginal costs for a range of relocation costs (30 000 roubles and 20 000 roubles), and the assumptions that measures for improving living conditions continue for three (Fig. 2-6) and ten years (Fig. 2-7).

Figures 2-8 and 2-9 display the variation in marginal cost as a function of the cost of providing improved living conditions and assuming that measures for improving living conditions continue for three (Fig. 2-8) and ten years (Fig. 2-9). In the absence of evidence about the possible uncertainty in these costs, two hypotheses have been tested: a multiplication and a division of reference costs by a factor 2.

The estimated marginal costs are sensitive to the costs of relocation and improved living conditions. This is particularly so for relocation, and where the measures to

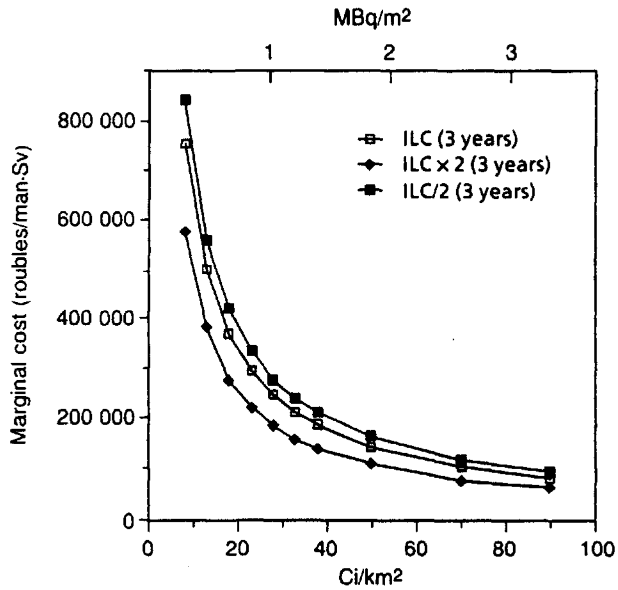


FIG. 2-8. Marginal cost per man-sievert averted according to the cost of improvement of living conditions (ILC: 3 years).

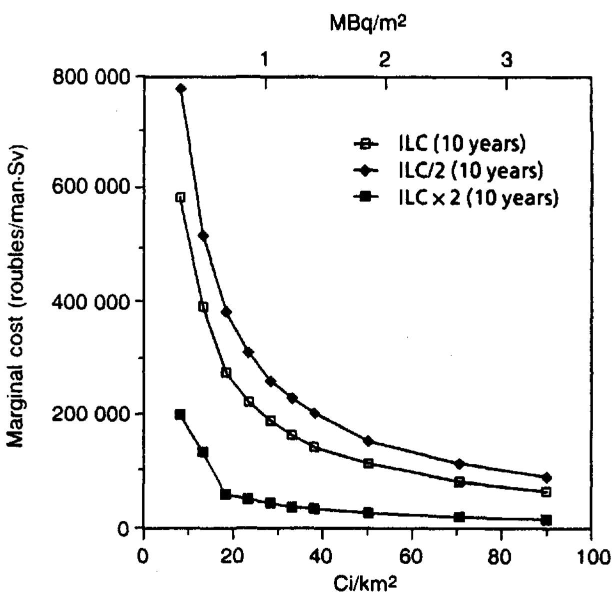


FIG. 2-9. Marginal cost per man-sievert averted according to the cost of improvement of living conditions (ILC: 10 years).

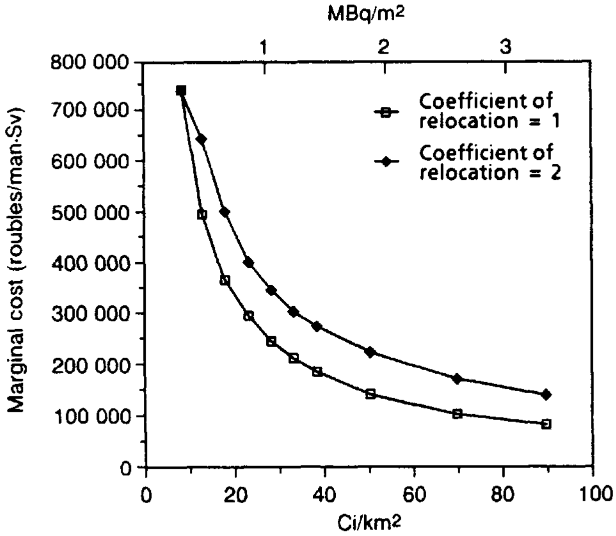


FIG. 2-10. Marginal cost per man-sievert averted according to the coefficient of relocation.

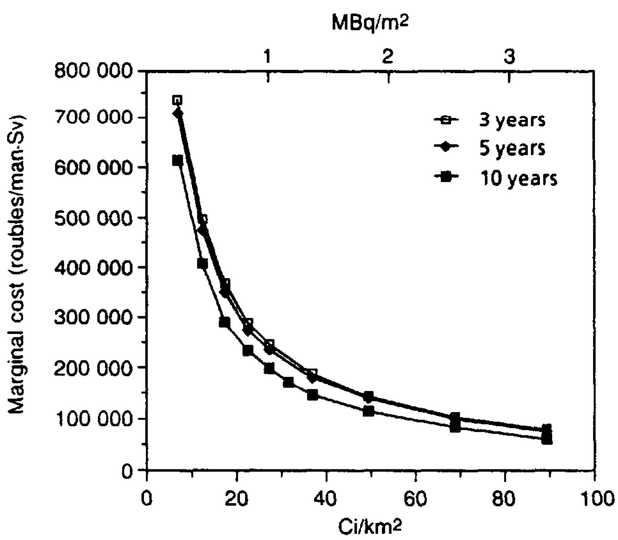


FIG. 2-11. Marginal cost per man-sievert averted according to the number of years of ILC.

improve living conditions are assumed to continue for ten years. It is therefore important to determine how realistic the present cost estimates are, and what provisions are foreseen with regard to safe living levels beyond 1992.

Figure 2-10 presents the effect of the relocation coefficient. For the relocation of people who are not in areas contaminated above level B (according to the selected strategy), the dose saved is calculated by using the mean individual dose for the remaining population, according to its distribution. The curves show that the effectiveness of relocation is directly reduced by an increase in the relocation coefficient, and it would be useful to analyse this issue in more detail, as a complement to the direct cost of relocation.

2-8.3. Duration of Protective Measures

Figure 2-11 presents the impact on the cost of unit dose averted when considering that measures to improve living conditions continue for three, five and ten years. The effect of varying this parameter is small, subject to all other factors being kept at the reference values.

2-8.4. Internal Dose Correction Factor

The dosimetric model used in this evaluation is based on average relationships between the level of ground contamination and the internal and external doses. In practice these relationships, especially that for internal exposure, vary with soil type and agricultural practice. In order to investigate the possible implications of using an average relationship, a limited sensitivity analysis has been undertaken for a subset of settlements in the Mogilev region, for which detailed dosimetric data were available.

Because of its limited nature, the results of this analysis should only be considered indicative of the importance of this parameter. Moreover, for a proper analysis on a settlement by settlement basis, account should be taken of variations from the average of other input parameters, e.g. costs of relocation, etc. A comparison between the lifetime dose estimated using internal data specific to the settlement and the lifetime dose calculated using the basic dosimetric model presented in

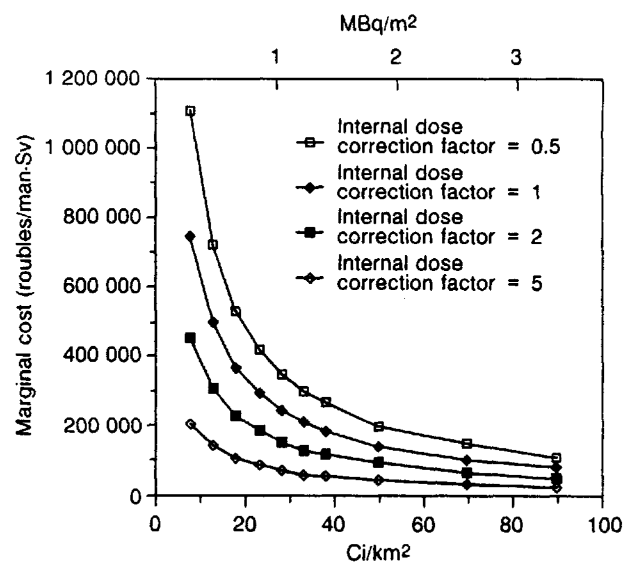


FIG. 2-12. Marginal cost per man-sievert averted according to the internal dose correction factor.

TABLE 2-16. Summary of Sensitivity Analysis

Parameter	Value	Cost effective strategy according to the risk aversion coefficient	
		a = 1.2	a = 1.5
Base case	ILC = 3 years	S11	S10 (<80)
	ILC = 10 years	S11	S10 (<80)
1. Correction factor for conservatism of the dosimetric model			
	3	S11	S11
2. Relocation cost			
ILC = 3 years	30 000 roubles	S11	S9 (<60)
	20 000 roubles	S9 (<60)	S8 (<40)
ILC = 10 years	30 000 roubles	S9 (<60)	S9 (<60)
	20 000 roubles	S5 (<25)	S4 (<20)
3. Cost of ILC			
ILC = 3 years	Base case × 2	S11	S10 (<80)
	Base case / 2	S11	S10 (<80)
ILC = 10 years	Base case × 2	S8 (<40)	S8 (<40)
	Base case / 2	S11	S10 (<80)
4. Coefficient of relocation			
ILC= 3 years	2	S11	S11
ILC = 10 years	2	S11	S11
5. Variation of internal dose (ILC = 3 years)			
	Base case × 2	S10 (<80)	S9 (<60)
	Base case / 2	S11	S11

Section 2-4.1 gives a ratio varying between 0.6 and 5.3, but the majority lies between 1 and 2. Using average costs for relocation and ILC, the costs of unit dose averted were calculated settlement by settlement. Figure 2-12 presents the distribution of the cost per man-sievert according to the internal dose correction factor.

2-8.5. Comments

The various sensitivity analyses do not significantly change the conclusions of the base case evaluation (see Table 2-16). From these analyses it is clear that further relocation than for 40 Ci/km^2 (1480 kBq/m^2) would only be beneficial if the cost structures were significantly different, particularly the cost of relocation. A large increase in the costs of improving living conditions, without a change in the costs of relocation, would lead to a situation where it is less expensive to relocate a large fraction of the population. Equally, a large decrease in relocation costs would lead to the same conclusion if the costs of improving living conditions remained as high as evaluated. From these results it seems important to envisage further investigations in order to reduce the uncertainties in costs of the possible countermeasures. However, these costs depend greatly upon the evolution of the economy in the various Republics, and it is very difficult to forecast future trends.

TABLE 2-17. **Demographic Data of the USSR: Annual Death Rates for 1987** [16]

Age range	Population (in thousands)		Annual death rate (per 100 000)	
	Males	Females	Males	Females
0	2 811	2 691	2 854.6	2206.6
1–4	10 652	10 226	246.9	221
5–14	23 230	22 523	63.1	37.7
15–24	21 535	21 029	146.5	58.9
25–34	23 750	23 421	262.7	89.7
35–44	15 419	15 972	471.4	171.8
45–54	16 052	18 170	1 111.3	422
55–64	12 215	17 356	2 418.8	1082.2
65–74	4 446	10 214	5 341.2	2937
75 and more	2 712	8 322	11 981.1	9149.7

TABLE 2-18. **Annual Additional Probability of Death**[a]

Age of population (year)	Annual death rate per 100 000 without exposure[b]	Annual increase of probability of death for 100 000 people born in 1990 and living continuously in contaminated areas		
		5 Ci/km^2 (185 kBq/m^2)	15 Ci/km^2 (555 kBq/m^2)	40 Ci/km^2 (1480 kBq/m^2)
1	234	0	0	0
10	50.6	1	2.5	5.9
20	103.2	4	8.8	21.2
30	176.8	7.6	17	42.2
40	319	15	35	83.4
50	745.3	39	90	216
60	1634.3	107	250	602
70	3666.1	251	583	1407
80	9845.6	445	1034	2488

[a] Probabilities are estimated in the absence of any protective measures.
[b] Based on Soviet demographic data (1987) [16].

2-9. Risk Considerations

The protective measures envisaged are intended to reduce the health impacts on the exposed population. In this context, it is of interest to express the estimated doses (with and without protective measures) in terms of their associated risk of fatal cancer, using the most recent risk coefficients proposed by UNSCEAR [15].

Table 2-17 presents demographic data for the USSR [16]. These data have been used as a basis for deriving the additional risk for an individual remaining in an affected area.

It should be noted that the average initial life expectancy of both sexes in the USSR is about 70 years. On the basis of these figures, a computer code of the Centre d'Etude sur l'Evaluation de la Protection dans le

Domaine Nucléaire (CEPN) was used to calculate the lifetime risk (and its distribution with time), expressed as a probability of fatal cancer or man-years lost [17]. These estimates have been derived for a child born in 1990 and subject to a level of ground contamination of 5, 15 and 40 Ci/km^2 (185, 555 and 1480 kBq/m^2). They are based on the following assumptions:

- The lifetime dose is distributed in time according to the equation in Section 4;
- The risk is derived from the present life table of the population of the USSR, considering the excess death due to irradiation which could appear from year 0 to 100.

The additional probability of fatal cancer for other age groups would be lower than those estimated. Table 2-18 presents the annual additional probability of death for a child born in 1990 as a function of time for various levels of ground contamination. These results were derived using UNSCEAR risk coefficients [15] (for exposure to high doses and dose rates) divided by a factor two to take into account the differences in dose and dose rate.

On the basis of the increase in annual death rates, the average lifetime risk was derived for the population born in 1990. Table 2-19 presents the excess deaths and the loss of life expectancy, according to the level of ground contamination.

Finally, Table 2-20 presents the average individual risk of fatal cancer averted and the average individual increase of life expectancy, with their corresponding implicit costs according to the various strategies.

2-11. Conclusions

The analysis presented above is an attempt to provide a coherent framework for all the available data concerning the cost and doses averted associated by various relocation strategies, for the population living in the contaminated areas affected by the Chernobyl accident. Ideally, the analysis should have been undertaken on a settlement by settlement basis, where proper account could have been taken of local variations in dosimetric and economic data. However, because of data limitations this was not possible. The model developed has been extensively discussed and presents what is believed to be the best compromise achievable, taking into account the available data and various uncertainties.

Using a baseline value of the man-sievert estimated on the basis of human capital considerations, it is not justified to relocate anyone from the controlled zones. With some allowance for risk aversion, the results suggest that there are no strong arguments for the implementation of further measures other than those already envisaged, unless relocation costs differ largely from the base case. This conclusion will remain valid as long as the cost of the protective measures and the reduction in risk they achieve are the only two factors taken into account by decision makers. Some other factors of a social or political nature could justify a more restrictive approach.

The sensitivity analyses performed on some of the key parameters driving the model do not drastically alter the final results. The analysis in terms of risk confirms the relatively low impact of the exposures on the population. From the point of view of resource allocation, it would be useful to evaluate the effectiveness of protection or safety measures adopted in the USSR in the field of public health, to save lives or to improve living conditions for people suffering from serious diseases. Unfortunately, because of time constraints, it was not possible to have access to this type of information during the course of the Project. Such an analysis should allow the implicit costs associated with the measures envisaged for saving lives or man-years of life to be put into better perspective.

TABLE 2-19. Lifetime Risk for the Population Born in 1990[a]

	Level of ground contamination		
	5 Ci/km^2 (185 kBq/m^2)	15 Ci/km^2 (555 kBq/m^2)	40 Ci/km^2 (1480 kBq/m^2)
Average excess deaths per 100 000	218	507	1223
Loss of life expectancy (days/person)	12.5	29	70.1

[a] Impacts are estimated in the absence of any protective measures.

TABLE 2-20. Average Decrease of Individual Risk (Cancer Averted and Increase of Life Expectancy) and Marginal Costs Associated[a]

Strategy	Population relocated	Average individual risk of fatal cancer averted (per 100 000)[b]	Average individual increase of life expectancy (year)[b]	Marginal cost per cancer averted (million roubles)	Marginal cost per man-year saved (million roubles)
S1 (5)	705 600	446	0.07	14.6	750.6
S2 (10)	293 800	663	0.10	9.7	502.3
S3 (15)	206 600	760	0.12	7.3	371.5
S4 (20)	88 700	1002	0.16	5.8	297.7
S5 (25)	60 600	1132	0.18	4.9	248.2
S6 (30)	35 700	1319	0.21	4.2	212.7
S7 (35)	20 000	1565	0.25	3.7	187.1
S8 (40)	14 700	1714	0.27	2.8	142.1
S9 (60)	4 300	2209	0.35	2	102.5
S10 (80)	900	2667	0.42	1.6	80
S11 (—)	0	0	0	0	0

[a] Estimations are made assuming no improvement of living conditions.

[b] The average individual risk of fatal cancer averted and the average individual increase in life expectancy are those resulting from one strategy to the next (i.e. resulting from a reduction in the relocation criterion from, for example, 60 to 40 Ci/km^2 (2220 to 1480 kBq/m^2) on moving from S10 to S9).

Finally, the study has indicated the need for further investigations on several points. The first point is the degree of conservatism in the dosimetric estimates. The effectiveness of protective measures should be evaluated on a realistic basis, since overestimation of the potential health impacts could lead to the misallocation of resources; moreover, it may place additional and unnecessary stress on the population. Secondly, the effectiveness of the possible protective measures should be re-evaluated more comprehensively. Some research programmes on this important issue are presently under development, and their results should be used to confirm the estimates made so far. Thirdly, the reliability of estimates of costs of relocation and improvement of living conditions for the population, and the time for which the latter will continue, should be further examined, as these are three of the more sensitive parameters in the assessment of the costs per unit dose averted.

References for Annex 2

[1] LINGE, I.I., Dose Related Distribution of Population from Contaminated Areas (5 Ci/km^2 of ^{137}Cs and above), Institute of Biophysics, USSR Ministry of Health, Moscow (September 1990).

[2] State All-Union and Republican Programme for Urgent Measures for Rectifying the Consequences of the Chernobyl Accident for 1990–1992, Moscow (1990).

[3] Russian Republic Programme for Urgent Measures for Rectification of the Consequences of the Chernobyl Accident for 1990–1995 Moscow (May 1990).

[4] State Programme for 1990–1995 on the Rectification in the Byelorussian Soviet Socialist Republic of the Consequences of the Chernobyl Accident, Minsk (1990).

[5] Ukrainian Programme for Urgent Measures for Rectification of the Consequences of the Chernobyl Accident for 1990–1992, Kiev (1990).

[6] LIKHTAREV, I.A., KOVGAN, L.N., "Doses of irradiation to population as a result of the Chernobyl accident", All-Union Centre for Radiation Medicine of the Academy of Medical Sciences of the USSR, Kiev. Presented at the Seminar on Comparative Assessment of the Environmental Impacts of Radionuclide Releases during Three Major Nuclear Accidents: Kyshtym, Windscale, Chernobyl, 1-5 October 1990, Luxembourg, organized by the Commission of the European Communities and the International Union of Radioecologists.

[7] KIRCHMANN, R., Agricultural Countermeasures Taken in the Chernobyl Region and Evaluation of the Results, Report for the Commission of the European Communities and the International Union of Radioecologists (April 1990).

[8] LINGE, I.I., BARCHUDAROV, R.M., LABUZOV, S.G., NIGIYAN, A.A., SAVKIN, M.N., "Statistical features of irradiation following the Chernobyl accident", in Statistics of Human Exposure to Ionizing Radiation (Proc. CEC Workshop, Oxford, 2-4 April 1990) Radiat. Prot. Dosim. (to be published).

[9] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, "Optimization and Decision-Making in Radiological Protection", ICRP Publication 55, Pergamon Press, Oxford and New York (1989).

[10] LOMBARD, J., Proposition for Reference Values for the Cost of the Man-Sievert, CEPN Rep. No. 136 (April 1988) (in French).

[11] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection, Publication 60, Pergamon Press, Oxford and New York (1990).

[12] NUCLEAR ENERGY AGENCY OF THE OECD, Protection of Population in Case of Nuclear Accident, OECD/NEA, Paris (1990).

[13] NUCLEAR REGULATORY COMMISSION, Optimization of Public and Occupational Radiation Protection at Nuclear Power Plants, prepared for the US NRC, Rep. NUREG/CR-3665, Office of Standards Development, Washington, DC (September 1984).

[14] CLARK, M.J., FLEISHMAN, A.B., The Cost of Collective Dose Equivalent, CEA/NRPB/UKAEA Joint Technical Meeting on Cost-Benefit Analysis, Chilton, 29–30 March (1979).

[15] UNITED NATIONS, Sources, Effects and Risks of Ionizing Radiation (Report to the General Assembly), Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), E.8IX.7, UN, New York (1988).

[16] WORLD HEALTH ORGANIZATION, 'World Health Statistics Annual', Geneva (1989).

[17] DARBY, S., FAGNANI, F., HUBERT, P., SCHNEIDER, T., THOMAS, D., VAETH, M., WEISS, K., Measures of Lifetime Detriment from Radiation Exposures: Principles and Methods', Rep. CEPN No. 175, Centre d'étude sur l'évaluation de la protection dans le domaine nucléaire, Fontenay-aux-Roses (June 1990).

Part G

Annex 3

The Decision Conferences in the USSR

3–1. Introduction

From the outset it was appreciated in planning the evaluation of the protective measures adopted within the USSR that it would not be adequate to concentrate on the radiological protection aspects alone. Social and political factors would also drive the decision making. Accordingly, the Project description, as approved by the International Advisory Committee, included the use of multiattribute decision aiding techniques to investigate and capture these factors. As the Project evolved, the specification of the manner in which these techniques were to be used was progressively clarified until it was decided to hold four decision conferences, one each in the BSSR, the RSFSR and the UkrSSR, and one at All-Union level. The purposes of these decision conferences were:

- To enable some of the decision problems related to the Chernobyl accident to be structured efficiently and thus to clarify and elucidate issues;
- To summarize for the Project the key socio-economic and political factors that together with the physical, radiological and medical evidence influence the relocation and protective measures taken in the Republics;
- To illustrate the use and potential benefits of formal decision analysis methods and the techniques of decision conferences for the resolution of complex issues.

Subsequently, a fifth decision conference was held at which representatives from the earlier conferences met to build a summary model that represented the main issues and concerns. This annex describes the running of these decision conferences, the principal conclusions that may be drawn from the evidence which was elicited, and the direction in which consensus may evolve between the many parties to the decisions concerning protective and relocation measures in the USSR.

3–2. Decision Conferences

There are many forms of multiattribute decision aiding techniques (see, e.g. [1–3]), and a decision had to be made on which techniques to use and in what manner they should be applied. Decision conferences using additive value models seemed to offer the best way forward. They have many advantages over other ways of applying decision analysis. In particular, decision conferences are very effective at stimulating discussion and eliciting issues. Thus they seemed ideally suited to achieve the objectives of the task. Also decision conferences are short, intensive events which fitted well with the tight time-scales of the Project. Briefly, a decision conference is essentially a two-day event at which a group of people who are responsible for formulating and implementing policy meet to discuss all the major issues and concerns that relate to the problem at hand and to carry out a decision analysis to help them choose a way forward. To help them in their task they are assisted by a facilitator and an analyst, who attend to the process and decision modelling, leaving the group free to concentrate on the content of their problem. During a decision conference, the facilitator and analyst construct a decision model of the choice facing the group. In point of fact they typically construct a sequence of models, each a revision or development of the previous, which keep pace with the group's evolving view of the problem [4, 5]. The assessment of the judgemental inputs necessary for each model leads to much discussion within the group. It is this ability to stimulate focused discussion within the group that is one of its prime strengths. In discussing the value to be assigned to a particular input, the group focuses its attention on single issues, avoiding the pitfalls and confusions of simultaneously discussing many issues. Although in many cases consensus emerges on the values to be used, there will inevitably be disagreement in others. During the sensitivity analysis phase the results of the model can be examined using a wide range of numerical values for the judgements upon which the group cannot agree. Often it is found that the final ranking of alternatives is unchanged or insignificantly affected by variations across the whole range of numerical values proposed by members. In some cases, of course, significant changes in the ranking do occur and the group must discuss further the numerical values that they will use. Again the effect is to focus their discussion. The process is described in more detail in the appendix to Annex 3.

In a strict sense, the Project did not organize five decision conferences, but rather five events with the structure of decision conferences. The prime objectives, given above, were to structure the decision problems and elucidate and clarify issues, thus summarizing for the Project all the factors driving the decisions relating to relocation and other protective measures. Also there was the intention to illustrate the use and potential benefits of the technique. There was no intention to guide the decision making of the various authorities at Republic or All-Union level, which would be the main objective of any true decision conference.

3–3. Organization of the Decision Conferences

The success of any decision conference depends largely on the selection of appropriate participants and their ability to commit their time fully for two days. Ideally, the number of participants should be in the range 10–15 and only in exceptional circumstances should the number exceed 15.

The choice of participants was a matter for the relevant Republic or All-Union authorities. They were requested to select participants who had responsibility for the development or formulation of the policy or policies relevant to the remedial measures in contaminated settlements and, in particular, the question of relocation and associated criteria. If possible, they were asked to involve relevant members of the Council of Ministers responsible for dealing with the effects of the Chernobyl accident and similar individuals charged with this responsibility at regional level. It was also desirable for these officials to be accompanied by their main scientific or technical advisers and for there to be some representation from those with the responsibility for the practical implementation of policy on remedial measures. Representation was also sought from various Academies. The same general guidelines were followed for the final conference, at which representatives from each of the earlier conferences took part.

Each participant was sent a calling note which described the objectives of the event and gave some details of the working of decision conferences. It was important that these calling notes set the right atmosphere for the conferences. The informality and the way of working differ markedly from the formality of meetings at which participants often begin with prepared statements, and at which all discussion takes place via a chairman.

The authorities in the Republics and at All-Union level were asked to provide a room large enough to accommodate all the participants comfortably. Seating was to be in a semicircle so that participants could see each other during discussion. It must be said that before the events took place this latter requirement was seen by many to be irrelevant. However, the success of the decision conferences at stimulating free and wide ranging discussion with the participants interacting directly rather than through a chairman argues for its relevance.

Liquid crystal diode (LCD) panels for overhead projection were used to display the decision models, which were built using the HIVIEW [6] and, in one case, VISA [1] software packages. Flip charts were also used to capture key ideas.

Simultaneous interpretation was not used. Sequential interpretation gives far more scope for ensuring that all nuances of meaning are faithfully translated. Moreover, although it slowed one aspect of the proceedings, the pauses gave all those present time for thought and reflection, and it is arguable that the overall effectiveness of the events was improved.

Draft reports on each of the first four conferences were produced within a few days of each event: in two of the four cases overnight. Each of these reports was agreed to be confidential to the participants at the event, except that the report could be used — but not included verbatim — in writing the Technical Report. Confidentiality is important in decision conferences because it encourages a free dialogue of ideas and an unfettered discussion of the issues and concerns. Moreover, the numbers that are used in any model are typically far from precise. They are judgements that reflect the group's thinking. Presenting such numbers to others who did not attend the decision conference and who are not fully aware of the context in which they were generated can lead to misunderstanding. A separate report on the fifth conference was not produced. Qualitative aspects of the model built and the conclusions reached are incorporated into the present annex.

3–4. Key Issues and Concerns

Each decision conference began with a general discussion of the key issues and concerns that were seen as relevant to decisions concerning relocation and other protective measures which may be taken to improve the living conditions of people in the affected areas.

Scale of the accident. The scale of the accident was emphasized. A large area had been affected, as had an enormous number of people. Resources required for the work in the Chernobyl region were a drain on those needed elsewhere. The problems arising from the accident must be seen in the long term, perhaps over decades.

Need for safe living concept. There is a perceived need for a concept of 'safe living'. However, while the conferences felt that appropriate future strategies must be based on a concept of acceptable risk, the concept of risk is not readily accepted by politicians or the public. There was a need for international standards to be applied. A dose limit of 0.1 rem (1 mSv) per year is used as a planning figure for the maximum exposure that could result from a nuclear installation in normal conditions. Both in the conferences and elsewhere in the USSR, there was a feeling that this same figure should be used as a lower limit for developing strategies for applying protective measures. This is not to say that protective measures would be automatic for those living in regions where the dose was above 0.1 rem (1 mSv) per year: far from it. Rather that there was no case for considering applying any protective measures at dose levels below this. There was also a common perception that identifying a safe living concept was a problem for scientists alone. The implication that such a concept involves value judgements and hence requires inputs from politicians and the public was not well appreciated. This is particularly important when conflicting scientific voices are heard.

Health problems. The initial protective measures in the affected regions were judged not to improve substantially the population's health, possibly because they were implemented either incompletely or with delay; and they were generally disliked because of the restrictions placed on life-styles. An increase in health problems was reported to have been observed in the affected regions: for example, changes in blood, hypothyroidism in children, severity of chronic illnesses and risks in pregnancy. Whether this increase was due directly to the Chernobyl accident, a consequence of the stress brought about by the accident, or simply an artefact of increased medical observation and investigation was a matter of some debate.

Stress. The risk of health effects caused by the Chernobyl accident is low. However, there are more serious factors which need addressing, including social stress and instability and the health problems resulting from these.

Relocation. Relocation brings sociopolitical problems, including problems concerning local culture and 'ethnic homogeneity'. Some people do not like to be relocated because of the importance they attach to their homeland. Also relocation in itself is stressful and is believed to cause increased morbidity and mortality.

Lack of trust and understanding. The population no longer credited any information that it received, including that given by doctors; primarily because first it received little, then suddenly much specialized and often contradictory technical information. People believe rumour before they trust official channels. The public believes that criteria in terms of ground contamination are appropriate for making decisions on protective measures, yet there is no simple relationship between ground contamination and dose. The fallout has a speckled pattern, but people do not understand this. It is impossible to move some families without moving those nearby. There is substantial pressure for a lower criterion to be adopted for relocation than at present, but this pressure is largely based on misinformation and fear.

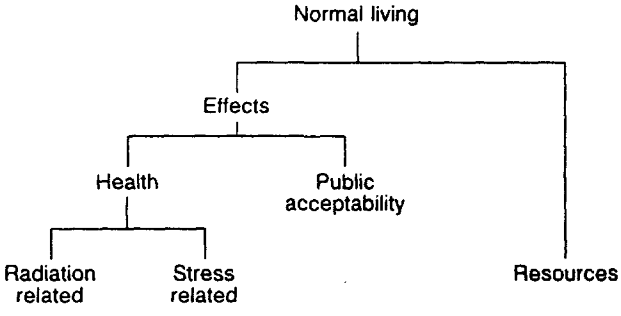


FIG. 3-1. Attribute hierarchy.

Sarcophagus. In the public's perception, the damaged reactor and the continued operation of Units 1, 2 and 3 remain a danger, and this adds to the stress in the populations living near Chernobyl. Moreover, more needs to be done to the sarcophagus to ensure its long term safety.

Water pollution. So far there has been no significant water pollution, but it remained a possibility.

3-5. Attribute Hierarchies

There was much consensus between the first four conferences concerning the attributes or criteria against which strategies should be evaluated. Each conference developed an attribute hierarchy which, in essence, had the general form shown in Fig. 3-1. Naturally, the hierarchies used in the conferences differed in many details but in substance there was little difference. It should also be said that there are no right or wrong hierarchies. Experience with decision conferences has shown that within broad limits the hierarchy used by a particular group can be chosen according to their taste: it reflects their way of working as well as the major issues within their problem.

The effect on health provided by a strategy was generally seen as having two components: the effect it had in reducing cancers and other radiological consequences of the Chernobyl accident and the effect it had in terms of increasing or decreasing stress.

The radiation related effects, both somatic and genetic, could be estimated from the dose saved in the protected and relocated populations. At the conferences, precise data were not available in a form suitable to estimate quickly the dose saved by each strategy. Accordingly, approximations and judgement were used. There was no consensus between the conferences on whether the saving in dose should be evaluated in terms of the number of (fatal) cancers saved or total years of life expectancy saved.

The stress related health effects were a subject of much debate in all the conferences. There are three separate populations to consider for each strategy: those neither protected nor relocated; those subject to protective measures other than relocation; and those relocated.

All agreed that relocation increases stress significantly and hence increases morbidity and mortality in the relocated population. There was no consensus between the conferences as to whether sympathetically applied protective measures would increase or decrease stress. There was agreement that current measures did not reduce stress, but some argued that future measures could be implemented in a manner to reduce stress.

It should be noted that stress effects are likely to be significant in evaluating strategies. At one conference an attempt was made to quantify the adverse health impact of relocation. Estimates were made of the number of people whose life expectancy would be reduced as a result of the stress of living under protective measures. On the basis of these estimates, life shortening from stress was, for each of the strategies investigated, found to exceed that predicted to arise from the radiation exposure which was being averted by the application of the protective measures. While these provisional estimates were emphasized as being very rough, they do indicate the importance of stress effects in developing well conceived policies on intervention.

Public acceptability of the strategies was felt to be an important attribute in all decision conferences. Many dimensions of this attribute were identified. Firstly, there was the acceptability to the affected populations and the acceptability to the populations in the unaffected parts of the Republics and elsewhere in the USSR. There was the political acceptability of any strategy, both in the Republics and at the All-Union level. Two of the conferences also included in their hierarchy an attribute of quality of life, which correlated in some sense with the concept of acceptability. All decision conferences concluded — and the decision models confirmed — that substantially different decisions would be taken if no account were taken of public acceptability.

The different resources required or costs are clearly an important factor in choosing between strategies. Several differences occurred between conferences in how this might be evaluated. Some felt that it was sufficient to use the cost in roubles. Others considered that an extra attribute needed to be included to measure the relative feasibility of the strategies, arguing that allocating money is not the same as providing medical services and the construction industry with all the physical and manpower resources that a strategy would require. There was also the related question of how large an effort the Republics' economies could absorb, independently of the source of the money.

Further differences occurred between the conferences in relation to the costs per person of relocation and protection. Relocation costs used ranged from 25 000 roubles per person to 45 000 roubles per person. Costs of protective measures ranged from 1000 roubles to 10 000 roubles per person per year. There were also differences in the choice of time horizon: some conferences evaluated strategies over three years, others over five.

3–6. Form of Strategies

All decision conferences discussed strategies for implementing relocation and other protective measures (e.g. food restrictions) which had a common form, defined by two dose levels, **a** and **b**. This form is illustrated in Fig. 3–2. All people receiving projected doses in excess of the upper dose level would be relocated (or, at least, offered relocation). Those receiving projected doses between the upper and lower dose levels would be subject to protective measures other than relocation and might also receive some compensation. All those receiving doses below the lower dose level would not be subject to any protective measures.

The upper and lower levels, **a** and **b**, in these strategies should not be thought of as any form of 'dose limit for safe living'. They are purely mechanisms for partitioning the population affected by the Chernobyl accident into three groups: one group to whom no measures will be applied; one group to whom protective measures other than relocation will be applied; and one group who will be relocated.

There was no consistency between the conferences — or, indeed, within any single conference — as to the convention used in expressing the dose levels: e.g. lifetime dose since 1986, lifetime dose since 1990, annual dose for 1991, average annual dose in the years 1991–1995, whether the upper level of dose should take account of any protective measures which may have been applied, or whether the doses are estimated realistically or contain some element of conservatism. Whatever convention is adopted, it is imperative that the dose quantities and the way they are to be estimated are defined unambiguously. To some extent the dose convention adopted is academic as reasonably accurate transformations can be made between the different quantities; the form of expression may, however, affect how it is perceived and accepted. There is, none the less, one conceptual matter of substance that warrants further consideration. This concerns whether the dose quantity should include previous doses (pre-1990) or only those yet to be received, i.e. only those doses which can be affected by a strategy. There seems little point in discussing doses already incurred or committed.

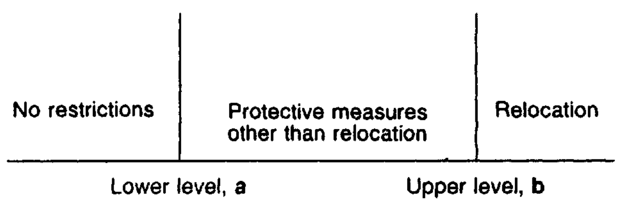


FIG. 3–2. Form of strategies proposed.

A common notation for the strategies was developed during the conferences:

SLa-b Relocate those living in settlements where the lifetime dose to a child born in 1986 exceeds **b** rem[1]; provide protective measures other than relocation for those living in settlements where the lifetime dose to a child born in 1986 lies between **a** and **b** rem; provide no protective measures otherwise.

SAa-b Relocate those living in settlements where the annual dose to a child in its first year of life exceeds **b** rem/year; provide protective measures other than relocation for settlements where the annual dose to a child in its first year of life lies between **a** and **b** rem/year; provide no protective measures otherwise.

SLa-NoR Provide protective measures other than relocation for those living in settlements where the lifetime dose to a child born in 1986 exceeds **a** rem; provide no protective measures otherwise. No one would be relocated.

SAa-NoR Provide protective measures other than relocation for those living in settlements where the annual dose to a child in its first year of life exceeds **a** rem/year; provide no protective measures otherwise. No one would be relocated.

Note that **SLa-a** and **SAa-a** are taken to denote strategies in which either relocation is applied (for doses greater than **a**) or no protective measures are applied (for doses less than **a**).

The strategies evaluated[2] in each of the decision conferences were as follows.

BSSR:

SA0.03-0.1, SA0.1-0.1, SA0.1-0.2, SA0.1-0.3, SA00.1-0.4, SA0.1-0.5, SL7-35

RSFSR:

SA0.1-0.1, SA0.1-0.3, SA0.1-0.5, SA0.3-0.5, SA0.3-1.0, SA0.5-0.5, SA0.5-1.0

UkrSSR:

SL7-7, SL7-15, SL7-20, SL7-24, SL7-35, SL7-70

All-Union:

SL7-35, SA0.1-0.5, SL20-50, SA0.1-1.0, SA0.5-5.0, SL35-35, SL7-NoR, SA0.1-NoR

[Caution should be exercised in making comparisons between the strategies analysed in each conference because the dose levels indicated may not be the same — e.g. they may be realistic or conservative, have different periods of evaluation, etc.]

At all the decision conferences it was emphasized that, while some of the strategies might be declared clearly unacceptable at the outset, they were, nevertheless, included in the analysis so that the reasons for their unacceptability could be elucidated.

It may be seen that although there are clear differences between these lists, roughly the same range of strategies were considered at each conference.

3–7. Fifth Decision Conference

It was decided, in the light of the experience of the four decision conferences, to hold a fifth conference at which representatives from the earlier conferences would meet to build a summary model that represented the main issues and concerns. The earlier conferences had been very successful in eliciting issues and structuring the problem, but some of the data used were not common between the conferences. Also, as noted above, there were several unresolved issues such as the convention used to express dose levels. Thus it was felt that a joint meeting which built upon a common database and which agreed on a common resolution of several outstanding issues would greatly enhance the value of the final report and the series of decision conferences themselves.

Accordingly, a common database was prepared by the Project based upon dosimetric and economic data collected from official documents and in discussions with Soviet scientists. These data enabled estimates to be made of the numbers of people affected by each of the strategies evaluated, of the costs of the possible strategies and of the collective dose saved.

The group decided to evaluate four strategies of the form described above (Fig. 3–2):

SL2-2, SL2-10, SL2-20, SL2-40.

The convention used to express the dose levels was: lifetime dose in rems from 1990 to 2060 assuming that no protective measures were applied. There was much debate as to whether this was the most appropriate

[1] 100 rem = 1 Sv.

[2] In fact, at all decision conferences other strategies were also discussed. The ones listed here are those evaluated in the final model.

TABLE 3–1. Numbers of People Subject to Protective Measures and Relocation and the Collective Dose Saved

Strategy	Number relocated (1000s)	Number protected (1000s)	Collective dose saved (man·Sv)
SL2-2	706	0	50 000
SL2-10	159	546	26 400
SL2-20	20	686	10 000
SL2-40	3	703	5 900

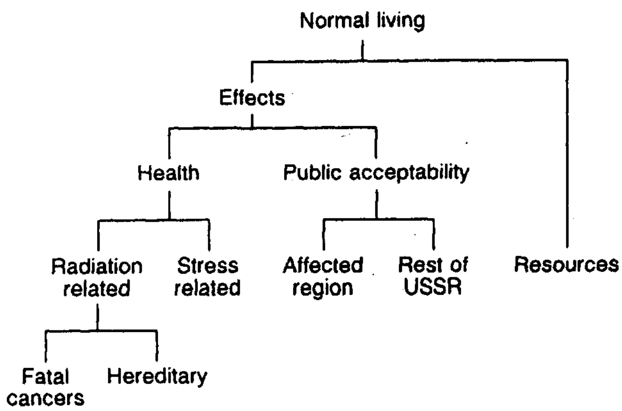


FIG. 3–3. Attribute hierarchy used at the fifth decision conference.

convention: many of the group felt that lifetime dose 1986–2056 should be used. Also there was some feeling that level **b** should be the lifetime dose after protective measures other than relocation had been applied. However, the debate was resolved pragmatically by noting that data were only readily available for lifetime dose 1990–2060 assuming no protective measures. The dose levels can, however, be readily transformed into other quantities or conventions.

The numbers of people relocated and protected by other measures under these strategies are given in Table 3–1. Also given are the collective doses saved.

The attribute hierarchy shown in Fig. 3–3 was used in the evaluation. This was developed from that shown in Fig. 3–1 by refining the radiation related health effects and the public acceptability attributes.

The radiation related attribute was evaluated in terms of the number of health effects avoided rather than life expectancy changes. The attribute was split into two further attributes representing the number of fatal cancers and the number of hereditary effects avoided, these being calculated from estimates of the collective dose saved. The number of fatal cancers avoided by a strategy was inflated by the factor 1.3 to allow for the morbidity arising from non-fatal cancers. This led to estimates of the number of fatal cancers avoided (inflated for the morbidity saving arising from the non-fatal cancers) and the number of hereditary effects avoided as in Table 3–2.

In weighting together the number of fatal cancers avoided and the number of hereditary effects avoided, it was agreed that 1 hereditary effect should be equated with 3 fatal cancers.

The stress related health effects were assessed judgementally and holistically: no attempt was made to assess these effects separately for different populations. It was agreed that stress led to both morbidity and mortality effects, reducing the general health and well-being of the population. Overall it was felt that **SL2-20** would reduce stress the most. This was because the group believed that setting the level for relocation at 20 rem (200 mSv) was acceptable to both scientists and politicians. It should be possible, therefore, to explain the strategy to the population in a consistent, non-controversial manner that would calm their fears and reduce stress considerably. Using similar arguments, it was believed that **SL2-10** would be slightly less effective than **SL2-20** in reducing stress; and **SL2-40** much less effective. The strategy **SL2-2** would be much the least effective, not only because of the argument given above, but also because it would lead to the relocation of over 700 thousand people with all the stress that this would engender.

Overall, the weight placed on the stress attribute was about twice that placed on the radiation related effects.

The public acceptability attribute was split into two: the acceptability in the affected region and the acceptability in the rest of the USSR. For the case of the rest

TABLE 3–2. Numbers of Fatal Cancers and Hereditary Effects Avoided for the Strategies over the Period 1990–2060

Strategy	Fatal cancers avoided	Hereditary effects avoided
SL2-2	3200	500
SL2-10	1700	260
SL2-20	650	100
SL2-40	380	60

of the USSR, it was agreed that the ordering of the strategies should be:

1st — **SL2-20**; 2nd — **SL2-40**; 3rd — **SL2-10**; 4th — **SL2-2**.

The scores that were assigned also reflected the view that **SL2-40** would be nearly as acceptable as **SL2-20**, and both of these would be considerably more acceptable than **SL2-10** and **SL2-2**. The arguments that underlay these judgements related to the complex balance between humanitarian and economic values.

For the case of public acceptability in the affected region there was less agreement. The model was initially explored with the ordering:

1st — **SL2-20**; 2nd — **SL2-10**; 3rd — **SL2-40**; 4th — **SL2-2**

with the scores assigned reflecting the view that **SL2-20** was only slightly more acceptable than **SL2-10**, but that both were considerably more acceptable than **SL2-40** and **SL2-2**. However, there was also a view held by some members of the group that within the affected region's population **SL2-2** would be by far the most acceptable strategy. As explained below, this alternative view was examined carefully during sensitivity analysis of the model.

The affected region and rest of the USSR attributes were weighted in the ratio 60:40; and overall the public acceptability attribute was given slightly more weight than the health attribute.

The resources attribute was taken to be the straight cost of the strategies in roubles assuming that on average relocation cost 40 600 roubles per person and that providing other protective measures and compensation cost 4000 roubles per person per annum. It was decided to cost the strategies over 5 years; thus the cost of providing protective measures over this period was 20 000 roubles per person. These costs lead to the following total costs in billions of roubles of the strategies:

SL2-2: 28
SL2-10: 17
SL2-20: 15
SL2-40: 14

To get an indication of the weight that should be applied to the resources attribute, it was noted that a saving of 1 man·rem was commonly taken to be equivalent to about 100 roubles. The radiation related attribute scale had a length corresponding to a saving which translated to an equivalent length of 0.44 billion roubles. The resources attribute scale is about 14 billion roubles long; i.e. the difference between the costs of **SL2-2** and **SL2-40** is 14 billion roubles. Thus a rough weighting factor to be applied to bring the resources and radiation related attributes onto a common scale could be derived. The weightings between the radiation related attributes and the stress and public acceptability attributes were found by 'swing weighting' (see the appendix to Annex 3). This enabled a weighting between the attribute effects and resources to be deduced.

The model was subjected to extensive sensitivity analysis and the conclusions described below were remarkably robust to reasonable changes in the weights and scores.

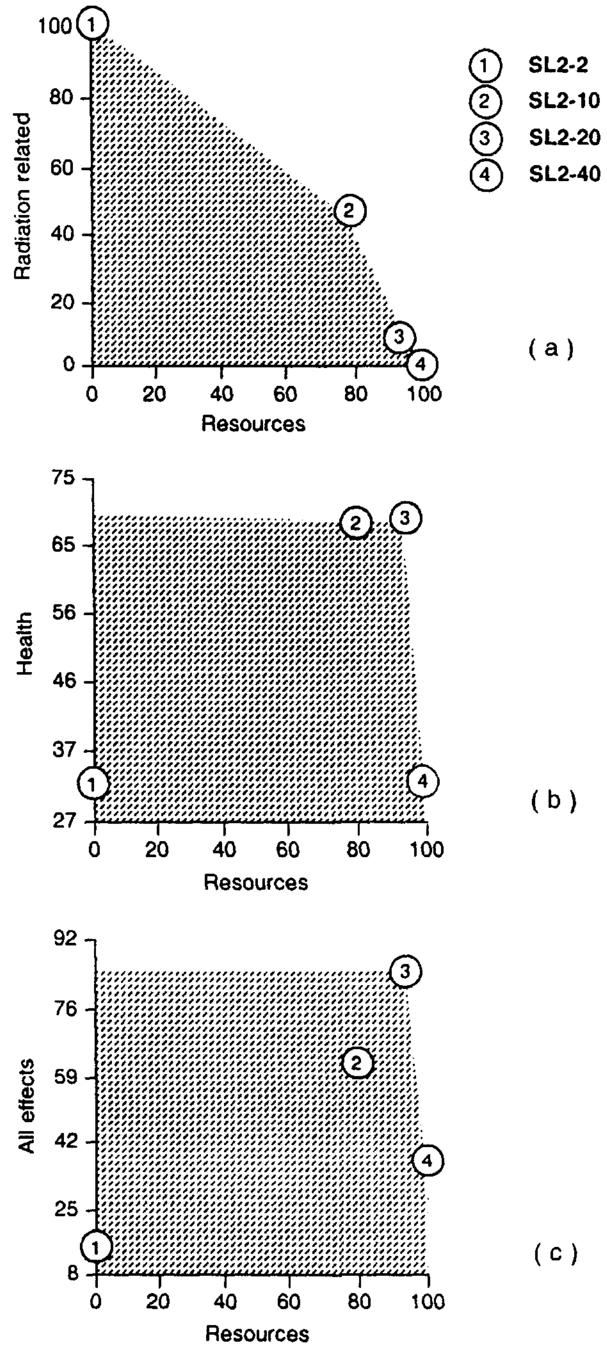


FIG. 3–4. Plots of effects against resources: (a) radiation related effects; (b) health effects; (c) all effects.

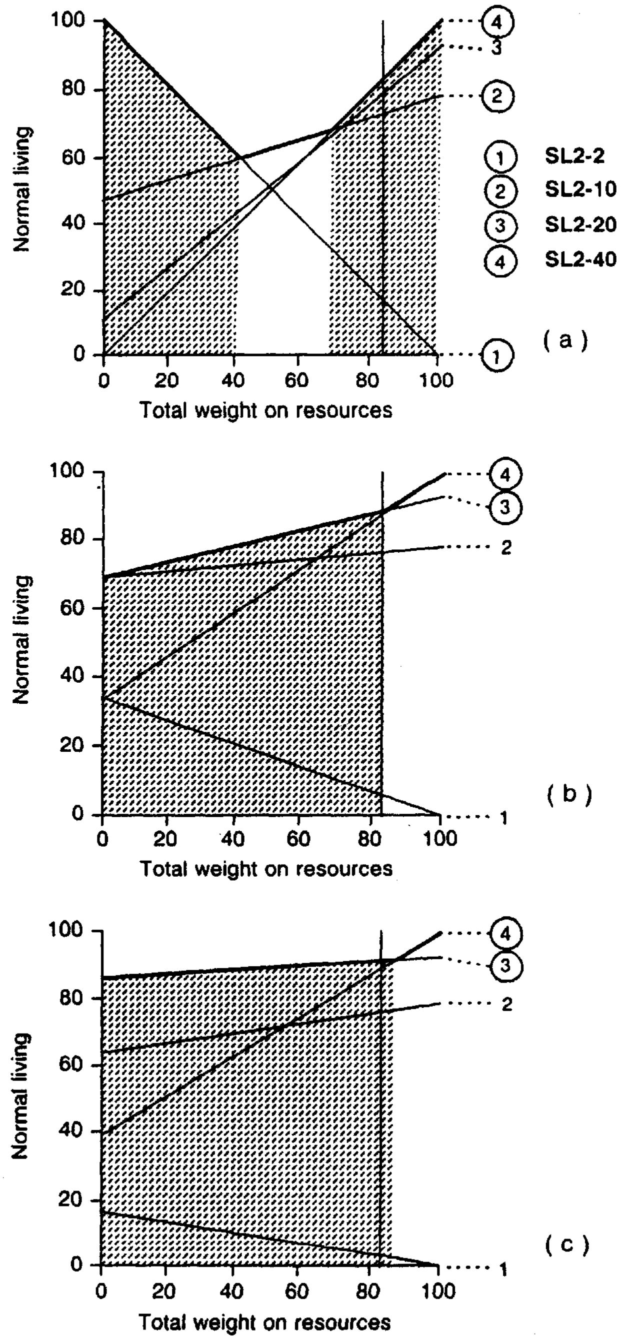


FIG. 3-5. Sensitivity plots: (a) neither stress nor public acceptability included; (b) public acceptability not included; (c) all effects included.

Figure 3–4 shows a sequence of plots of effects against the costs of the strategies. In Fig. 3–4(a) the radiation related effects are plotted against resources, i.e. the costs of the strategies. Note first that the resources scale is a preference scale (as, indeed, are all the other scales in the model). This means that greater scores correspond to increasing preference and, in this case, decreasing cost. Moreover, conventionally all scales are renormalized to have a range 0–100. Thus on the resources scale, here the horizontal axis, **SL2-40** has a score of 100, since it is the cheapest, whereas **SL2-2** has a score of 0 since it is the most expensive. The vertical axis gives the scores for the strategies on the radiation related effects, again renormalized to a 0–100 scale with the most preferred strategy **SL2-2** under this attribute scoring 100.

Figure 3–4(b) gives a similar plot in which the vertical axis now represents the overall health effects, given by combining radiation related and stress scales. Figure 3–4(c) again differs in the vertical scale, in this case the attribute effects which arises from combining the radiation related, stress and public acceptability scales.

In each of Figs 3–4(a)–3–4(c) 'ideal' strategies would lie in the top right hand corner, because such strategies would score 100 on both the horizontal and vertical preference scales. When stress and public acceptability are included as in Figs 3–4(b) and 3–4(c), it may be seen that **SL2-20** (strategy 3) moves towards the top right hand corner.

Figures 3–5(a) to 3–5(c) show sensitivity plots of the form described in the appendix. The vertical line is set to the weight on resources which corresponds to the approximate equivalence of 100 roubles with 1 man·rem saved.

Figure 3–5(a) gives the sensitivity plot when zero weight is applied to both the stress and public acceptability attributes. With the weight on resources corresponding to the equivalence of a saving of 1 man·rem with 100 roubles, **SL2-40** is optimal. As the weight on resources is decreased (i.e. as the number of roubles per man·rem is increased), **SL2-10** and then **SL2-2** become optimal. In a very rough way, Fig. 3–5(a) corresponds to a simple cost-benefit analysis of the strategies which trades off the radiological protection benefits against the resources required.

Figure 3–5(b) shows the same sensitivity plot when stress is given its assessed weight, but public acceptability is still given zero weight. **SL2-20** is now optimal, but only just so. If the weight on resources is increased very slightly, then **SL2-40** becomes optimal. This can be seen by the fact that the vertical line representing the weight on resources given by the equivalence of a saving of 1 man·rem with 100 roubles is right on the boundary between the range of values for which **SL2-20** is optimal and the range for which **SL2-40** is optimal. Decreasing the weight on resources causes a shift further into the range for which **SL2-20** is optimal. Note that with the weight on stress included, **SL2-2** and **SL2-10** are not optimal for any value of the weight on resources.

Figure 3–5(c) shows the same sensitivity plot when public acceptability is given its assessed weight. **SL2-20** remains optimal over a wider range of weights on the resources attribute. Furthermore, with the weight on resources set at the value implied by the equivalence of a saving of 1 man·rem with 100 roubles, **SL2-20** is

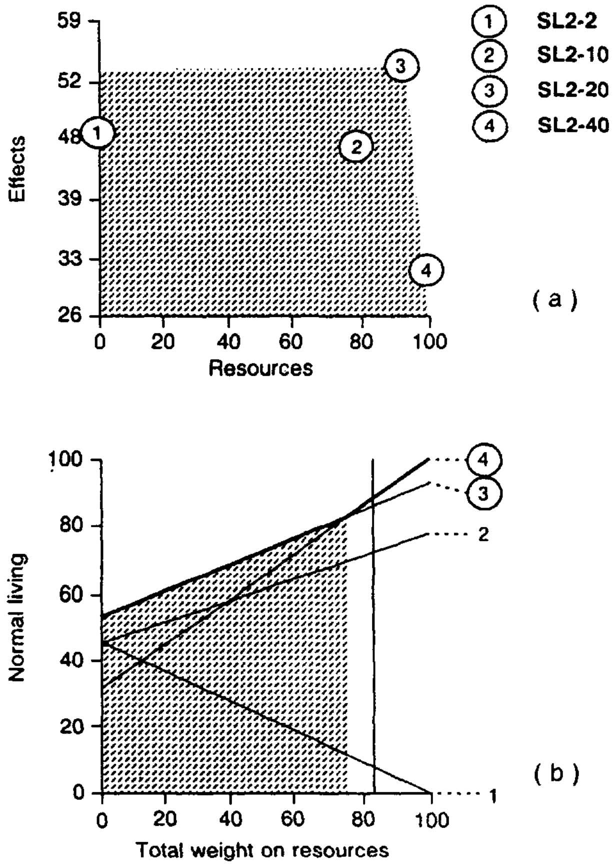


FIG. 3–6. Sensitivity plots corresponding to the case where SL2-2 is most acceptable to those living in the affected region.

optimal and remains optimal if the weight is slightly increased.

From Figs 3–4 and 3–5 it is clear that introducing the stress and public acceptability attributes into the model suggests that **SL2-20** is the preferred strategy in place of **SL2-40**, which is the strategy that a simple trade-off between costs and radiation effects would suggest.

Much the same conclusions may be drawn if the scores on the public acceptability in the affected region are changed to make **SL2-2** the preferred strategy. Figure 3–6 gives plots corresponding to Figs 3–4(c) and 3–5(c) for this model. Now it is not the case that **SL2-20** is the preferred strategy when stress and public acceptability are included in the evaluation: the model suggests that **SL2-40** is. However, this observation is relatively less important than the observation that **SL2-2** is suggested as the most preferred strategy even when it receives a score of 100 on the public acceptability scale and **SL2-20** and **SL2-40** are both scored at 0, as they are in the model which gives Fig. 3–6. In other words, with the weight currently on public acceptability, neither **SL2-2** nor **SL2-10** can be made optimal simply by giving them a high public acceptability score. Sensitivity analysis of the weight on public acceptability confirmed that this observation holds for all values of this weight which the group felt reasonable.

Thus the main conclusion that may be drawn from the model is that, if only the radiation related and resources attributes are included, then **SL2-40** would be the strategy that provides the best balance. However, once the stress and public acceptability attributes are included, it becomes quite clear that **SL2-20** is the strategy that provides the best balance. This is shown particularly clearly by the sequence of plots in Figs 3–4 and 3–5.

3–8. General Conclusions

In all important respects the conferences achieved the objectives set for them. They achieved a considerable consensus in terms of the structure of the decision model used, the evaluation criteria and also the general form of relocation and protection strategies being considered. Many issues were clarified and summarized. In particular, it was clear that the medical effects arising from stress could not be ignored in the decision making. Moreover, issues relating to public acceptability were prime driving forces in evaluating strategies. The reduction brought about in radiological effects was of secondary importance compared with public acceptability. There was also considerable consensus on the current lack of trust and the amount of misinformation and rumour circulating in the population, which in turn affects the public acceptability of any strategy.

All this was shown particularly clearly by the model explored in the fifth decision conference and discussed above; but the same conclusion could be drawn from any of the models developed in the earlier four conferences.

3–9. Summary

The early countermeasures taken were based on intervention levels of projected doses to avoid deterministic effects and to reduce stochastic effects as well. The basic principles were in good agreement with the recommendations given by international organizations.

This reduction of the temporary dose limits (100 mSv in 1986, 30 mSv in 1987, 25 mSv in 1988 and 1989) might have been based on the practical necessity of distributing the relocation of people over a time span larger than the first year (1986). As a result of the radioactive decay and environmental decontamination processes, people not relocated in 1986 (because the dose received during that year was evaluated to be lower than 100 mSv) were supposed to remain below the total dose up until 1990 (180 mSv) if the dose evaluated for 1987 was lower than 30 mSv, and so on for the following two years. Using dose limits for relocation does not address the option of bringing people back to the area and this might have the implication that the relocation will be for ever. A dose rate criterion for relocation will automatically address the problem of resettlement.

A lifetime dose limit of 350 mSv has been recommended by the USSR National Commission on Radiation Protection (NCRP) as a relocation criterion but it was not accepted and was therefore modified in the BSSR and UkrSSR. In these Republics, relocation was considered also below the lifetime dose limit, in fact all the way down to a dose of 70 mSv in a lifetime. In the BSSR, reference is also made to the need to comply with the 1 mSv/a dose limit recommended by the ICRP for the population in planned situations. The misconceptions in the use of dose limits for intervention are very difficult to understand for people outside the radiation protection community. Anyhow, such an approach must be criticized as being inconsistent with the basic radiation protection philosophy for accident situations. The annual average risk corresponding to the lifetime dose limit of 70–350 mSv is of the order of 10^{-5}–10^{-4} a^{-1}. Such a risk is comparable with many of the risks associated with everyday life. An annual risk of the order 10^{-5}–10^{-4} a^{-1} could not justify such a disruptive measure as relocation on radiation protection grounds alone.

A projected dose of 350 mSv in 70 years appears to be a very ambitious level of action, and a higher intervention level for disruptive countermeasures would be perfectly acceptable if justified and optimized. In other words, the NCRP level might be recommended as an intervention level only for such countermeasures as are very easy to implement, but not for disruptive interventions. For these extreme countermeasures, much higher intervention levels could be applied when only radiation protection grounds are considered.

The use of dose limits recommended by the ICRP for planned situations or of any other predetermined dose limit as the basis for intervention in the strict controlled zones in the USSR might involve measures that would be out of all proportion to the benefit obtained. The annual effective doses from radon in houses are, in many countries, in the range of 1–10 mSv/a. The doses from radon in the USSR will probably be in the same range. A relocation criterion of 70 mSv/70 a (1 mSv/a on average) as recommended by the authorities in the BSSR might easily cause the relocated people to receive a higher total annual dose than before relocation. In such cases, relocation is not justified even on a dose to dose comparison, regardless of the economic and social costs. In other words, allocating the resources to reduce radiation doses from radon instead of to reduce the doses due to the Chernobyl accident would probably result in a much larger collective dose reduction and, consequently, a much larger improvement in the health conditions of the population.

Countermeasures are normally introduced to reduce future doses that would otherwise be received in order to reduce certain health effects. In the late phase, the measures will only limit the expected number of late stochastic effects in proportion to the collective dose averted by the remedial actions. They will not have any influence on the expected number of cancer cases caused by doses received before the intervention. The inclusion of doses received in the past in the 350 mSv intervention level or lifetime dose limit is therefore in disagreement with the basic principles for radiation protection in accident (pre-existing) situations but might be in agreement with the assumptions made by the USSR authorities on the existence of a 'safe level'. However, doses received in the past will affect the distribution of the individual risk attributed to radiation in the irradiated population.

Projected doses should be calculated from measured dose rates and assumptions on dose rate reduction as a result of radioactive decay and other removal processes. Owing to the uncertainties of these assumptions, dose projections should be made only for shorter time periods and not for many years. The derived intervention level for relocation should therefore be expressed as a dose rate, for instance in mSv/month, above which relocation should be introduced and below which it can be terminated.

In the absence of any countermeasures in the controlled zones, i.e. areas with a surface contamination level of ^{137}Cs above 5 Ci/km^2 (185 kBq/m^2) inhabited by some 700 000 persons, the total collective lifetime dose (1990–2060) in all the Republics has been estimated to be in the order of 50 000 man·Sv. The ultimate goal of the countermeasures is hereby set: the saving of 2500 fatal cancers in, say, 40–50 years, corresponding to an average annual reduction of approximately 50 fatal cancers. For comparison, the annual spontaneous rate of fatal cancers in a USSR population of 700 000 people is of the order of 2000. The spontaneous annual cancer rate is thus around 40 times as high as the expected cancer rate from the Chernobyl accident.

In principle, the decision on the different criteria for intervention should be taken on the basis of radiological considerations. In practice, however, political and other related considerations will enter the decision making process. It is important that the decision maker should realize that if these are allowed to carry a greater weight than the radiological considerations, then either a lower degree of protection will be given to the public or unwarranted expenditure and unnecessary social and economic disruption may be incurred.

In the decision process in the Republics, it was clearly apparent that the reduction of the objective health effects was of minor importance for the introduction of countermeasures. The considerable expenditures that have been allocated to future countermeasures were grossly disproportionate with the savings in health effects that might be achieved by relocation and this was recognized by all. The factors which were driving their decisions were clearly more associated with the need to overcome the considerable public anxiety and fear that has built up over the past two years and the need to restore trust and to calm the situation. This will only be achievable if there is clear understanding of the non-radiological basis for further intervention and of the danger of further fuelling of anxiety by unwarranted restrictive action.

Inevitably, socioeconomic and political factors thus have become the most important ones in the decision process. This is in fact a vicious spiral. The population believes that the countermeasures are introduced with the prime purpose of protecting people against the objective health detriments and therefore presses the decision makers to reduce the intervention levels further down. The decision makers, on the other hand, striving for acceptance of their decisions to calm the population, will reduce the levels even when they are aware that this will not cause any significant improvement of the objective health conditions. This process will have a large risk of converging to extremely low intervention levels creating more harm than good because at the end it will result in a misallocation of scarce resources in the name of radiation protection.

Appendix

Decision Analysis and Decision Conferences

Purpose of Decision Analysis

What is the purpose of providing a decision analysis for a decision maker (DM) or, more usually, a group of decision makers? Surprising though it seems to many, the purpose is not to tell them what to decide. Rather it is to help the DMs to investigate and come to understand their beliefs and preferences in the context of the particular choice facing them. The language and formalism of decision analysis facilitates communication between DMs, focusing attention on critical issues and avoiding sterile debate of irrelevant matters. Through their greater understanding of the choice before them, of their own beliefs and preferences and of those of their colleagues, the DMs are able to make a better informed decision.

During the course of the analysis, the views of the DMs may — indeed probably will — change as their beliefs and preferences evolve. Too often a static view is taken. The beliefs and preferences of the DMs are assumed to be fixed and the purpose of the analysis taken to be that of capturing these within a model in order to predict and justify the ultimate choice. Far from it: decision analyses are dynamic, creative exercises. The DMs' beliefs, preferences and perceptions of the choice evolve as discussion and analysis elucidate issues they had not previously addressed. Phillips has articulated this view of decision analysis within a theory of requisite modelling [4] (see also [2, 3 and 7–12]).

This view of decision analysis has led to the development of the process of decision conferences.

Decision Conferences

There are times when complex and difficult issues arise that cause decision makers to pause and take stock of strategy. Sometimes straightforward discussion can lead to a clear decision and a view of a way forward, but the complexity of the issues and the uncertainties involved may be too great for simple discussion to resolve.

In such cases, it has become the practice in some organizations for the team responsible for the decision to meet together for a day or more away from their normal working environment to discuss and explore the issues. Often the teams are aided at these meetings by a facilitator. A facilitator is skilled in the process of group discussion, but seldom does he or she have any expertise in the context of the issues at hand, and even more seldom would he or she use such expertise in the discussion. The facilitator's role is to smooth the team's work, to help the process and make the team more productive, more creative. The content of the discussion comes entirely from the management team itself. They are the specialists in their organization's business. No one can know it as well as they.

Harvey-Jones [13, p. 282] describes how a facilitator has supported board meetings in ICI:

> "Some boards use external counsellors and consultants to help them in these discussions. ICI has, for the last fifteen years at least, had the services of one absolutely excellent American consultant, who has helped the board processes very greatly. He is not by any means an expert in ICI's business, nor would he set out to be, but he is an expert in helping the board to help itself, and to bring to the surface niggling problems. Very often he has been able to sort out process difficulties, or to suggest ways in which discussion problems or relationships can be dealt with."

It is very important that it is the team members who provide the content of the discussion, who identify opportunities, who create and evaluate the options to exploit these and who generate the action lists to implement their decisions. Through their total involvement in the creation of policy the team become fully committed to its implementation. They 'own' the policy. Moreover, because of their shared understanding of the reasons behind its adoption, they can explain the policy to others in the organization.

Decision conferences build upon this format by using the latest in information technology and decision analytic models to support the management team in its work.

Decision analytic models enable the team members to investigate the implications of their beliefs and their preferences. More importantly, the models are implemented in such a way that variations in the input judgements can be easily explored. Thus the team can discover both the importance of differences in opinions between the team members and the sensitivity of their conclusions to these differences and to those judgements of which they are most unsure.

The forms of decision analytic models which are commonly used in decision conferences are very simple. More often than not, they are based upon additive value theory (see below). The important attribute of these models is that they can be explained quickly and effectively to the team. The mathematics involved is no more than addition and multiplication. Within a short time of encountering the models, the team can draw valuable insights from their use.

A decision conference is generally a two-day event. Other time-scales are possible, but the inclusion of a night is more or less essential. In the evening the team are able to relax together and reflect on the progress and discussion so far. This reflection, together with the distance from the previous day's deliberations that a night's sleep brings, helps the team acquire a more mature perspective on the issues that concern them. Without the night's break the team may have 'second thoughts' soon after the conference ends, perhaps on the journey home, and much of the value of the event will be lost as their commitment to its conclusions fades.

The entire management team takes part in the conference, which concentrates entirely upon the strategic issues that led to its being called. There are no time-outs to consider peripheral matters 'while the team are together'. For that reason it is sensible to hold decision conferences away from the team's normal place(s) of work: perhaps a country hotel or a purpose built decision conference suite. The team members must make themselves unavailable to other demands on their time: they must clear their diaries for the conference. Ideally, too, they should deny themselves the use of the telephone.

The facilitator leads the meeting, guiding the discussion forward in a constructive fashion. He or she is expert in three areas: group dynamics, rational decision theory and communication. The expertise in group dynamics enables the facilitator to involve all participants in the debate. He or she contributes to the decision process by ensuring that the objectives and uncertainties are taken account of in a rational manner and by keeping the team task oriented. Throughout, the facilitator uses communication skills to ensure that all participants understand all the issues as they are identified.

The facilitator is assisted by an analyst and, possibly, a recorder. The analyst runs the software, generating decision analytic models of the issues as they arise, which help the team members to gain insight into the situation facing them. The recorder uses a word processor to record the development of the debate and the reasoning behind the judgements and decisions made by the management team. Because of the presence of the recorder, the team members are able to take a record of all the important conclusions and an action list with them at the conclusion of the conference. A full report follows in a matter of days. More and more, the roles of recorder and analyst are becoming identified. In the early days of decision conferences, the recorder and analyst needed a computer each; but with the advent of multitasking windowing environments it is possible for one person to fulfil both roles. Moreover, there are advantages if one person does. Inevitably, an analyst is far more closely involved with the process than a recorder and so better placed to record, for instance, the reasoning underlying a particular model.

Every decision conference is different. They evolve according to the needs of the team and not according to some fixed agenda. There are, however, common themes and patterns. The facilitator is always careful to ensure that the opening discussion is as wide ranging as possible. It is a rare decision conference in which a single focus for discussion emerges in the opening few minutes. Throughout the event, discussion returns again and again to the main issues as insights are gained and understanding shared. No model is taken as definitive: all are simply vehicles for exploring ideas. Phillips [4], who has done much to introduce decision conferences into the United Kingdom and elsewhere in Europe, terms the models *requisite* to capture this idea and distinguish the modelling from the more definitive modelling process found elsewhere in operational research and science.

Surprisingly, the analysis in decision conferences needs much less hard data than one would, at first, think. Strategies have to be costed: that is clear. But the costings need only be rough. It is a broad brush picture that the event seeks to create. Detail can be added at a later date.

Decision conferences are highly creative events. Typically, participants arrive as individuals, bemused and uncomfortable, unsure of a way forward. During the event they create, evaluate, modify and re-evaluate options, building a strategy which they all support. They leave as a committed team with a common purpose and understanding of the issues, ready to implement the strategy they have created.

Decision conferencing has been used with great success in:

- developing strategic options
- allocating budgets between the various divisions of an organization
- formulating organizational change
- developing industrial relations strategies
- evaluating competitive bids
- choosing investment strategies.

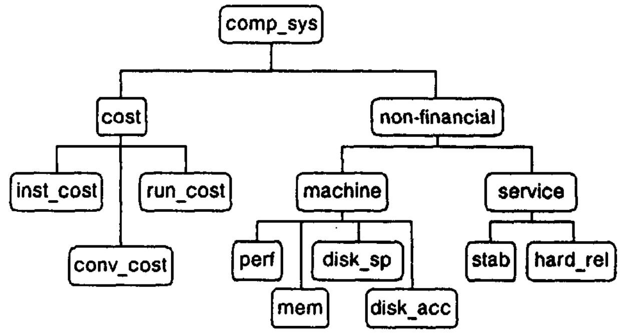


FIG. 3-7. Example of an attribute hierarchy.

Additive Value Theory

One of the most common decision analytic techniques is the evaluation of alternatives by means of additive value functions. A value function v(●) represents a DM's preferences between alternatives in the following sense. For any pair of alternatives, a and b:

$$v(a) \geq v(b) \qquad (1)$$

if and only if a is held to be at least as good as b. If a is strictly preferred to b, then strict inequality holds in (1). Thus v(●) assigns a higher number to the more preferred alternative.

Suppose that the alternatives in the decision problem are represented according to their levels on a number of attributes. For instance, in a problem relating to the installation of a new computer system the attributes might be: installation costs; conversion costs of software, databases, etc.; running costs; performance (MIPS); memory (Mb); diskspace (Gb); disk access times (μs); stability of supplier; and reliability of hardware (mtbf). In a real problem rather more attributes might be specified, but these will serve for illustration. Thus each possible computer system would be described by a vector of attribute levels:

comp_sys = (inst_cost, conv_cost, run_cost, perf, mem, disk_sp, disk_acc, stab, hard_rel) (2)

Thus a particular alternative might be:

HAL = (£1m, £0.8m, £0.5m, 25MIPS, 64Mb, 5.4Gb, 5μs, 70, 27d)

Note the attribute score of 70 for HAL on 'stab', the stability of supplier. There being no objective scale of measurement for such a quality, this would be a subjective assessment by the DM. We will return to such assessments shortly.

The set of attributes used in a problem are usually grouped together in a hierarchy. Figure 3-7 shows a possible hierarchy for this example. The hierarchy groups together the attributes in ways that:

- are suggestive cognitively and, therefore, helpful to the DM's understanding,
- help structure a subsequent sensitivity analysis.

The first point should be clear intuitively; we illustrate the latter point shortly.

Henceforth, we shall assume that all alternatives in a decision problem are represented as vectors of k attribute levels, writing alternatives as:

$$\mathbf{a} = (a_1, a_2, \ldots, a_k),$$

where a_i is the level achieved by alternative **a** on the i^{th} attribute.

In many cases the value function v(●) is a 'nice' function of these levels. In particular, v(●) can often be shown to have an additive form:

$$v(\mathbf{a}) = u_1(a_1) + u_2(a_2) + \ldots + u_k(a_k)$$
$$= \Sigma_i \, u_i(a_i) \qquad (3)$$

Discussions of the circumstances in which additivity holds may be found in the literature (see, for example, Ref. [2]). In fact, there is an element of chicken and egg in all such discussions since the choice of attributes is closely intertwined with the validity of an additive representation. The folklore among many decision analysts is that it is usually possible to select appropriate attributes in a problem such that additivity holds.

A variation on the additive form (3) is usually adopted in practice. As given, the component value functions u_i(●) are all assessed on the same scale.

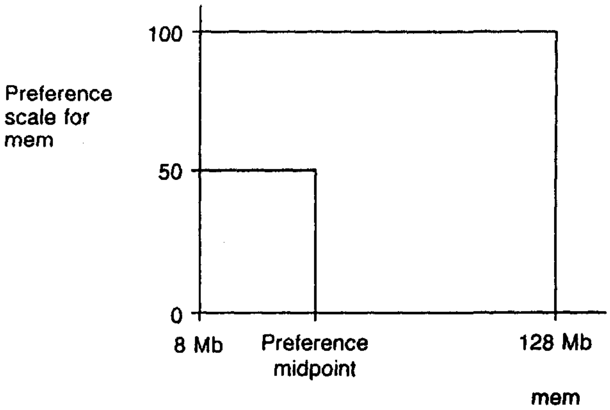


FIG. 3-8. Possible form for v_{mem} (•).

There are many advantages in separating the assessment of these component functions from the task of bringing them to a common scale. Thus non-negative weights w_i are introduced:

$$v(\mathbf{a}) = w_1v_1(a_1) + w_2v_2(a_2) + \ldots + w_kv_k(a_k)$$

$$= \Sigma_i\ w_iv_i(a_i) \qquad (4)$$

Comparing (3) and (4) shows that apparently all that is being done is to write $w_iv_i(a_i)$ for $u_i(a_i)$, but, in fact, some assumptions are being made about the underlying preferences. Strictly, we are describing a measurable additive value function, which represents strength of preference both between alternatives **a** and between attribute levels a_i. None the less, they are assumptions that are usually made and we shall not discuss them here.

Given the structure of the additive value model (4), we can indicate the judgements required of the DM in the assessment of preferences and the construction of v(**a**) for each alternative. Roughly, preference judgements need to be elicited in order to construct each of the k component value functions $v_i(\bullet)$ in turn. Then further judgements are required in order to identify appropriate values of the k weights w_i.

For instance, $v_{mem}(\bullet)$ might have the form shown in Fig. 3-8. Its concave (bending downwards) shape indicates that the decision maker values an increase of memory from 8Mb to 9Mb more than he values an increase from 32Mb to 33Mb. This curve could be assessed in a number of ways. Perhaps the most common is to ask the DM for his midpoint in preference between 8Mb and 128Mb: i.e. what is the value xMb such that he values an increase from 8Mb to xMb equally to an increase from xMb to 128Mb? If the scale of $v_{mem}(\bullet)$ is fixed by setting $v_{mem}(8) = 0$ and $v_{mem}(128) = 100$, then it follows that $v_{mem}(x) = 50$. Asking him for his midpoint in preference between 8Mb and xMb locates x′Mb such that $v_{mem}(x') = 25$. And so on. When sufficient points on $v_{mem}(\bullet)$ have been located, the curve can be sketched in.

The point to note about this assessment is that the DM is required to locate the midpoints by judgement. Although, typically, he is able to do this without too much difficulty, he is usually aware that he is really only able to give a range for the midpoint. Later in the analysis it would be appropriate to return to the assessment and input slightly different midpoints, but ones that are, nevertheless, acceptable to the DM, to see if they would lead to a different conclusion.

The assessment procedure described here makes sense when there are many alternatives to evaluate and the levels of the alternatives on the i^{th} attribute can be found easily. When there are only a few alternatives in the decision problem, the effort required of the decision maker may be reduced substantially if, instead of constructing $v_i(\bullet)$ for all possible levels of the attribute and then transforming a_i through $v_i(\bullet)$ to give $v_i(a_i)$, the DM is asked to assess $v_i(a_i)$ directly. Moreover, direct assessment of $v_i(a_i)$ is necessary when there is no objective scale for the i^{th} attribute, such as would be the case for the attribute 'stab' in the example. Figure 3-9 illustrates the direct assessment of v_{stab} (comp_sys).

The DM is asked to rank the alternative computer systems in terms of his preferences for the suppliers' stabilities. Then, scoring his most preferred alternative at, say, 100 and his least preferred at 0, he is asked to score the other alternatives in such a way that his strength of preference between them is reflected in the scores. Figure 3-9 illustrates the result of this in the case that comp_sys_3 is felt to bring as much improvement over comp_sys_6 as comp_sys_1 brings over comp_sys_2: in both cases the difference in point scores is 40.

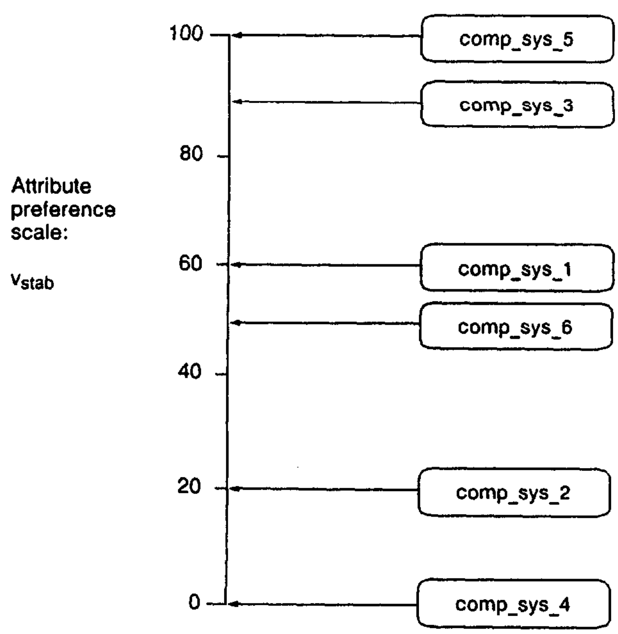


FIG. 3-9. Direct assessment of v_{stab} (comp_sys).

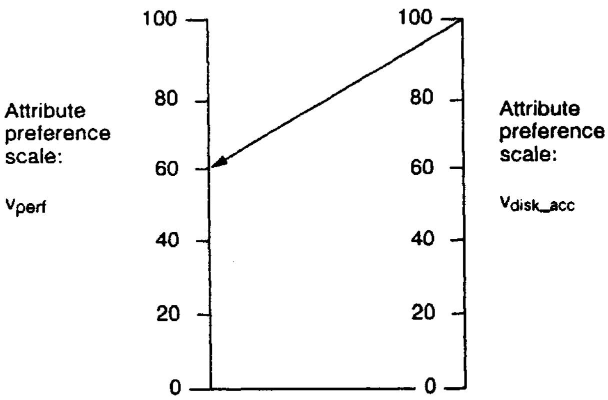


FIG. 3-10. Illustration of swing weights.

Again, note that the DM is required to locate numerical values by judgement. This usually does not cause too much difficulty, providing that, as before, he is allowed to return later and investigate the effect of using slightly different values.

The next step is to assess the weights w_i. It is not simply a case of the DM judging that, say, 'installation costs should carry 30% of the weight'. This would imply that the weights have some sort of absolute values independent of the length of the attribute preference scales. Remember that the greatest and least values of each $v_i(\bullet)$ have been set arbitrarily to 100 and 0, respectively. Weights have two closely intertwined roles:

— they represent the relative importance to the decision maker of the different attributes;
— they provide an 'exchange rate' between the different attribute preference scales, bringing them onto a common scale.

Swing weighting is an assessment method that takes account of both roles. The DM is asked to compare a pair of hypothetical alternatives which differ only in their scores along two attribute preference scales: on the other (k - 2) attributes they share the same scores. Suppose the two attributes on which they differ are 'disk_acc' and 'perf'. The DM is asked to imagine that one alternative scores 100 on 'disk_acc' and 0 on 'perf' and that the other scores 0 on 'disk_acc' and 100 on 'perf'. Which would he prefer? Suppose that he prefers the second. Then a score of 100 on 'perf' is worth more to him than a score of 100 on 'disk_acc'. Hence $w_{perf} > w_{disk\_acc}$. Suppose now he is asked to imagine that the second alternative is modified so that it scores, say, y on 'perf'. Suppose further that the value of y is varied until the DM is indifferent between the two alternatives. Then, if w_{perf} is set to 100, w_{disk_acc} should be set to y/100 because a score of 100 on the 'disk_acc' preference scale is worth a score of y on the 'perf' preference scale.

Figure 3–10 illustrates the essence of swing weighting. If the value of y at which indifference is obtained is, say, 60, then a score of 100 on the 'disk_acc' preference scale maps onto 60 on the 'perf' preference scale.

By repeating the process on other pairs of hypothetical alternatives a full set of weights can be deduced. In practice it makes sense to begin the process by identifying the attribute with the greatest w_i and then considering the (k - 1) pairs in which this attribute is compared with each of the others in turn.

Yet again, note that the DM is required to locate numerical values by judgement. Some investigation of the sensitivity of any conclusions to the effects of varying these will be needed later in the decision analysis.

The next step is to calculate $v(\mathbf{a}) = \Sigma_i w_i v_i(a_i)$ for the alternatives in the decision problem, thus obtaining a preliminary ranking. However, the DM would be wise to take this ranking with a pinch of salt until he has identified how sensitive this ranking is to variations in his judgemental input.

Sensitivity Analysis

There are two forms of numeric input to decision models: objective and judgemental data. By 'objective data' is meant parameters that define physical aspects of the alternatives, states and consequences of the decision model. 'Judgemental data' means parameters relating to the DMs' subjective beliefs and preferences. Although one should always check the robustness of the conclusions of any analysis to changes in both forms of data, the emphasis in the following is entirely on sensitivity analysis in relation to judgemental data.

Intuitively, sensitivity calculations allow DMs to explore the effects of variations in their judgemental inputs on the ranking of alternatives. When small variations produce substantial effects, it is clear that the DMs should pause and reflect on those judgements and ensure that the numbers used best represent their beliefs and preferences. When there are no effects even for moderate or large variations, then they can be reassured that any lack of confidence felt in giving those judgements can be ignored. Sensitivity analysis also plays a role in focusing group discussion. The results of the model can be examined using a wide range of numerical values for any judgements upon which the group cannot agree. Often it is found that the final ranking of alternatives is little affected by variations across the range of numerical values proposed by members. In some cases, of course, significant changes do occur and the group must discuss the values of these judgemental data further. Thus sensitivity analysis draws attention to issues that matter and avoids sterile discussion of those that do not. A full discussion of the motivation behind sensitivity investigations within decision analyses can be found in Ref. [14].

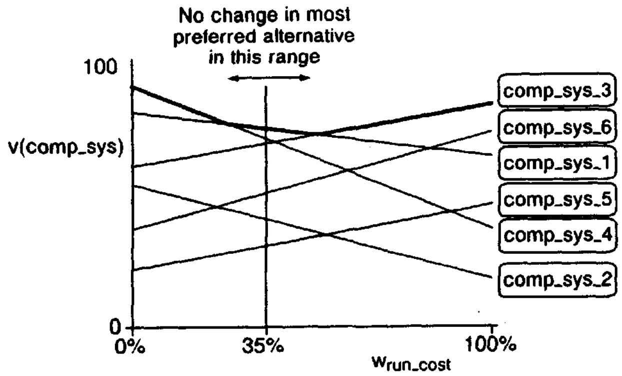


FIG. 3-11. Sensitivity to the variation of a single weight.

The commonest and simplest form of sensitivity analysis currently used within additive value theory is to examine the effect of varying a single weight. Figure 3-11 illustrates this for the weight w_{run_cost}. The idea is as follows. Suppose that the weights are normalized to sum to 1. Then w_{run_cost} is the fraction of the total weight assigned to the running costs. Suppose that, at present, w_{run_cost} is 35%. This is shown in Fig. 3-11 by the dotted vertical line at 35%.

Suppose that w_{run_cost} is varied and all the other weights varied so that the sum of all the weights remains 1 and the ratios between all pairs of weights not involving w_{run_cost} is maintained. With this understanding one may talk unambiguously of w_{run_cost}, say, increasing to 42% or decreasing to 23%. As w_{run_cost} varies in this manner, so will v(comp_sys) change for each alternative computer system. In fact, v(comp_sys) will vary linearly with w_{run_cost}. Thus a straight line is plotted in Fig. 3–11 for each computer system showing the variation of v(comp_sys) with w_{run_cost}. The ordering of the points of intersection of these lines with any vertical corresponds to the ranking given by the additive value function at the particular value of w_{run_cost}. It is, therefore, easy to see the values of w_{run_cost} at which a change in the ranking occurs, namely values corresponding to intersections of two or more v(comp_sys) lines. In particular, values of w_{run_cost} at which the most preferred alternative changes correspond to vertices in the upper envelope of the lines. (The upper envelope is shown as a thicker line in Fig. 3-11.)

We mentioned above that the attribute hierarchy could help in structuring the sensitivity analysis. For instance, the DM could be concerned that he or she is putting too much weight on non-financial attributes. In the hierarchy shown in Fig. 3-7 it is possible to define a weight at the node 'non-financial' simply as the sum of the weights at the bottom nodes below it:

$$w_{non\text{-}financial} = w_{perf} + w_{mem} + w_{disk\_sp} + w_{disk\_acc} + w_{stab} + w_{hard\_rel} \quad (5)$$

Investigating the sensitivity of the results to $w_{non\text{-}financial}$ will address the DM's concerns.

Standard software packages, such as HIVIEW, Logical Decision and VISA, produce plots similar to Fig. 3-11 as a matter of course.

From at the expression (4) for the additive value function v(**a**), it is clear that the effect of varying a single weight w_i is effectively the same as varying the number $v_i(a_i)$, where by $v_i(a_i)$ is meant the i^{th} attribute preference scale value for the alternative not a_i, the level this alternative achieves on the i^{th} attribute. When $v_i(a_i)$ has been assessed directly as in Fig. 3-9, the DM can investigate the sensitivity of the conclusions to variations in his judgemental input by means of a plot similar to Fig. 3-11 with the horizontal axis representing $v_i(a_i)$ instead of w_i. When $v_i(a_i)$ has been assessed indirectly as in Fig. 3-8, however, such sensitivity analysis is not necessarily directly related to judgemental inputs because of the possible non-linear relationship between $v_i(a_i)$ and the judgements of preference midpoints.

Part G

References for Annex 3

[1] BELTON, V., VICKERS, S., VISA Software Package, Department of Management Science, University of Strathclyde, Glasgow.

[2] FRENCH, S., Decision Theory: An Introduction to the Mathematics of Rationality, Horwood, Chichester (1986).

[3] WATSON, S.R., BUEDE, D., Decision Synthesis: The Principles and Practice of Decision Analysis, Cambridge University Press, Cambridge (1987).

[4] PHILLIPS, L.D., A theory of requisite decision models, Acta Psychol. **56** (1984) 29–48.

[5] PHILLIPS, L. D., "Decision analysis for group decision support", in Ref. [9].

[6] BARCLAY, S., HIVIEW Software Package, Decision Analysis Unit, London School of Economics and Political Science, London.

[7] BELL, D.E., RAIFFA, H., TVERSKY, A. (Eds), Decision Making: Descriptive, Normative and Prescriptive Interactions, Cambridge University Press, Cambridge (1988).

[8] BELTON, V., "Multiple criteria decision analysis — practically the only way to choose", Operational Research Tutorial Papers 1990 (HENDRY, L.C., EGLESE, R.W., Eds), Operational Research Society, Birmingham (1990) 53–101.

[9] EDEN, C., RADFORD, J. (Eds), Tackling Strategic Problems: The Role of Group Decision Support, Sage, London (1990).

[10] FRENCH, S. (Ed), Readings in Decision Analysis, Chapman and Hall, London (1989).

[11] HALL, P., Managing change and gaining corporate commitment, ICL Tech. J. **7** (1986) 213–227.

[12] VON WINTERFELDT, D., EDWARDS, W., Decision Analysis and Behavioral Research, Cambridge University Press, Cambridge (1986).

[13] HARVEY-JONES, J., Making It Happen, Fontana, London (1988).

[14] FRENCH, S., "The role of sensitivity analysis in decision analysis', Executive Information Systems and Decision Making (MITRA, G., Ed.), Chapman and Hall, London (1991).

Part H
Conclusions and Recommendations

Contents

1. Constraints and Limitations

The conclusions and recommendations of the International Chernobyl Project were approved by the International Advisory Committee (IAC) at its meeting in Vienna from 18 to 22 March 1991 and they are based upon the radiological and health assessments carried out under the Project.

The conclusions and recommendations are subject to the constraints and limitations of the Project design. These constraints and limitations should be recognized so that the conclusions and recommendations are not interpreted to be more or less than is warranted by the Project. Ideally, the Project teams would have had sufficient time and resources to examine exhaustively and verify independently all the information available to them as well as to carry out more extensive independent analyses. Such comprehensive efforts were not feasible nor were they altogether warranted. More limited objectives were necessary and were adopted for a number of reasons: the time available to complete the Project was limited; the data provided to the Project teams were not always adequate; the evaluation of the radiological situation immediately after the accident could no longer be independently assessed because of the time that had elapsed and the consequent decay of short lived radioisotopes; the number of available independent experts as well as their time were limited; the thousands of square kilometres that were contaminated could not be thoroughly monitored or systematically surveyed for 'hot spots' of contamination; and the hundreds of thousands of people living in these areas could not be individually examined. Finally, the Project survey was concerned principally with human problems and relevant environmental considerations such as agricultural contamination; consequences of the accident for other species were not specifically considered.

Efforts were therefore directed to the assessment of data, techniques and methodologies employed to estimate contamination levels, doses[1] and health effects, and to the evaluation of radiological protection policies. Sufficient data were obtained independently to enable the Project teams to formulate independent judgements.

In order to assist the authorities of the USSR, the BSSR, the RSFSR and the UkrSSR, major efforts were devoted to the urgent need to provide guidance with respect to radiological protection measures (including the 'safe living concept') and the associated radiological protection practices and policies. The radiological considerations influencing a policy such as relocation (for example, the radiation doses and risks averted by relocating populations) had to be evaluated within the context of the resulting psychological, social and economic factors.

An assessment was made of the health of persons who had been residing in settlements in the contaminated areas of concern since the time of the accident. This was done by examining the population for potential health effects due directly to radiation as well as health effects that may have occurred as a result of factors related to the accident but not due to radiation exposure. Since there were few baseline data for these populations from the time before the accident, it was necessary to compare results for these people with those for other people living in the region but outside the contaminated areas of concern[2].

As the Project was directed at those currently living in the contaminated areas, the radiological health effects to the more than 100 000 people evacuated from the prohibited zone around the Chernobyl site were considered only for those currently living in the areas under review. Nor did the Project address health effects for the large number of emergency personnel (the so-called 'liquidators') who were brought into the region temporarily for accident management and recovery work. The health of this occupationally exposed population is reportedly being monitored at medical centres throughout the USSR.

Some issues received comparatively little attention, owing primarily to the unavailability of necessary and sufficient data. For example, it was not possible to corroborate the early contamination of land and the exposures of the public due to iodine isotopes. Nor were the early remedial protective actions undertaken (e.g. thyroid blocking by iodine prophylaxis and evacuation) subject to thorough evaluation.

---

1 The word 'dose', unless otherwise specified, is generally used to mean 'effective dose', i.e. the total absorbed dose appropriately weighted for the harmfulness of the radiation type and the susceptibility to harm of human tissues.

2 The Project selected, in co-operation with local authorities, a number of settlements in the contaminated areas of concern in order to perform the necessary surveys. Some of the settlements were located in areas of relatively high soil surface contamination while others were located in areas of relatively low soil surface contamination but with the potential for high radiation doses to people. In this text, these settlements are termed 'surveyed contaminated settlements'. Settlements were also selected outside the contaminated areas of concern to serve as references for comparative purposes. These settlements are termed 'surveyed control settlements'.

Despite the limitations of time and financial and human resources, the IAC is of the opinion that the Project represents a much needed international humanitarian and scientific response to the needs of the authorities and the people of the USSR who were affected by the Chernobyl accident.

The IAC acknowledges the many problems in a study of such breadth. Nonetheless, the work has involved leading and eminent international scientific investigators and medical specialists who endorse its adequacy and its results. It is a significant step in the evaluation of the consequences of the accident.

2. Environmental Contamination

2.1. General Conclusions

Measurements and assessments carried out under the Project provided general corroboration of the levels of surface contamination for caesium as reported in the official maps that were made available to the Project teams. Analytical results from a limited set of soil samples obtained by the Project teams corresponded to the surface contamination estimates for plutonium but were lower than those for strontium.

The concentrations of radionuclides measured in drinking water and, in most cases, in food from the areas investigated were significantly below guideline levels for radionuclide contamination of food moving in international trade and in many cases were below the limit of detection.

2.2. Detailed Conclusions

2.2.1. Capabilities of Soviet Laboratories

The analytical capabilities of Soviet laboratories appeared to be adequate. There is an extensive infrastructure for the analysis of environmental and food samples. The range of performance of the Soviet laboratories that participated in the intercomparison exercise was broad, but similar to that found in previous international comparison exercises. The few problems identified, including the tendency to overestimate strontium, did not significantly affect the use of data for conservative dose assessment purposes.

The field studies which were assessed, even though they excluded 'hot spots', appeared to give adequate results for the average values characterizing surface deposition in a region. In accordance with the methodology that reportedly had been used, 'hot spots' that had been identified were systematically excluded in the reported estimation of average surface deposition for a given region and were not listed in the detailed data provided to the Project teams.

The extensive surface water sampling programmes are adequate. Certain problems during sampling and/or analytical procedures could lead to possible overestimation of the concentrations of radionuclides in water.

Insufficient information was available to evaluate air sampling equipment and procedures. Although the relative contributions from airborne resuspension of radioactive materials to dose are believed to be minor, it should be noted that the occurrence of airborne resuspension, particularly during agricultural activities or dry periods, cannot be excluded.

Rapid screening and sophisticated techniques used locally for monitoring commercially available food from production to consumption appeared to be satisfactory. The relevant instrument calibration techniques could not be evaluated sufficiently by the Project teams owing to the lack of detailed technical information.

2.2.2. Independent Project Surveys

A variety of surveillance methods were used in the surveyed contaminated settlements and the surveyed control settlements to estimate surface contamination. The ranges of average values of surface contamination due to the deposition of caesium on the ground that were given in the official maps made available to the Project teams were corroborated. On the basis of the limited number of soil samples independently analysed for plutonium and strontium, the results for plutonium were found to correspond to the reported estimates, whereas a potential for overestimation in the reported data for strontium was identified.

The radioactive contamination of drinking water resources that were sampled in the surveyed contaminated settlements was found by the Project teams to be significantly lower than the intervention levels established by the authorities.

The radioactive contamination of food samples was found to be in most cases below the intervention levels established by the responsible authorities in the settlements surveyed. In some settlements, milk from individual farms and food collected in natural areas in contravention of official recommendations could be contaminated above these levels.

2.3. Recommendations

Local laboratories should, as is customary, be confidentially notified of the Project findings of relevance for them and should take appropriate remedial actions where needed. Local laboratories which have participated in the intercomparison exercise should be informed confidentially of their performance so that they can rectify problems where necessary.

Quality assurance programmes to ensure consistently reliable results should be in place in local laboratories. These laboratories should participate regularly in international intercomparison programmes and international intercalibration exercises.

A programme should be established to assess the significance of 'hot spots'. Research programmes on the characteristics of hot particles and their occurrence in the environment are warranted and should be continued.

Water sampling and analytical techniques should be improved to comply with established procedures. The potential for long term contamination of water bodies, possibly leading to contamination of the aquatic foodchain, should be investigated. Research should be planned to study radionuclide behaviour in ecosystems and desorption of strontium from sediments in surface water bodies and its effects on agriculture through irrigation practices.

It may be advantageous to consider the future use in the USSR of validated models to predict radionuclide levels in food. The use of these models could be cost effective in the long term and reduce the need for extensive sample analysis.

All data from the BSSR, the RSFSR and the UkrSSR relating to radiological contamination should be shared with the USSR Central Data Bank in Obninsk so as to be made available to all Republics. All such information should also be made available to relevant institutes and institutions.

A programme should be implemented to derive more detailed official large scale contamination maps.

A collaborative programme of air sampling and analysis should be established between the local laboratories and the network of international laboratories set up by the IAEA Laboratory at Seibersdorf in order to obtain more definitive information on the relevance of the resuspension and inhalation pathways.

3. Radiation Exposure of the Population

3.1. General Conclusions

The official procedures for estimating doses were scientifically sound. The methodologies that were used were intended to provide results that would not underestimate the doses. Independent measurements in individual residents monitored for external and for internal exposure from caesium incorporated into the body yielded results that would be predicted on the basis of calculational models. Independent Project estimates for the surveyed contaminated settlements were lower than the officially reported dose estimates[3].

3.2. Detailed Conclusions

3.2.1. External Exposure

The external exposure due to deposited radionuclides is, in most areas, the most significant contributor to dose, especially in those areas where food restrictions have been applied. The reported methodology for calculations of external dose is being confirmed by local measurements using thermoluminescence dosimetry.

Independent measurements of external exposure were carried out under the auspices of the IAEA for the Project. Eight thousand film badge dosimeters were distributed to residents of seven settlements. Ninety per cent of the results were below the detection limit of 0.2 mSv for a two month exposure period. This result is in agreement with what would be expected on the basis of calculational models.

3.2.2. Internal Exposure

Doses from incorporation of caesium in the first four years after the accident were estimated by the authorities on the basis of measurements of incorporated caesium, including both ^{134}Cs and ^{137}Cs. The procedure for estimating doses from these measurements is in accordance with that used in the independent evaluations made under the Project.

Official estimates of projected doses due to the intake of caesium are based on a number of influencing factors, including an assumed half-time of 14 years for ^{137}Cs in the environment. This assumption is designed to ensure that doses are not underestimated and is prudent.

Official estimates of doses due to the intake of strontium in the first four years after the accident were based on a metabolic model and measurements of strontium in foods, or on an assumed ratio of strontium to caesium in foods if no data on strontium were available.

Official estimates of projected doses due to the intake of ^{90}Sr in the diet were made on the assumption of an environmental half-time of 10 years; this assumption was not referenced, but is stated to be derived from experience gained after the accident at a nuclear materials production plant in Kyshtym in the USSR in 1957.

On the basis of the results of an intercomparison programme with the participation of local laboratories and the IAEA Laboratory using standardized phantoms, it can be concluded that the accuracy obtained in local whole body measurements for caesium is adequate for radiological protection purposes.

Whole body counting of caesium was carried out under the auspices of the IAEA for the Project and covered more than 9000 people in nine settlements. The results indicated generally lower body contents of caesium than would be predicted on the basis of most models of environmental transfer, dietary intake and metabolism. Similar results for whole body counting of caesium have been reported in other countries.

Absorbed thyroid doses due to iodine were officially reported on the basis of thyroid measurements made in the early stages after the accident and assumptions concerning intake. Mean absorbed thyroid doses for children from birth to seven years old were officially reported to vary from less than 0.2 Gy to 3.2 Gy for seven surveyed contaminated settlements[4]. However, since the iodine had completely decayed by the time of the Project, no independent verification of the reported absorbed thyroid doses was possible.

3.2.3. Dose Estimate Comparison

Independent estimates of doses were made for the surveyed contaminated settlements on the basis of average deposition results. It could not be assumed that such generalized dose estimation assumptions or environmental modelling calculations would accurately reflect the local soil conditions, agricultural practices and living habits in the surveyed contaminated settlements but the results could be expected to provide a general basis for comparisons.

[3] These estimates were derived on the basis of doses due to ^{137}Cs and ^{90}Sr; where appropriate, shorter lived isotopes of caesium and strontium were also taken into account.

[4] The maximum (reconstructed) absorbed thyroid dose (in Bragin) was officially reported as 30–40 Gy.

The ranges in the estimates of 70 year (1986-2056) doses were as follows:

Independent estimates for the surveyed contaminated settlements:

External dose:	60–130 mSv
Internal dose (caesium):	20– 30 mSv
Total (including strontium):	80–160 mSv

Officially reported estimates for the same settlements:

External dose:	80–160 mSv
Internal dose (caesium):	60–230 mSv
Total (including strontium):	150–400 mSv

Independent Project estimates for the surveyed contaminated settlements were lower than the officially reported dose estimates. Overall, there is agreement to within a factor of 2–3 between the independent estimates and the officially reported estimates[5].

[5] These conclusions were drawn on the basis of estimated or reported doses from external exposure due to all relevant radionuclides and internal exposure due to ^{134}Cs, ^{137}Cs and ^{90}Sr. Doses to the thyroid from ^{131}I and other short lived isotopes of iodine and their precursors were also considered.

3.3. Recommendations

The official procedures for dose assessment reported to the Project use deterministic models that are designed not to underestimate doses. Probabilistic dose assessment methods should be developed so that more realistic estimates of dose are eventually available and uncertainties in the calculation are fully assessed.

Over the next few decades it should be possible to extend scientific knowledge of environmental transfer factors by studies in the contaminated areas of concern. Measurement of external exposure rate, caesium body burden and the caesium and strontium content of foodstuffs should be continued.

Although the potential relative contributions from resuspension to dose are believed to be minor, even for outdoor workers, doses should be assessed for critical groups such as agricultural workers.

Local scientists should participate more actively in international dose assessment validation studies. Such activities include intercomparisons of environmental transfer models and internal and external dosimetry intercomparisons.

Local scientists should participate more actively in international programmes on both the formal level (for example, through attendance at seminars, symposia and conferences) and the informal level to provide an exchange of information on technology that can be applied to the effective solution of dosimetric problems. Support should be given for specialists to gain experience working in laboratories in other countries.

4. Public Health and Possible Clinical Effects of Irradiation

4.1. General Conclusions

At the time of the Project study, there were significant non-radiation-related health disorders in the populations of both surveyed contaminated and surveyed control settlements, but no health disorders that could be attributed directly to radiation exposure. The accident had substantial negative psychological consequences in terms of anxiety and stress due to the continuing and high levels of uncertainty, the occurrence of which extended beyond the contaminated areas of concern. These were compounded by socioeconomic and political changes occurring in the USSR.

The official data that were examined did not indicate a marked increase in the incidence of leukaemia or cancers. However, the data were not detailed enough to exclude the possibility of an increase in the incidence of some tumour types. Reported absorbed thyroid dose estimates in children are such that there may be a statistically detectable increase in the incidence of thyroid tumours in the future.

On the basis of the doses estimated by the Project teams and currently accepted radiation risk estimates, future increases over the natural incidence of cancers or hereditary effects would be difficult to discern, even with large and well designed long term epidemiological studies.

4.2. Detailed Conclusions

4.2.1. Current Health Effects Attributed to Radiation

Reported adverse health effects attributed to radiation were not substantiated either by those local studies that were adequately performed or by the studies under the Project.

Many of the local clinical investigations of health effects had been done poorly, producing confusing, often contradictory results. The reasons for these failures included: lack of well maintained equipment and supplies; poor information through lack of documentation and lack of access to scientific literature; and shortages of well trained specialists. Nevertheless, despite these obstacles, a number of the local clinical studies were carefully and competently performed and the Project teams were to corroborate the results in most cases.

4.2.2. Specific Results of Project Field Studies

Field studies were undertaken of continuous residents of rural surveyed contaminated settlements (with surface contamination higher than 555 kBq/m^2 (15 Ci/km^2) due to caesium) and surveyed control settlements of 2000 to 50 000 persons, using an age matched study design. The studies were performed in the second half of 1990 and relate to the health status at that time. The strategy of the study, to elucidate major health problems identified by general clinical examinations and sophisticated laboratory tests, was adequate to answer most concerns of the population. There was no exhaustive testing of each individual, and the study did not resolve all questions relating to potential health effects.

Psychological Disorders

There were many important psychological problems of anxiety and stress related to the Chernobyl accident and in the areas studied under the Project these were wholly disproportionate to the biological significance of the radioactive contamination. These problems are prevalent even in the surveyed control settlements. The consequences of the accident are inextricably linked with the many socioeconomic and political developments that were occurring in the USSR.

A large proportion of the population had serious concerns; these people were not acting in an irrational way that could be termed radiophobic. The vast majority of adults examined in both the surveyed contaminated settlements and the surveyed control settlements visited either believed or suspected that they had an illness due to radiation. Most adults in both surveyed contaminated and surveyed control settlements were native to the local area and virtually all stated that they had lived in the settlements since birth; therefore relocation is a major concern. While only about 8% of adults in surveyed control settlements wanted to relocate, the adults in the surveyed contaminated settlements were so concerned that 72% wanted to relocate. The percentages of the population who thought that the Government should relocate the whole population were higher: 20% and 83%, respectively.

General Health

The children who were examined were found to be generally healthy. Field studies indicated that a significant number of adults in both surveyed contaminated and surveyed control settlements had substantial medical problems, with 10% to 15% (excluding hypertensive adults) requiring medical care.

Cardiovascular Disorders

Many adults were hypertensive; however, the statistics related to both systolic and diastolic blood pressure were similar for both surveyed contaminated and surveyed control settlements, and both were comparable with published values for Moscow and Leningrad.

Nutrition

Diet appeared to be limited in range but adequate. No significant differences in reported eating habits were found between surveyed contaminated and surveyed control settlements. No detrimental effects on growth due to voluntary or official dietary restrictions imposed as a result of the accident were found. There were no significant differences between the growth rates of children in surveyed contaminated and surveyed control settlements, and the rates for both groups were well within published USSR and international norms. Adults were generally overweight by international standards in all areas studied. Intake and excretion of iodine were found to be at the low end of the acceptable range. Most other dietary constituents and components were found to be adequate; however, vitamin intake was not examined. Dietary intakes of toxic elements (lead, cadmium and mercury) were low in comparison with those reported for many other countries and were well below the maximum tolerable intake levels specified by international organizations. Blood lead levels were also investigated and were found to be well within the normal range.

Thyroid Gland Disorders

No abnormalities in either thyroid stimulating hormone (TSH) or thyroid hormone (free T4) were found in children examined. No statistically significant difference was found between surveyed contaminated and surveyed control settlements for any age group.

Mean thyroid sizes and size distributions were the same for populations of surveyed contaminated and surveyed control settlements. Thyroid nodules were extremely rare in children; they occurred in up to 15% of adults in both surveyed contaminated and surveyed control settlements. Project results are similar to those reported for populations in other countries.

Haematology

Some young children with low haemoglobin levels and low red cell counts were identified. However, there was no statistically significant difference between values in surveyed contaminated and surveyed control settlements for any age group of the population. No difference was found between the populations when leucocytes and platelets were examined. Immune systems (as judged from the lymphocyte level and the prevalence of other diseases) did not appear to have been significantly affected by the accident.

Neoplasms

Review of Soviet data indicated that reported cancer incidence had been rising for the last decade (starting before the Chernobyl accident occurred) and has continued to rise at the same rate since the accident. The Project teams considered that there had been incomplete reporting in the past and could not assess whether the rise was due to increased incidence, methodological differences, better detection and diagnosis or other causes. The data did not reveal a marked increase in the incidence of leukaemia or thyroid tumours since the accident. However, owing to the classification scheme used and other factors, the possibility of a slight increase in the incidence of these tumours cannot be excluded. Only hearsay information relating to such tumours was available.

Radiation Induced Cataracts

There was no evidence of radiation induced cataracts in the general population.

Biological Dosimetry

Chromosomal and somatic cell mutation assays were performed on adults who had worked outdoors, selected since their exposures were assumed to be the highest. No significant difference were found between adults living in surveyed contaminated and surveyed control settlements. The data obtained were consistent with the Project dose estimates.

Foetal and Genetic Anomalies

Review of Soviet data for settlements in contaminated areas of concern as well as for the three Republics as a whole indicated relatively high infant and perinatal mortality levels. These levels prevailed before the accident and appear to be decreasing. No statistically significant evidence was found of an increase in the incidence of foetal anomalies as a result of radiation exposure.

4.2.3. Potential Delayed Health Effects

Available data reviewed did not provide an adequate basis for determining whether there had been an increase in leukaemia or thyroid cancers as a consequence of the accident. The data were not detailed enough to exclude the possibility of an increase in the incidence of some tumour types. On the basis of the doses estimated by the Project teams and currently accepted radiation risk estimates, future increases over the natural incidence of all cancers or hereditary effects would be difficult to discern, even with large and well designed long term epidemiological studies. Reported estimates of absorbed thyroid dose in children are such that there may be a statistically detectable increase in the incidence of thyroid tumours in the future.

4.3. Recommendations

4.3.1. General Health and Potential Accident Consequences

The adverse health consequences of relocation should be considered before any further relocation takes place.

Consideration should be given to the introduction of programmes to alleviate psychological effects. These might include informational programmes for the public. There should also be educational programmes set up for teachers and local physicians in general preventive health care and radiation health effects.

The current policy of annual physical examinations is conceptually adequate for the health needs of the general population in the contaminated areas of concern. However, certain high risk groups (such as children with high absorbed thyroid doses) will need specific medical programmes based on their potential risks.

Energetic action should be taken to improve the standard of medical, diagnostic and research equipment and the availability of medical supplies, manuals and spare parts.

Clinical and research investigations should emphasize the use of appropriate control groups, standards and quality control procedures.

Improvements should be made in the statistical, data collection and registry systems used by local scientists by the adoption and application of internationally accepted standards and methods.

There should be increased opportunities for information exchange and greater availability of scientific literature for local health professionals.

4.3.2. Potential Delayed Health Effects

In view of the limited resources available, the concept of the WHO Scientific Advisory Group on the Health Effects of Chernobyl, namely to concentrate on prospective cohort studies of selected high risk populations, should be endorsed. It is impractical, owing to the extreme difficulty and cost, to conduct long term studies or to evaluate all persons who live in the affected Republics.

4.3.3. General Public Health Issues in the Affected Republics

Action should be taken on adult hypertension and dental hygiene as major health issues. The need for continuing programmes for iodization of salt should be reevaluated; if these are found to be necessary, the effectiveness of the chemical process should be assessed.

5. Radiation Protection Measures

5.1. General Conclusions

The unprecedented nature and scale of the Chernobyl accident obliged the responsible authorities to respond to a situation that had not been planned for and was not expected. Thus, many early actions had to be improvised. The Project teams were not able to investigate in detail many actions taken by the authorities owing to the complexity of the events.

In those cases in which the Project teams were able to assess these actions, it was found that the general response of the authorities had been broadly reasonable and consistent with internationally established guidelines prevailing at the time of the accident. Some measures could doubtless have been better or taken in a more timely manner, but these need to be viewed in the context of the overall response.

The protective measures taken or planned for the longer term, albeit well intentioned, generally exceed what would have been strictly necessary from a radiological protection viewpoint. The relocation and foodstuff restrictions should have been less extensive. These measures are not justified on radiological protection grounds; however, any relaxation of the current policy would almost certainly be counterproductive in view of the present high levels of stress and anxiety amongst inhabitants of the contaminated areas of concern and people's present expectations. It is recognized, however, that there are many social and political factors to be taken into consideration, and the final decision must rest with the responsible authorities. At any rate, no modification introduced should lead to more restrictive criteria.

5.2. Detailed Conclusions

5.2.1. Evacuation and Thyroid Blocking

The intervention levels of dose for evacuation established by the authorities were consistent with international guidance at the time of the accident.

The general policy for administration of stable iodine established by the authorities was in compliance with the international guidance at the time of the accident. The numerical values of the intervention levels, however, were not in full agreement with those recommended internationally.

The resources required to evaluate the practical implementation of these two protective measures were far in excess of those available under the Project. Consequently, only a superficial analysis was made of these aspects, on which no further conclusions can be made.

5.2.2. Surface Decontamination

Efforts were made after the Chernobyl accident over a period of several months to reduce external exposure due to radioactive materials that were released in the accident and deposited on surfaces. The wide range of measures taken included: the removal of soil to a depth of 10–15 cm; asphalting and covering soil with gravel, broken stones, sand or clean soil; daily mechanized washing; surface washing; demolition of structures; and burial of waste. These measures are reported to have been moderately effective; however, the Project teams did not specifically investigate these reports.

5.2.3. Food Restrictions

Criteria

The basis on which the intervention levels for food restrictions established by the authorities were derived was broadly consistent with international guidance prevailing at the time of the accident. There was, however, considerable ambiguity in the international guidance. Furthermore, the derived levels of radionuclide concentrations for various foodstuffs established by the authorities were based on consideration of the most exposed persons, i.e. the critical group, as opposed to the average individual in the affected group.

With allowance made for the differences in formulation between the respective criteria, the intervention levels established by the authorities are at the lower bound of the range recommended internationally. In view of the scale of the accident, the extent over which restrictions were needed and the shortcomings in food supply and distribution in the areas concerned, higher values of intervention levels would have been justifiable.

Impact

Doses actually received due to the ingestion of contaminated foodstuffs were substantially lower than the prescribed intervention levels of dose, typically by a factor of 2–4, and as a consequence foodstuffs may have been restricted unnecessarily.

The social consequences, including costs, of banning the consumption of foodstuffs were in many cases disproportionate to the doses averted.

Relaxation of the criteria for foodstuffs should be considered as a preferable alternative to relocation when overall health, social and economic effects are taken into account. Continuing restrictions on the consumption of domestically produced food in the contaminated areas of concern imply for some people a serious deterioration in the quality of life which may only be remedied by relocation to areas where previous lifestyles can be resumed. The relatively low intervention levels adopted for foodstuff restrictions may have exacerbated these problems.

An immense and largely successful effort has been made by the authorities to contain the agricultural consequences of the Chernobyl accident. Great efforts have also been made to reduce radiation risks to the population as a whole and to agricultural workers and their families in particular. The negative social effects of agricultural countermeasures could be further reduced by employing certain types of caesium binder.

5.2.4. Relocation

Criteria

The bases on which the criteria for relocation were derived by the authorities are not wholly consistent with the principles currently recommended internationally; this, however, does not necessarily imply that the quantitative criteria adopted are inappropriate.

In establishing relocation criteria, there were various conceptual misunderstandings and terminological problems among the parties concerned (including central and local authorities) that contributed to many of the present problems.

The use of imprecise terminology and the misunderstanding and/or misrepresentation of some fundamental radiological protection concepts and principles, on the part of both the scientific community and others, were a source of much confusion and disagreement in the USSR. This, taken together with the considerable delays in developing policy and effectively communicating it, was largely responsible for the failure to reach a broad consensus on relocation policy.

Moreover, it contributed to a loss of confidence on the part of the affected population in the measures being taken in their interest.

One of the more important misunderstandings or misrepresentations was confusion over, and lack of recognition of, the very different origins and purposes of the dose limits recommended internationally for controlling planned increases in radiation exposure and those of the dose levels at which intervention is prompted to reduce existing radiation exposures. Dose limits per se are not the appropriate levels at which to intervene following an accident. The dose averted by relocation is the relevant quantity for judging the radiological benefits of relocation and, where practicable, quantitative criteria should be expressed in terms of this quantity.

It was not evident that considerations of averted dose were at the origin of all the criteria that were proposed by the authorities. Criteria may also be formulated in terms of other, more useful derived quantities that are surrogates for averted dose (for example, contamination level, annual dose, lifetime dose or dose rate). A number of these have been used in the USSR, each having merits and disadvantages. In particular, surface contamination is not generally applicable for dose estimates because there is a strong dependence of dose estimates on local soil conditions, food consumption habits and lifestyle.

Social Impact

It appeared that due account had not been taken by the authorities of the many negative aspects of relocation in formulating the relocation policy. There are indications from studies in other areas that the mass relocation of people leads to a reduction in average life expectancy (through increased stress and changes of lifestyle) and a reduced quality of life in a new habitat.

In applying a lifetime dose criterion for relocation, it is inappropriate to take account of past doses. Intervention may reduce the risk of adverse health effects in proportion to the dose averted but it can have no influence on doses already received before the intervention. For dose ranges below the threshold for deterministic effects, it is conceptually unsound and in contradiction to the principles for intervention to take past doses into account. There are, however, circumstances in which the total, past and projected, doses received may be the relevant quantity, for example in judging the need for and extent of any long term medical follow-up or care of those exposed as a result of the accident.

The cautious approach adopted (i.e. overestimation) in the estimation of doses to people living in the contaminated areas of concern, on the grounds that this was in their best interest, was inappropriate in principle and contradictory to the fundamental objectives of intervention. It had two important negative consequences: firstly, the radiological consequences of continuing to live in contaminated areas were overstated and this contributed to additional and unnecessary fear and anxiety in the population; secondly, and more importantly, some people would be relocated needlessly.

The average levels of individual lifetime dose that could potentially be averted by relocation, prompted by either the 35 rem (350 mSv) or the 40 Ci/km^2 (1480 kBq/m^2) criterion, are of the same order as or less than the doses due to average natural background radiation.

It is not clear that the modest nature of the doses that could be averted by relocation, and their assumed risks, are fully appreciated by either the population of the contaminated areas of concern or many of those people advocating a more stringent regime. The extra incremental risk to which an individual remaining in a contaminated area would be exposed would be marginal in comparison with risks experienced in everyday life and in itself would not justify such a radical measure as relocation.

Policy Reappraisal

On strictly radiological protection grounds, there can be little if any justification for the adoption of more restrictive relocation criteria than those currently adopted in the All-Union programme (i.e. 40 Ci/km^2 (1480 kBq/m^2)). Indeed, a reasonable case could be made for a relaxation in the policy; that is, for an increase of the intervention levels.

A much larger number of people than those living in settlements with contamination levels in excess of 40 Ci/km^2 (1480 kBq/m^2) are to be relocated; the doses averted by the relocation of these people will be significantly less than the modest values already indicated. The implications of this are that more restrictive criteria are being adopted in practice.

Many factors, other than those of a strictly radiological protection nature, have had an important and possibly overriding influence on relocation policy. The need to restore public confidence, which has been seriously eroded for many reasons over the past five years, to reduce anxiety and to gain broad acceptance for the policy was identified to be particularly important. In ongoing reappraisals by the authorities of the relocation policy, these factors are being assigned much greater weight than factors of a strictly radiological protection nature. The relative importance to be attached to the various factors is, however, a matter for the relevant authorities.

Future changes in relocation policy will inevitably be constrained by past actions. Notwithstanding the merits of and technical justification for a change in policy, acceptance of major changes would be difficult to achieve, particularly where these involved a relaxation in the criterion previously adopted. A relaxation in the current relocation policy (i.e. a higher intervention level) would, however, almost certainly be counterproductive given the very difficult social conditions in the contaminated areas of concern. There can be no justification on radiological protection grounds for the adoption of a more restrictive policy. This should be strongly resisted unless there are overriding considerations of a social nature.

5.3. Recommendations

5.3.1. Protective Measures

Arrangements should be made in the future for the compilation of a comprehensive and agreed database containing all relevant information on the implementation and the efficacy of the protective measures taken and this should be processed into a coherent framework.

A complete and detailed evaluation should be made of the protective measures taken (or planned to be taken) in order to validate the conclusions of the Project study. This should cover all aspects related to radiological protection, namely the doses, the costs and the efficacy of the protective measures.

Agricultural measures that may have a less adverse impact on traditional agricultural practices should be investigated.

5.3.2. Public Information

Factors that may influence the acceptability to the local population of continued habitation of settlements in the contaminated areas of concern should be further identified and analysed.

More realistic and comprehensive information should be provided to the public on the levels of dose and risk consequent upon their remaining in the contaminated areas of concern. These risks should be compared with risks experienced in everyday life and with risks from other environmental contaminants, e.g. radon and industrial emissions.

5.3.3. Resource Allocation

A comparison should be made between the effectiveness of resources allocated to the mitigation of the consequences of the accident and those allocated elsewhere to other programmes for public health improvement.

An assessment should be undertaken of the cost and effectiveness of relocation for a number of individual settlements, chosen to encompass the range of different characteristics encountered, in order to confirm the validity of the conclusions reached for average settlements.

Annex I
^{137}Cs and ^{90}Sr Contamination Levels

Contents

Note

The following tables present data on caesium-137 and strontium-90 contamination levels in populated areas of the BSSR, the RSFSR and the UkrSSR as of June–July 1989. Data provided by the State Committees for Hydrometeorology of the BSSR, the UkrSSR and the USSR, the Ministries of Health of the BSSR and the USSR, the Academies of Science of the BSSR, the UkrSSR and the USSR, the State Agroindustrial Committees of the BSSR, the RSFSR and the UkrSSR, and by a number of other organizations were used in the preparation of these tables.

The USSR State Committee for Hydrometeorology is the leading organization in this area. Therefore, figures are given for all the data available from the USSR State Committee for Hydrometeorology; these data were used to draw up the area contamination maps sanctioned by the Interdepartmental Commission of the USSR State Committee for Hydrometeorology.

The averaged values given are, on the whole, based on a large number of samples (the number of samples is indicated).

The tables list all populated areas with caesium-137 contamination levels of 5 Ci/km^2 (185 kBq/m^2) and above, and all those where the strontium-90 contamination levels are 1 Ci/km^2 (37 kBq/m^2) and above. Lists of villages where the contamination levels were lower than the average are also given, but the measurement of below average levels was still in progress when these data were first published and some villages have therefore not been included.

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ БССР ЦЕЗИЕМ-137 (Ки/км^2)
(Caesium-137)

БРЕСТСКАЯ ОБЛАСТЬ (BREST)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Барановичский		Барановичи	10	0,0
2			Городище	10	0,0
3			Крошин	10	0,0
4			Малаховцы	10	0,0
5			Миловиды	10	0,3
6			Петковичи	10	0,0
7			Столовичи	10	0,1
8	Березовский		Береза	10	0,2
9			Пересудовичи	10	1,0
10			Малеч	10	0,0
11	Брестский		Брест	10	0,1
12			Медно	10	0,0
13			Мухавец	10	0,0
14			Черни	10	0,0
15			Лыщицы	10	0,0
16			Домачево	10	0,3
17			Кошелево	10	0,0
18	Ганцевичский		Ганцевичи	10	0,1
19			Радзяловичи	10	0,1
20			Мальковичи	10	0,1
21	Дрогичинский	Антопольский	Антополь	10	0,3
22		Брашевичский	Брашевичи	10	1,0
23		Гутовский	Гутово	10	0,0
24		Головчицкий	Головчицы	10	0,3
25		Дрогичинский	Липники	10	0,0
26		Детковичский	Детковичи	10	0,2
27			Залесье	10	1,0
28		Закозельский	Закозель	10	0,0
29			Малиновка	10	0,2
30		Именинский	Именин	10	0,2
31		Осовецкий	Осовцы	10	0,0
32		Попинский	Попина	10	0,5
33			Заречка	10	0,0
34		Радостовский	Радостово	10	2,0
35			Сваринь	10	1,0
36		Хомский	Хомск	10	0,0
37			г. Дрогичин	10	0,5
38	Жабинковский		Жабинка	10	0,3
39			Бульково	10	0,0
40			Озяты	10	0,4
41			Хмелево	10	0,0
42			Редьковичи	10	0,0
43	Ивановский	Бродницкий	Бродница	10	0,1
44			Потаповичи	10	0,2
45		Горбахский	Горбаха	10	0,0
46			Глинно	10	0,3
47		Достоевский	Достоево	10	0,4
48		Дружиловичский	Дружиловичи	10	0,2
49		Крытышинский	Крытышин	10	0,2
50		Лясковичский	Лясковичи	10	0,0
51		Мохровский	Мохро	10	1,0
52		Мотольский	Мотоль	10	0,1
53		Одрижинский	Одрижин	10	0,1
54		Опольский	Ополь	10	0,0
55		Псыщевский	Псыщево	10	0,2
56		Рудский	Сухое	10	0,2
57			Рудск	10	1,0
58		Снитовский	Снитово	10	0,1
59		Стрельненский	Стрельно	10	0,0
60			Иваново	10	0,5
61	Иванцевичский		Иванцевичи	10	0,3
62			Телеханы	10	0,3
63			Яглевичи	10	0,2
64			Житлин	10	0,0
65			Колонск	10	1,0
66			Святая Воля	10	1,0
67			Коссово	10	0,0
68			Бытень	10	0,2
69	Каменецкий		Волчин	10	0,0
70			Каменюки	10	0,0
71			Каленковичи	10	0,0
72			Каменец	10	0,0
73	Кобринский		Городец	10	0,1
74			Залесье	10	0,0
75			Хидры	10	0,0
76			Новоселки	10	0,2
77			Повитье	10	0,0
78			Еремичи	10	0,0
79			Леликово	10	0,1
80			Кобрин	10	0,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
81	Ляховичский		Ляховичи	10	0,0
82	Лунинецкий	Богдановский	Богдановка	10	0,5
83		Бостынский	Бостынь	10	0,3
84			Велута	10	0,2
85			Новоселки	10	0,2
86		Вульковский	Бродница	10	3,0
87			Вулька 2	10	7,0
88			Добрая Воля	10	5,0
89			Застенок	10	5,0
90			Красная Воля	10	6,0
91			Галый Бор	10	6,0
92			Межлесье	10	2,0
93		Городокский	Кожан Городок	10	2,0
94			Дребск	10	2,0
95			Цна	10	1,0
96		Дворецкий	Язвинки	10	4,0
97			Яжевки	10	3,0
98			Любожердье	10	2,0
99			Сосновка	10	6,0
100			Ракитно	10	2,0
101			Вичин	10	2,0
102			Дворец	10	2,0
103			Любачин	10	1,0
104			Озерница	10	2,0
105		Дятловичский	ст. Дятловичи	10	0,5
106			Дятловичи	10	2,0
107			Боровцы	10	4,0
108			Куповцы	10	2,0
109		Лахвенский	Лахва	10	3,0
110			Барсуково	10	9,0
111			Обруб	10	1,0
112			Любань	10	2,0
113			Лаковка	10	3,0
114			Периново	10	2,0
115		Лунинский	Дубовка	10	0,3
116			Лунин	10	3,0
117			Поллеский	10	2,0
118			Вулька 1	10	3,0
119			Мелесница	10	4,0
120		Микашевичский	Морщиновичи	10	1,0
121			Запросье	10	1,0
122			Ситница	10	1,0
123			Микашевичи	10	2,0
124		Редигировский	Флерово	10	4,0
125			Редигирово	10	2,0
126			Черебасово	10	2,0
127			Моносеево	10	1,0
128		Синкевичский	Лутовень	10	1,0
129			Синкевичи	10	2,0
130			Острово	10	2,0
131			Мокрово	10	1,0
132			Ситницкий Двор	10	2,0
133		Чучевичский	Б. Чучевичи	10	0,1
134			М. Чучевичи	10	0,2
135			Боровики	10	0,2
136			Луги	10	1,0
137			г. Лунинец	10	2,0
138			Кормуж	10	0,3
139	Малоритский		Олтуш	10	0,1
140			Черняны	10	0,0
141			Малорита	10	0,0
142	Пинский	Березцовский	Березцы	10	1,0
143		Березовичский	Березовичи	10	0,5
144		Бобриковский	Бобрик	10	1,0
145		Боричевский	Боричевичи	10	0,4
146			Гривковичи	10	0,4
147			Тырвовичи	10	0,2
148		Валищенский	Валище	10	1,0
149		Городищенский	Вулька	10	1,0
150			Сушицк	10	0,5
151			Городище	10	1,0
152		Дубойский	Кончицы	10	0,2
153			Дубое	10	1,0
154			Перекресье	10	5,0
155			Сосновичи	10	2,0
156		Ласицкий	Ласицк	10	0,2
157			Ладорож	10	7,0
158			Жолкино	10	0,4
159			Вешня	10	0,1
160			Трушево	10	0,4
161			Остров	10	0,3
162		Каллауровичский	Каллауровичи	10	2,0
163			Кудричи	10	1,0
164		Ласицкий	Паре	10	4,0
165		Лемешевичский	Гнеребень	10	0,5
166			Лемешевичи	10	1,0
167		Лыщенский	Лыще	10	0,5
168		Логишинский	Логишин	10	1,0
169		Лопатинский	Лопатин	10	0,2
170			Колбы	10	0,3

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
171		Мерчицкий	Мерчицы	10	1,0
172		Молотковичский	Молотковичи	10	0,2
173			Домашицы	10	1,0
174			Жабницы	10	0,3
175		Н. Дворский	Новый Двор	10	0,0
176		Оснежицкий	Оснежицы	10	0,3
177			Вишевичи	10	0,0
178			Галево	10	0,3
179			Тосеничи	10	0,4
180		Оховский	Кошевичи	10	0,2
181			Охово	10	1,0
182		Парохонский	Дубновичи	10	0,2
183			Селищи	10	0,5
184			Сошно	10	1,0
185			Парохонск	10	3,0
186			Ст. Парохонск	10	1,0
187			Вылазы	10	2,0
188			Молодельчицы	10	0,3
189		П. Загородский	П. Загородск	10	1,0
190		Поречский	Поречье	10	1,0
191		Плещицкий	Плещицы	10	0,5
192			Завидчицы	10	1,0
193			М. Дворцы	10	0,4
194			Б. Дворцы	10	0,5
195			Статычево	10	0,1
196		Ставокский	Ставок	10	1,0
197		Хойновский	М. Вулька	10	1,0
198			Хойно	10	2,0
199			Стайки	10	1,0
200			Жидче	10	2,0
201			Невель	10	4,0
202			г. Пинск	10	0,5
203	Столинский	Видиборский	Дубой	10	0,2
204			Осовцы	10	0,4
205		Ремельский	Оздамичи	10	0,3
206			Ремель	10	0,4
207			Теребличи	10	0,3
208		Большемалешевский	Ольгомель	10	0,4
209			Б. Малешево	10	1,0
210			Коротичи	10	1,0
211			Лутки	10	1,0
212			Толкачево	10	1,0
213		Белоушский	Рыбники	10	3,0
214			Белоуша	10	7,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
215		Бережновский	Бережное	10	2,0
216			Бор-Дубенец	10	1,0
217			Дубенец	10	2,0
218		Велемичский	Старина	10	1,0
219		Видиборский	Видибор	10	1,0
220		Глинковский	Глинка	10	2,0
221			Лука	10	1,0
222			Первомайск	10	2,0
223		Городнянский	Городная	10	3,0
224			Деревная	10	1,0
225			Колония	10	5,0
226			Лучица	10	1,0
227		Лядецкий	Б. Орлы	10	1,0
228			Городец	10	1,0
229			Лядец	10	1,0
230			М. Орлы	10	1,0
231		Ольшанский	Высокое	10	1,0
232			Ольшаны	10	1,0
233			Семигостичи	10	1,0
234		Плотницкий	Плотница	10	0,4
235			Стаково	10	0,5
236		Радчицкий	Колодное	10	0,3
237			Радчицк	10	1,0
238			Овсемирово	10	1,0
239		Речицкий п.с.	Бухличи	10	4,0
240			Ворони	10	2,0
241			В. Пиребежов	10	4,0
242			Н. Пиребежов	10	4,0
243			Копани	10	1,0
244			Лютый Бор	10	1,0
245			Пос. Лесной	10	3,0
246			Речица	10	4,0
247		Рубельский	Рубель	10	2,0
248			Хотомель	10	1,0
249		Стружский	Б. Викоровичи	10	1,0
250			М. Викоровичи	10	1,0
251			Ольманы	10	7,0
252			Кошара	10	5,0
253			Струга	10	1,0
254		Столинский г.с.	Маньковичи	10	1,0
255			Отвержичи	10	5,0
256			Крушин	10	2,0
257		Рухчанский	Рухча 1	10	0,0
258		Федоровский	Нечатово	10	2,0
259			Федоры	10	1,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
260		Хоромский	Хорск	10	0,4
261			Лисовичи	10	1,0
262			Туры	10	1,0
263			Уголек	10	1,0
264			Хоромск	10	1,0
265			Давид Городок	10	1,0
266			г. Столин	10	2,0
267	Пружанский		Калядичи	10	0,4
268			Щерчево	10	0,5
269			Ровбицк	10	0,0
270			Пружаны	10	0,3
271			Хорева	10	0,1

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ БССР ЦЕЗИЕМ-137 (Ки/км^2)
(Caesium-137)

ГОМЕЛЬСКАЯ ОБЛАСТЬ (GOMEL)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Обл. подчинения		Гомель	49	2,0
2			Добруш	36	5,0
3			Жлобин	11	3,0
4			Калинковичи	16	1,0
5			Мозырь	15	2,0
6			Речица	14	1,4
7			Рогачев	19	1,2
8	Рогачевский	Районного подчин.	Белицк	15	5,0
9		Болотнянский	Болотня	10	6,0
10			Гутище	10	14,0
11			Зеленая Роща	10	5,0
12			Загребье	10	8,0
13			Хвойник	10	5,0
14			Кристополье	10	6,0
15			Лесное	10	5,0
16			Ленинский	10	7,0
17			Осиновка	10	5,0
18			Победа	10	6,0
19			Ст. Алешня	10	7,0
20		Гадиловичский	Гадиловичи	15	3,0
21		Городецкий	Городец	15	5,0
22		Довский	Довск	19	7,2
23			Ковалевка	11	7,0
24			Клетище	15	9,0
25			Малиновка	15	5,0
26			Хмелец	15	6,0
27			Юдичи	15	7,4
28			Ямнов	15	6,0
29			Старый Довск	10	9,0
30			Сычман	12	10,0
31		Журавичский	Волосовичи	15	8,0
32			Гута	15	5,0
33			Драгунск	15	5,0
34			Журавичи	15	6,0
35			Красногорка	10	7,0
36			Канава	15	5,0
37			Новые Журавичи	15	5,0
38			Прилеповка	10	5,0
39			Пахарь	15	5,0
40		Звонецкий	Борхов	15	6,0
41			Гумнище	15	5,0
42			Дружба	15	5,0
43			Звонец	15	6,4
44			Ильич	15	5,0
45			Шапчицы	15	7,0
46		Курганский	Каменка Рисковская	13	5,0
47			Курганье	15	6,0
48			Малашковичи	15	5,0
49			Рисков	15	7,0
50			Старый Кривск	15	5,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
51			Перекоп	10	6,0
52			Осмоловичи	10	6,0
53			Новый Кривск	15	5,0
54		Столпненский	Столпня	10	9,0
55		Старосельский	Лавы	13	0,9
56	Кормянский	Районного подчин.	Корма	20	18,0
57		Барсуковский	Белев	15	6,0
58			Барсуки	10	5,0
59			Реут	15	5,0
60			Тараховка	14	7,0
61			Барсуки	15	7,0
62			Сырская Буда	10	7,0
63			Новоселки	10	6,0
64		Волынецкий	Волынцы	15	9,0
65			Жауница	21	18,0
66			Кляпин	15	9,0
67			Кляпинская Буда	15	11,0
68			Колюды	15	13,0
69			Ясень	25	19,0
70			Корсунь	10	5,0
71		Ворновский	Ворновка	15	7,0
72			Енцы	15	8,0
73			Острая Корма	15	5,0
74			Рудня	15	11,0
75			Добрич	10	16,0
76			Ивановка	10	10,0
77			Высокая	10	17,0
78			Кавказ	10	15,0
79			Халаповка	10	10,0
80		Золотоминский	Боровая Глинка	15	9,0
81			Золотомино	25	43,0
82			Казимирово	25	7,0
83			Костюковка	25	60,0
84			Лобыревка	25	34,0
85			Никольский	25	8,0
86			Салабута	25	34,0
87			Студенец	25	15,0
88			Хлевно	23	44,0
89			Луначарский	10	6,0
90			Почтовая Глинка	10	6,0
91		Каменский	Березовка	14	6,0
92			Покровский	16	5,0
93			Яновка	15	5,0
94			Лебедевка	10	9,0
95			Каменка	10	8,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
96			Кучин	10	6,0
97			Бор	10	9,0
98		Коротьковский	Бервены	25	26,0
99			Богдановичи	15	10,0
100			Коротьки	15	10,0
101			Остров	15	9,0
102			Сапожки	30	21,0
103			Выношевка	15	9,0
104			Кураковщина	25	10,0
105			Новая Зеньковина	31	21,0
106			Семеновка	13	9,0
107			Старая Зеньковина	31	16,0
108			Сырск	26	7,0
109			Городок	20	36,0
110		Литвиновичский	Вознесенск	15	6,0
111			Вощанки	14	5,0
112			Дубровино	15	12,0
113			Дубролеж	15	5,0
114			Зятковичи	15	10,0
115			Коселяцкий	22	8,0
116			Литвиновичи	25	8,0
117			Рудня	22	17,0
118			Ступень 1	25	10,0
119		Лужковский	Александровка	15	6,0
120			Жабин	15	7,0
121			Новые Рассохи	15	8,0
122			Скартынь	15	3,0
123			Лужок	10	10,0
124			Чамышель	10	9,0
125		Октябревский	Заболоцкое	27	15,0
126			Косель	25	19,0
127			Косельский Прудок	25	18,0
128			Курганье	25	23,0
129			Октябрево	25	10,0
130		Староградский	Берестовец	15	8,0
131			Лубянка	15	5,0
132			Пасека-Слободка	15	7,0
133			Петравичи	15	6,0
134			Староград	15	5,0
135			Задубье	15	8,0
136			Хизов	10	7,0
137		Струкачевский	Буда Боровая	15	7,0
138			Буда Лесовая	15	9,0
139			Городок	15	19,0
140			Дубовица	14	8,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
141			Колосово	15	10,0
142			Михалевка	15	9,0
143			Норковщина	15	7,0
144			Шереховская Буда	15	9,0
145			Жданово	15	6,0
146			Шаломея	10	6,0
147			Правда	10	12,0
148			Моторовка	10	9,0
149		Струменский	Васильевка	19	17,0
150			Курганица	30	12,0
151			Лозовица	26	24,0
152			Малашки	21	9,0
153			Маленик	19	10,0
154			Осов	19	8,0
155			Струмень	27	42,0
156			Труд	21	10,0
157	Чечерский	Районного подчин.	Чечерск	26	16,0
158		Горсовет	Красный Берег	12	6,0
159		Беляевский	Беляевка	27	5,0
160			Загорье	20	11,0
161			Закриничный	23	12,0
162			Пехтерово	19	5,0
163			Слободка	25	33,0
164			Томино	18	5,0
165			Салтановка	10	15,0
166			Бобровский	25	15,0
167			Каменка	10	5,0
168			Подыгрушка	10	10,0
169		Залесский	Городовка	16	9,0
170			Добрынь	14	11,0
171			Дубок	15	6,0
172			Кукличи	18	7,0
173			Подосовье	11	23,0
174			Покоть	14	7,0
175			Залесье	10	13,0
176		Крутоевский	Алексеевка	23	26,0
177			Белица	24	20,0
178			Рассвет	25	15,8
179			Братство	19	34,0
180			Вольск	25	32,0
181			Дубровка	25	49,0
182			Залавье	25	23,0
183			Заря	26	28,0
184			Крутое	28	22,0
185			Медвежье	25	18,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
186			Науховичи	25	30,0
187			Нивки	25	7,0
188			Новые Малыничи	15	7,0
189			Самсоновка	32	29,0
190			Слободка	26	22,0
191			Сойки	25	20,0
192			Средние Малыничи	15	6,0
193			Старые Малыничи	15	5,0
194			Поплавы-Лукомские	23	29,0
195			Шапрудовка	11	14,0
196		Ленинский	Бердыж	14	9,0
197			Вознесенский	15	9,0
198			Ивановка	25	16,0
199			Михайловский	18	7,0
200			Новозаречье	21	42,0
201			Озерище	15	7,0
202			Подлужье	25	25,0
203			Поплавы-Шепотовичские	31	72,0
204			Себровичи	23	45,0
205			Селянин	15	9,0
206			Чернявские Малыничи	25	13,0
207			Шепотовичи	21	73,0
208		Меркуловичский	Алес	14	5,0
209			Ботвиново	13	5,0
210			Бошица	14	6,0
211			Ветвица	15	6,0
212			Зеленая Поляна	15	7,0
213			Искра	14	5,0
214			Красница	14	5,0
215			Меркуловичи	14	6,0
216			Осиновка	15	7,0
217			Первомайский	14	6,0
218			Причалесня	15	5,0
219			Прогресс	15	6,0
220			Шерихово	14	5,0
221			Шиловичи	15	6,0
222			Широкая	14	5,0
223		Нисимковичский	Бабичи	13	6,0
224			Гаек	14	5,0
225			Ивановка	14	5,0
226			Ключевой	16	5,0
227			Никольск	15	6,0
228			Нисимковичи	14	6,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
229			Рудня-Нисимковичская	14	6,0
230			Сычевка-Нисимковичская	20	8,0
231			Сычевка-Рудницкая	15	6,0
232			Ямицкое	14	5,0
233			Усошное	15	5,0
234			Гатское	10	7,0
235			Гудок	10	7,0
236			Маковье	10	5,0
237			Ново-Никольск	10	6,0
238			Ново-Залесье	10	7,0
239		Полесский	Барсуки	19	5,0
240			Болсуны	21	8,0
241			Заручье	18	7,0
242			Палом	25	35,0
243			Полесье	11	9,0
244			Коммунар	16	5,0
245			Безбожный	13	5,0
246			Калинино	10	10,0
247		Ровковичский	Гольч	15	7,0
248			Дружбичи	18	15,0
249			Заложье	15	5,0
250			Зеленый Мох	25	15,0
251			Кораблище	15	9,0
252			Кураки	19	5,0
253			Любимое	23	14,0
254			Макеевка	14	7,0
255			Максимовский	18	16,0
256			Мотневичи	15	8,0
257			Никольск	15	6,0
258			Подозерье	23	13,0
259			Раков Лог	20	8,0
260			Решище	21	5,0
261			Ржавец	15	5,0
262			Ровковичи	24	14,0
263			Васильевский	21	15,0
264			Мокрень	16	11,0
265		Сидоровский	Высокая Грива	19	8,0
266			Будище	25	15,0
267			Дзержинский	15	5,0
268			Осиновка	27	24,0
269			Рудня-Бартоломеевка	24	11,0
270			Сидоровичи	10	7,0
271			Волосовичи	10	7,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
272			Передовик	10	5,0
273			Гута-Осиновская	25	15,0
274		Холочский	Болтово	25	32,0
275			Восход	15	35,0
276			Дубовица	25	29,0
277			Дудичи	25	29,0
278			Канавы	25	27,0
279			Красный	29	32,0
280			Новохолочье	25	23,0
281			Новый Путь	15	26,0
282			Поскобовка	17	27,0
283			Пролетарский	25	24,0
284			Рудня Дудичская	26	32,0
285			Холочье	25	23,0
286			Ясная Поляна	17	28,0
287		Чечерский	Брилево	15	5,0
288			Восход	15	6,0
289			Городок	15	6,0
290			Единство	15	7,0
291			Ковалев Рог	25	9,0
292			Коробка	15	8,0
293			Красный Бор	15	6,0
294			Красный Дворец	14	6,0
295			Новая Яцковщина	15	6,0
296			Новозахарполье	23	7,0
297			Октябрь	15	5,0
298			Отор	25	10,0
299			Покровский	15	5,0
300			Саприки	25	5,0
301			Старая Яцковщина	14	6,0
302			Турищевичи	11	7,0
303			Юный	14	5,0
304			Глубочица	10	5,0
305			Ипполитовка	15	15,0
306	Октябрьский	Ломовичский	Ломовичи	13	0,4
307		Любанский	Любань	12	0,6
308		Протасовский	Протасы	14	0,3
309	Светлогорский	Районного подчин.	Сосновый Бор	10	2,0
310		Красновский	Васильевка	15	6,0
311			Дражня	10	4,0
312			Ковчицы 1	10	0,4
313			Королевская Слобода 1	15	7,0
314			Красновка	10	0,6
315			Малимоны	10	0,3

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
316		Николаевский	Вяжны	10	0,4
317		Чирковичский	Жердь	10	0,4
318			Страковичи	10	1,0
320	Жлобинский	Кировский	Кирово	10	3,0
321			Питеровка	10	4,0
322			Селивоновка	10	4,0
323			Шапарня	10	2,0
324		Луковский	Луки	12	2,0
325		Радушский	Круги	10	0,6
326		Стрешинский	Стрешин	10	0,9
327	Буда-Кошелевский	Районного подчин.	Буда-Кошелево	12	3,0
328		Глазовский	Ивановка	15	1,0
329			Житонеж	15	1,0
330		Дуравичский	Болдуи	17	7,0
331			Броды	16	6,0
332			Бурлак	16	9,0
333			Дубовица	15	7,0
334			Дуравичи	20	7,0
335			Залуневье	18	6,0
336			Ленино	15	7,0
337			Мачулище	17	9,0
338		Заболотский	Борки	23	35,0
339			Веселый Курган	40	26,0
340			Веселый Пахарь	41	33,0
341			Заболотье	20	10,0
342			Застенный	25	29,0
343			Кучинск	25	16,0
344			Никольск	28	11,0
345			Новозаболотье	29	21,0
346			Хорошевка	25	24,0
347			Восход	29	16,0
348			Долгий	32	14,0
349		Ивольский	Букалов	15	1,0
350			Дунай	14	1,0
351			Ивольск	18	1,0
352			Красный Лужок	15	1,0
353			Осов	15	1,0
354			Синичино	14	2,0
355		Калининский	Калинино	19	5,0
356			Руденец	13	2,0
357			Уза	17	4,0
358		Коммунарский	Блюдница	20	3,0
359			Зимник	10	5,0
360			Особино	10	6,0
361			Подсеменовка	10	7,0
362			Северный	10	5,0
363			Маковье	10	7,0
364			Коммунар	13	5,0
365		Кошелевский	Брилев	20	5,0
366			Великий Мох	16	3,0
367			Городище	15	8,0
368			Кошелев	25	5,0
369			Кулешовка	14	11,4
370			Любица	16	6,0
371			Озеро Пойма	10	5,0
372			Рудня-Кошелевская	10	5,0
373			Рудня-Викторинская	10	5,0
374			Староселье	15	6,0
375			Шарибовка	18	4,0
376			Селец	20	8,0
377		Кривский	Бацунь	10	2,0
378			Кривск	10	7,0
379		Липиничский	Струки	12	8,0
380			Борок	10	5,0
381			Буда	10	6,0
382			Бронница	10	6,0
383			Зеленый Дуб	10	5,0
384			Зеленая Роща	10	9,0
385			Люшев	10	8,0
386			Липиничи	10	8,0
387			Новый Путь	10	5,0
388			Первомайский	10	7,0
389			Солтановка	10	5,0
390			Якимовка	10	5,0
391		Морозовичский	Березина	12	2,0
392			Бушевка	10	0,4
393		Недойский	Боец	10	1,0
394			Еленец	10	0,3
395			Старая Буда	10	1,0
396		Николаевский	Выдрица	10	5,0
397			Головачи	10	6,0
398			Зорька	10	6,0
399			Прибор	10	6,0
400		Октябрьский	Боевой	28	48,0
401			Герой	35	16,0
402			Затишье	24	21,0
403			Красный Октябрь	20	6,0
404			Липа	25	40,0
405			Лугиничи	25	17,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
406			Лукьяновка	20	33,0
407			Луч	15	5,0
408			Новая Липа	20	15,0
409			Октябрь	20	6,0
410			Пытьковка	28	8,0
411			Уютный	25	17,0
412			Череповка	15	6,0
413		Потаповский	Гавли	16	2,0
414			Галы	17	2,0
415			Дубровка	19	2,0
416			Забабье	16	1,0
417			Медведево	19	2,0
418			Муравей	20	1,0
419			Победа	10	2,0
420			Потаповка	21	4,0
421		Рогинский	Антоновка	20	6,0
422			Михалевка	15	6,8
423			Дербичи	15	7,0
424			Коромка	15	7,0
425			Курганье	19	5,0
426			Лозов	10	6,0
427			Моисеевка	19	6,0
428			Рогинь	20	6,0
429			Рудня	20	5,0
430			Слободка	22	7,0
431			Факел	15	3,0
432		Уваровичский	Высокая Грива	16	3,0
433			Лапичи	13	3,0
434			Радеево	26	2,0
435			Теклевка	16	2,0
436			Уваровичи	11	3,0
437		Чеботовичский	Заречье	15	0,7
438			Зеленая	15	0,8
439			Кленовица	15	1,0
440			Красный	15	0,7
441			Крылов	16	0,6
442			Смычек	14	0,5
443			Столпище	15	0,8
444			Чеботовичи	19	1,0
445		Широковский	Александровка	26	6,0
446			Андреевка	30	15,0
447			Березовая Роща	20	10,0
448			Ерополье	25	11,0
449			Колос	20	11,0
450			Колотин	24	15,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
451			Коминтерн	25	11,0
452			Красногорский	21	6,0
453			Михалевка	20	5,0
454			Новая Гута	25	16,0
455			Новый Свет	39	12,0
456			Присенщина	23	18,0
457			Соловьевка	23	17,0
458			Широкое	19	5,0
459			Череты	16	7,0
460			Чернятин	23	6,0
461			Черняцкая Поляна	25	8,0
462	Ветковский	Районного подчин.	Ветка	18	20,0
463		Акшинковский	Акшинка	30	22,0
464			Габровка	29	35,0
465			Залужье	27	21,0
466			Мальков 1 (нов)	17	18,0
467			Мальков 2 (стар)	29	19,0
468			Нестеровка	27	19,0
469			Подлоги	19	26,0
470			Подлужье	27	22,0
471			Решительный	25	8,0
472			Симоновка	17	19,0
473			Усохи	22	17,0
474			Скачек	16	15,0
475		Бартоломеевский	Бартоломеевка	25	40,0
476			Беседь	29	42,0
477			Воробьевка	24	46,0
478			Восток	16	22,0
479			Лески	23	43,0
480			Осово	29	46,0
481			Петуховка	38	47,0
482			Побужье	22	43,0
483		Великонемковский	Антоновка	15	8,0
484			Великие Немки	14	5,0
485			Даринполье	12	3,0
486			Казацкие Болсуны	13	5,0
487			Новое Залядье	12	5,0
488			Новомихайловка	14	10,0
489			Победа	13	5,0
490		Даниловичский	Борки	12	9,0
491			Выгорь	15	8,0
492			Даниловичи	13	6,0
493			Замостье	12	11,0
494			Зеленая Хвоя	12	6,0
495			Красный Пахарь	13	7,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
496			Новины	10	8,0
497			Первомайский	10	8,0
498			Пролетарский	12	11,0
499			Пыхань	13	7,0
500			Середняцкий	10	5,0
501			Синий Остров	10	5,0
502			Шевцов	12	7,0
503			Хрущовка	14	10,0
504		Калининский	Купреевка	23	21,0
505			Рудня-Спонинская	23	10,0
506			Тарасовка	26	10,0
507			Тумарин	13	9,0
508			Чистые Лужи	13	5,0
509		Малонемковский	Затишье	10	4,0
510			Иванькин	10	5,0
511			Малые Немки	12	4,0
512			Память	10	2,0
513			Перелевка	13	9,0
514		Неглюбский	Гибки	33	37,0
515			Коновалово	26	8,0
516			Лядо	24	16,0
517			Неглюбка	24	10,0
518			Перевесье	25	11,0
519			Передовец	26	17,0
520			Репище	32	17,0
521			Свобода	24	16,0
522			Селище	23	17,0
523			Синицыно	27	16,0
524		Новиловский	Новиловка	24	26,0
525			Петрополье	26	30,0
526			Селицкое	26	32,0
527			Федоровка	22	12,0
528		Новогромыкский	Глыбовка	22	12,0
529			Куты	28	5,0
530			Новые Громыки	22	32,0
531			Подгорье	16	5,0
532			Потесы	25	29,0
533			Рудня-Столбунская	13	5,0
534			Шейка	19	20,0
535		Приснянский	Барченки	12	9,0
536			Однополье	10	14,0
537			Присно	12	6,0
538		Радужский	Контуровка	26	11,0
539			Новая Жизнь	12	6,0
540			Новый Мир	12	9,0
541			Радуга	22	12,0
542		Речковский	Заречье	28	33,0
543			Пролетарский	21	26,0
544			Речки	24	37,0
545			Рудня-Шлягина	28	33,0
546			Рыславль	26	50,0
547			Ухово	26	29,0
548			Рудня-Гулева	18	41,0
549			Камылин	20	31,0
550			Первомайский	15	35,0
551		Светиловичский	Глуховка	14	9,0
552			Железники	24	16,0
553			Малиновка	16	4,0
554			Некрасово	22	17,0
555			Непобедимый	20	7,0
556			Нинель	12	6,0
557			Светиловичи	27	20,0
558			Чемерня	16	5,0
559		Сивинский	Борьба	22	32,0
560			Ириновка	21	40,0
561			Косицкое	29	33,0
562			Красный Путь	23	35,0
563			Красный Угол	22	31,0
564			Попсуевка	20	36,0
565			Сивинка	26	32,0
566		Старозакружский	Амельное	25	25,0
567			Гута	21	43,0
568			Подкаменье	20	42,0
569			Старое Закружье	20	34,0
570		Столбунский	Городок	20	6,0
571			Калинин	31	16,0
572			Колбовка	24	6,0
573			Столбун	16	5,0
574			Уютный	28	5,0
575			Юрга	22	7,0
576		Хальченский	Борец	12	7,0
577			Золотой Рог	13	7,0
578			Каничев	13	5,0
579			Победа	12	6,0
580			Поляновка	23	10,0
581			Станки	10	4,0
582			Старое Село	18	6,0
583			Хальч	27	15,0
584		Хизовский	Быковец	10	45,0
585			Гарусты	10	21,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
586			Новоивановка	18	33,0
587			Старые Громыки	20	23,0
588			Хизы	25	50,0
589			Гута	15	43,0
590		Шерстинский	Ляды	16	13,0
591			Новоселки	22	22,0
592			Романов Лес	18	11,0
593			Шерстин	21	18,0
594			Юрковичи	24	18,0
595			Ягодный	14	12,0
596			Ильич	15	8,0
597		Яновский	Будище-Столбунское	11	3,0
598			Желудье	22	3,0
599			Лазаревский	17	5,0
600			Расуха	22	7,0
601			Яново	17	6,0
602			Ветковское Лес-во	15	35,0
603			Закружское Лес-во	15	32,0
604	Житковичский	Районного подчин.	Житковичи	17	2,0
605		Бронеславский	Гряда	14	1,0
606		Люденевичский	Люденевичи	14	4,0
607		Мороховский	Семенча	13	0,3
608		Рудненский	Борки	15	0,6
609			Гребень	14	1,0
610	Петриковский	Районного подчин.	Петриков	14	1,0
611			Копаткевичи	12	0,5
612		Концевичский	Копцевичи	19	0,5
613		Мышанский	Мышанка	12	1,0
614		Птичский	Птичь	10	0,7
615	Калинковичский	Горбовичский	Горбовичи	14	1,0
616		Березовский	Березовка	15	10,0
617			Игнатовка-Фабияновка	13	3,0
618			Малые Водовичи	14	5,0
619			Обуховщина	15	7,0
620			Огородники	12	7,0
621			Слободка	14	5,0
622		Горочичский	Руденька	10	1,4
623			Сельцы	10	0,9
624		Наховский	Селище	10	2,0
625			Лозки	16	2,0
626		Михновичский	Клинск	25	1,2
627		Прудокский	Крышичи	15	3,0
628			Прудок	12	2,0
629		Малоавтюковский	Малые Автюки	10	2,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
630		Хобненский	Деревище	10	2,0
631		Юровичский	Юровичи	14	2,0
632	Речицкий	Белоболотский	Черное	14	1,0
633		Борщовский	Борщовка	14	1,0
634		Жмуровский	Ивановка	13	3,0
635			Жмуровка	14	0,8
636			Бронное	10	0,9
637		Капоровский	Капоровка	15	2,0
638			Лазаревка	14	2,0
639		Короватичский	Короватичи	20	2,0
640			Тишковка	15	1,0
641		Лисковский	Лиски	18	1,0
642		Новобарсуковский	Малодуша	15	2,0
643			Сергеевка	15	2,0
644		Ровенско-Слободский	Смогорин	14	2,0
645		Пересвятский	Коростань	14	1,0
646	Гомельский	Бобовичский	Бобовичи	14	0,4
647			Борец	11	0,4
648			Цыкуны	14	0,5
649		Большевик	Песчаная	10	5,0
650		Красненский	Пролетарий	14	3,0
651		Маримоновский	Рудня Жигальская	12	0,8
652		Приборский	Новая Буда	15	0,6
653		Севрюковский	Ченки	15	0,5
654		Старобелицкий	Островы	15	5,0
655		Шарпиловский	Михайловск	14	1,0
656		Терюховский	Студеная Гута	20	0,5
657			Новая Гута	15	0,5
658	Добрушский	Борщовский	Борщевка	11	0,5
659		Васильевский	Васильевка	21	0,8
660			Красные Олесы	19	0,3
661			Красный Рог	18	0,8
662			Орел	21	0,4
663		Горсовет	Добрушское Лес-во	14	9,8
664		Демьянковский	Большой Лес	29	24,0
665			Вылево	43	60,0
666			Демьянки	33	23,0
667			Дубовый Лог	30	20,0
668			Красное Знамя	34	36,0
669			Леонтьево	34	22,0
670			Млынок	34	38,0
671		Дубровский	Дмитриевский	10	0,2
672			Дубровка	21	0,1
673			Красная Буда	21	0,4

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
674			Лукьяновка	10	0,1
675		Жгуно-Будский	Жгунь	21	0,7
676			Жгунская Буда	21	0,7
677		Иваковский	Вербов	21	0,3
678			Иваки	21	0,3
679			Надежда	10	0,1
680			Борок	18	0,2
681		Кормянский	Дубецкий	34	28,0
682			Зайцев	37	15,0
683			Закопытье	32	32,0
684			Колодье	26	9,0
685			Корма	21	8,0
686			Плоское	39	27,0
687			Селище 1	40	11,0
688			Селище 2	20	18,0
689		Круговец-Калининский	Веселовка	10	0,1
690			Круговец-Калинино	10	0,1
691			Усохи	21	0,1
692		Круговский	Березки	29	31,0
693			Красный Лог	29	49,0
694			Круговка	31	23,0
695			Морозовка	26	18,0
696			Очеса-Рудня	43	56,0
697			Пенное	33	72,0
698			Ясная Долина	29	23,0
699		Крупецкий	Высокое	10	0,6
700			Высокополье	10	5,0
701			Иговка	10	1,0
702			Майский	10	5,0
703			Мостище	10	0,4
704			Новый Крупец	10	0,3
705			Покровский	22	7,0
706			Старый Крупец	21	0,4
707			Ясенки	10	5,0
708		Кузьминичский	Галое	18	2,0
709			Знамя	10	1,0
710			Красный Камень	13	6,0
711			Красный Партизан	31	2,0
712			Кузьминичи	26	2,6
713			Слобода	19	5,0
714			Степанов	12	7,0
715		Ленинский	Завидовка	10	0,2
716			Лениндар	10	0,3
717			Ленино	10	0,2

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
718		Носовичский	Антоновка	10	0,5
719			Запрудовка	10	0,2
720			Ковалев	21	0,2
721			Красная Гора	21	0,1
722			Красный Октябрь	10	0,1
723			Логуны	10	0,3
724			Новодружский	21	3,0
725			Носовичи	12	0,2
726			Первомайский	10	2,0
727			Светлый	10	0,1
728			Семеновский	10	0,1
729			Староселье	21	0,1
730		Огородня-Гомельский	Огородня-Гомельская	37	5,0
731			Огородня-Кузьминичская	14	5,0
732			Уборок	34	17,0
733			Хорошевка	37	15,0
734		Переростовский	Березняки	21	1,0
735			Красный Курган	10	0,3
736			Лебедевка	10	0,2
737			Новая Жизнь	10	0,2
738			Новый Мир	21	0,2
739			Перерост	20	1,0
740			Перерост Хутор	10	1,0
741		Рассветовский	Василевка	22	5,0
742			Дударево	21	1,0
743			Залесье	32	7,0
744			Ларищево	22	1,0
745			Марьино	27	5,0
746			Рассвет	21	1,0
747			Шабринское Лес-во	20	7,1
748		Усохо-Будский	Андреевка	21	0,1
749			Николаевка	11	0,1
750			Ольховое	11	0,1
751			Усохская Буда	21	0,1
752		Утевский	Антоново	21	0,3
753			Гордуны	22	2,0
754			Зарадвинье	19	6,0
755			Иванполье	15	7,0
756			Степь	10	0,5
757			Уть	10	0,1
758		Тереховский	Высокий Хутор	10	0,3
759			Грушевка	10	1,0
760			Криничный	10	0,2

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
761			Нивки	24	1,0
762			Прудовка	10	1,0
763			Тереховка	10	0,1
764	Лельчицкий	Районного подчин.	Лельчицы	25	2,5
765			Лельчицы (метеостанция)	10	2,5
766		Буйновичский	Буйновичи	24	2,0
767			Зарубаное	24	2,0
768			Синицкое Поле	24	2,0
769		Глушкевичский	Глушкевичи	13	2,0
770		Гребеневский	Гребени	30	7,0
771			Лохница	25	4,0
772			Усов	39	15,0
773			Жмурное	10	5,0
774			Запесочное	10	5,0
775			Вороново	15	15,0
776		Дубровский	Дуброва	24	2,0
777		Замошский	Замошенье	15	0,9
778			Ударная	15	2,0
779			КрасноБережье	14	5,0
780		Милашевичский	Милашевичи	15	1,0
781			Приболовичи	15	0,9
782		Острожанский	Убортская Рудня	15	0,7
783		Стодоличский	Забродье	14	4,0
784		Тонежский	Тонеж	15	2,0
785			Иванова Слобода (пос)	15	0,7
786	Мозырский	Козенский	Козенки	13	1,0
787		Каменковский	Березовка	15	10,0
788		Криничанский	Лубня	13	2,0
789		Махновичский	Махновичи	12	1,4
790			Зеленый Мох	12	2,0
791		Михалковский	Митьки	15	2,0
792			Рудня	13	1,0
793		Прудковский	Меребель	21	1,0
794			Прудок	14	1,0
795	Ельский	Районного подчин.	Ельск	15	7,0
796		Богутичский	Богутичи	13	7,0
797			Забозье	15	9,0
798			Красный Остров	15	2,0
799		Валавский	Шия	10	9,0
800		Горсовет	Красный Пильщик	13	2,0
801		Зосинцевский	Гриши	15	4,0
802			Казимировка	13	1,0
803			Капсаны	18	2,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
804			Ковали	15	3,0
805			Козлы	12	1,0
806			Подгалье	14	2,0
807			Серые	11	2,0
808			Сугаки	11	2,0
809			Шатуны	15	2,0
810			Шуты	15	2,0
811		Кочищевский	Калиновое	15	9,0
812			Чертень	10	6,0
813			Некрашевка	15	6,0
814		Млынокский	Бобруйки	16	9,0
815			Даниловка	15	9,0
816			Добрынский	15	6,0
817			Добрынь	15	8,0
818			Млынок	25	7,0
819			Осовы	23	14,0
820			Половки	13	7,0
821			Половковский Млынок	10	14,0
822			Санюки	10	3,0
823		Роза-Люксембургский	Зеленый Бор	15	13,0
824			Новая Рудня	15	10,0
825			Роза Люксембург	15	12,0
826			Словечно	15	13,0
827		Скородненский	Баранцы	15	5,0
828			Беки	15	6,0
829			Демиды	15	5,0
830			Захарки 2	15	6,0
831			Кузьмичи	36	17,0
832			Погорелое	15	9,0
833			Потапы	15	11,0
834			Сизаны	15	3,0
835			Скородное	15	7,0
836			Старый Мост	15	6,0
837			Шишки	25	11,0
838		Старовысоковский	Чапаевка	15	8,0
839			Николаевка	15	3,0
840			Прачемышля	14	2,0
841	Наровлянский	Районного подчин.	Наровля	30	17,0
842		Вербовичский	Вербовичи	22	18,0
843			Дворище	29	18,0
844			Конотоп	24	25,0
845			Антонов	22	15,0
846			Грушевка	22	16,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
847		Головчицкий	Буда	34	6,0
848			Будки	25	11,0
849			Гажин	24	9,0
850			Головчицы	24	16,0
851			Демидов	24	13,0
852			Красный Борец	20	13,0
853			Красный Луч	22	11,0
854			Красный Остров	27	15,0
855			Линов	20	7,0
856			Победа	15	9,0
857			Свеча	14	11,0
858			Чехи	24	16,0
859			Лубень	24	27,0
860			Мальцы	14	13,0
861		Горсовет	Гута	30	17,0
862			Заракитное	25	26,0
863			Ласка	27	13,0
864			Физинки	27	11,0
865		Завойтянский	Завойть	24	16,0
866			Калиничи	24	14,0
867			Романовка	24	22,0
868			Смолегов	25	23,0
869			Смолеговская Рудня	34	35,0
870		Кировский	Александровка	24	4,0
871			Братская	15	5,0
872			Габрилеевка	14	4,0
873			Кирово	19	31,0
874			Хильчиха	23	23,0
875			Хутор Сергеев	24	6,0
876			Дятлик	15	4,0
877		Красновский	Буда-Красновская	24	5,0
878			Дзержинск	22	16,0
879			Красновка	15	5,0
880			Москалевка	22	17,0
881			Ничипоровка	23	22,0
882			Хаменки	25	25,0
883	Хойникский	Районного подчин.	Хойники	20	6,0
884		Алексичский	Алексичи	18	8,0
885			Глинище	17	5,0
886			Гречихина	16	5,0
887			Дуброва	19	5,0
888			Застенок	19	7,0
889			Кореневка	15	4,0
890			Моклище	16	8,0
891			Нариманов	15	4,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
892			Поселок Ленина	11	9,0
893			Рабец	18	5,0
894			Слобожанка	11	5,0
895			Туневщина	22	6,0
896			Хвойное	17	3,0
897			Хорошеевка	12	5,8
898		Борисовщинский	Борисовщина	16	7,0
899			Вить	18	7,0
900		Великоборский	Бересневка	24	2,0
901			Великий Бор	25	3,0
902			Избынь	34	2,0
903			Осов	24	2,0
904			Партизанская	23	2,0
905			Руденка	24	4,0
906			Старч	26	3,0
907			Хвойная Поляна	23	2,0
908		Горсовет	Будовник	26	3,0
909			Езефов	21	9,0
910			Красная Нива	22	4,0
911			Малешев	31	5,7
912			Настолье	19	6,0
913			Пальмира	16	12,0
914		Дворищенский	Людвин	22	14,0
915			Новоселки	27	19,1
916			Пикулиха	16	10,0
917			Рудное	16	14,0
918			Смирнов	23	16,0
919			Судков	16	9,0
920			Храпков	17	7,0
921		Козелужский	Загалье	17	6,0
922			Загальская Слободка	18	3,0
923			Куровое	24	4,0
924			Небытов	17	3,0
925			Кливы	10	5,0
926			Козелужье	12	6,0
927			Поташня	16	5,0
928		Омельковщинский	Дубровица	27	8,0
929			Омельковщина	24	25,0
930			Рашев	25	14,0
931		Поселичский	Берестечко	15	16,0
932			Велитин	28	13,0
933			Горошков	14	3,0
934			Звинятское	26	13,0
935			Карпиловка	27	5,0
936			Королин	14	20,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
937			Корчевое	16	3,0
938			Красная Заря	15	22,0
939			Красный Пахарь	14	4,0
940			Листвин	14	17,0
941			Мархлевск	15	21,0
942			Октябрь	15	4,0
943			Петраш	14	16,0
944			Поселичи	14	14,0
945			Пудаков	25	13,0
946			Сокол	16	15,0
947		Рудаковский	Высокое	32	13,0
948			Плоское	25	26,0
949			Рудаков	26	10,0
950			Рудые	25	29,0
951			Чехи	25	25,0
952			Мокиш	27	20,0
953		Стреличевский	Губоревичи	25	11,0
954			Ивановка	28	15,0
955			Красное Озеро	24	15,0
956			Красный Рог	22	12,0
957			Пос. им. Ленина	22	11,0
958			Стреличево	30	17,0
959		Тульговичский	Буда	20	19,0
960			Ломачи	20	63,0
961			Ломыш	15	18,0
962			Тульговичи	17	21,0
963	Брагинский	Районного подчин.	Брагин	18	27,0
964			Комарин	27	3,0
965		Асаревичский	Асаревичи	16	3,0
966			Вялье	24	3,0
967			Галки	15	2,0
968		Верхнежарский	Верхние Жары	15	1,0
969			Нижние Жары	15	2,0
970		Гденский	Гдень	20	5,0
971			Скородное	20	3,0
972			Чикаловичи	30	5,0
973			Заречье	18	5,8
974			Стежерное	16	5,0
975			Городок	16	4,0
976		Кривченский	Дубровка	19	3,0
977			Красная Нива	17	2,0
978			Алексеевка	16	5,0
979			Кривча	22	3,0
980			Переносы	15	3,0
981			Демеевка	16	3,0
982		Малейковский	Городище	21	6,0
983			Котловица	22	5,0
984			Малейки	21	8,0
985			Новый Мокрец	15	4,0
986			Петрицкое	21	4,0
987			Старый Мокрец	15	3,0
988			Стежерное	10	5,0
989			Селец	22	5,0
990			Пацков	13	7,0
991			Тельман	17	6,0
992		Маложинский	Бересневка	26	2,0
993			Громкий	30	1,0
994			Доброгоща	26	1,0
995			Жиличи	26	1,0
996			Красная Поляна	20	4,0
997			Маложин	28	2,0
998			Рытов	26	3,0
999		Микуличский	Великий Лес	15	2,0
1000			Кононовщина	16	3,0
1001			Красная Горка	16	21,0
1002			Микуличи	16	17,0
1003			Красное Поле	18	9,0
1004			Рыжков	16	10,0
1005		Новоиолченский	Березки	19	3,0
1006			Голубовка	10	6,0
1007			Нивки	10	2,0
1008			Красное	13	5,0
1009			Новая Иолча	10	4,0
1010			Осинник	10	14,0
1011			Старая Иолча	12	4,0
1012			Александровка	10	3,0
1013		Остроглядовский	Вязок	10	43,0
1014			Дубровное	18	15,0
1015			Маритон	17	10,0
1016			Ковали	19	10,0
1017			Бакуны	18	12,0
1018			Бурки	19	11,0
1019			Щербины	19	17,0
1020		Храковичский	Сувиды	46	6,0
1021			Ляды	30	3,0
1022			Двор-Савичи	20	3,0
1023			Грушное	36	3,0
1024			Просмычи	29	4,0
1025			Целуйки	27	3,0
1026			Калинин 1 (Калининский)	26	5,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1027			Ленинский	36	2,0
1028			Новая Гребля	28	4,0
1029			Новые Храковичи	25	4,0
1030			Старые Храковичи	15	4,0
1031		Сперижский	Волоховщина	24	7,0
1032			Дублин	18	7,0
1033			Михалов	24	12,0
1034			Старые Юрковичи	18	3,0
1035		Угловский	Команов	18	5,0
1036			Лубеники	22	3,0
1037			Майский	20	3,0
1038			Михновка	33	5,0
1039			Новый Путь	26	8,0
1040			Рудня Журавлева	24	4,0
1041			Теклинов	18	6,0
1042			Углы	18	5,0
1043			Шкураты	27	7,0
1044		Чемерисский	Братский	31	3,0
1045			Садовый	32	4,0
1046			Чемерисы	20	1,0
1047		Брагинский	Кавака	26	8,0
1048			Пожарки	21	15,0
1049			Млынок	16	10,0
1050		Комаринский	Иванки	16	3,0
1051			Карловка	16	3,0
1052			Катичев	21	3,0
1053			Кирова	15	2,0
1054			Пасека	16	2,0
1055	Лоевский	Районного подчин.	Лоев	18	0,5
1056		Колпенский	Крупейки	14	1,0
1057			Мохов	14	0,3
1058		Малиновский	Белый Колодец	23	12,0
1059			Буда-Петрицкая	11	5,0
1060			Вышков-Бурицкая	22	7,0
1061			Лесуны	24	9,1
1062			Малиновка	14	14,0
1063			Новая Борщевка	10	5,0
1064			Рудня-Удалевская	20	5,0
1065			Хатки	14	7,0
1066		Уборковский	Громыки	14	2,0
1067			Липняки	16	1,0
1068			Михалевка	13	12,0
1069			Уборовка	14	1,8
1070			Уборок	12	3,0
1071	Районы г. Гомеля	Железнодорожный	Гомель	15	2,3
1072		Новобелицкий	Гомель	13	0,7
1073			Новобелица	15	1,0
1074		Советский	Гомель	15	1,6
1075		Центральный	Гомель	13	2,3

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ БССР ЦЕЗИЕМ-137 Ки/км^2)
(Caesium-137)

МИНСКАЯ ОБЛАСТЬ (MINSK)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Борисовский		Оздятичи	10	2,0
2			Борисов	10	0,0
3			Велятичи	10	0,5
4			Забашевичи	10	0,0
5			Иканы	10	0,0
6			Колки	10	0,0
7			Корсаковичи	10	0,0
8			Клыпенка	10	0,1
9			Моисеевщина	10	0,0
10			Недаль	10	0,0
11			Пересады	10	0,1
12			Гливин	10	1,0
13			Новая Метча	10	1,0
14			Черневичи	10	1,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
15		Гливинский	Новоселки	10	0,5
16	Березинский		Каменный Борок	10	1,0
17			Орешковичи	10	1,0
18			Березино	10	0,0
19			Уша	10	0,3
20		Вишневский	Бертимы	10	0,0
21			Затишек	10	0,2
22	Вилейский	Хотенчецкий	Хотенчицы	10	2,0
23		Долгиновский	Долгиново	10	0,0
24		Ижский	Ижа	10	0,0
25		Костеневичский	Костеневичи	10	0,0
26		Нарочанский	Боровцы	10	1,0
27			Русское Село	10	0,0
28			Ручица	10	0,0
29		Любанский	Бильцевичи	10	0,0
30			Талуть	10	0,0
31		Ольковичский	Ольковичи	10	0,2
32		Осиповичский	Осиповичи	10	1,0
33			Вилейка	10	0,0
34			Избино	10	0,1
35			Медведино	10	0,1
36			Ручевые	10	0,2
37	Воложинский		Родьки	10	5,0
38			Конющевщина	10	5,0
39			Тихановщина	10	5,0
40		Бобровичский	Поликщина	10	0,0
41		Богдановский	Война Войштовичи	10	1,0
42			Войганы	10	0,3
43			Заречное	10	0,0
44			Иванишки	10	0,2
45			Игнатово	10	0,1
46			Котовщина	10	0,5
47			Якимовщина	10	0,3
48			Ольшанка	10	1,0
49		Вишневский	Янишки	10	1,0
50		Дорский	Доры	10	1,0
51		Ивенецкий	Ивенец	10	1,0
52			Камень	10	4,0
53		Першайский	Довгулевщина	10	2,0
54			Першай	10	8,0
55			Конюшевщина	10	5,0
56			Ротьки	10	5,0
57			Тихоновщина	10	5,0
58		Сугвоздовский	Лосокино	10	3,0
59			Клериманты	10	1,0
60			Тябуты	10	5,0
61		Городьковский	Городьки	10	0,1
62			Слобода	10	0,2
63		Дорский	Дубовцы	10	0,2
64			Шараи	10	0,3
65		Залесский	Богданово	10	0,1
66		Ивенецкий	Букатово	10	0,1
67			Углы	10	0,0
68		Першайский	Лесники	10	0,0
69		Подберезовский	Подберезье	10	0,0
70			Анцелевщина	10	0,2
71			Ворони	10	0,0
72			Геленово	10	0,4
73		Раковский	Борок	10	0,1
74			Полочанка	10	0,1
75			Пережоры	10	0,0
76		Саковщинский	Саковщина	10	0,4
77			Бертениха	10	0,1
78			Кальвария	10	0,0
79			Кибы	10	0,2
80			Савичи	10	0,0
81		Сугвоздовский	Сугвозды	10	0,0
82			Лужаны	10	0,0
83			Новосады	10	0,2
84		Яршевичский	Бакшты	10	0,0
85			Маньковщина	10	0,0
86			Великое Поле	10	0,0
87			Глеи	10	0,0
88			Дворец	10	0,0
89			Есьмановцы	10	0,2
90			Жоховщина	10	0,1
91		Кудевцы	Лютино	10	0,0
92			Ликачи	10	0,0
93			Мажулево	10	0,2
94			Новино	10	0,0
95			Яршевичи	10	0,2
96			Воложин	10	0,0
97				10	0,0
98				10	0,0
99				10	0,0
100	Дзержинский		Волма	10	0,0
101			Дзержинск	10	0,0
102			Станьково	10	0,3
103			Негорелово	10	0,0
104			Фаниполь	10	0,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
105	Клецкий		Клецк	10	0,0
106			Загорное	10	0,0
107			Морочь	10	0,0
108			Синявка	10	0,0
109			Смоличи	10	0,0
110	Копыльский		Бобовня	10	0,0
111			Бучатино	10	0,0
112			Копыль	10	0,0
113			Слобода-Кучинка	10	0,0
114	Крупский		Бобр	10	0,2
115			Крупки	10	0,0
116			Обчуга	10	0,0
117			Прошика	10	0,0
118			Старая Пересека	10	0,1
119			Ухвала	10	0,0
120			Холопеничи	10	0,0
121			Хотюхово	10	0,0
122			Яновщина	10	0,0
123	Логойский		Плещеницы	10	0,0
124			Логойск	10	0,0
125			Белое	10	0,4
126			Крайск	10	0,0
127			Прусевичи	10	0,0
128	Молодечненский		Холхлово	10	2,0
129			Граничи	10	0,0
130			Засковичи	10	0,1
131			Марково	10	0,1
132			Родошковичи	10	0,0
133			Пекари	10	0,0
134			Молодечно	10	0,0
135	Мядельский		Андрейки	10	0,0
136			Брусы	10	0,0
137			Буйки	10	0,0
138			Городище	10	0,0
139			Кривичи	10	0,0
140			Константиново	10	0,0
141			Лотва	10	0,0
142			Мядель	10	0,0
143			Нарочь	10	0,1
144			Ольсевичи	10	0,0
145			Ольшево	10	0,0
146			Свирь	10	0,0
147			Слобода	10	0,0
148			Узла	10	0,2
149	Минский		Заславль	10	0,0
150			Крупица	10	0,0
151			Колодищи	10	0,0
152			Паперня	10	0,2
153			Сосны	10	0,4
154			Юзуфово	10	0,0
155	Несвижский		Войниловичи	10	0,0
156			Ганусовщина	10	0,0
157			Городея	10	0,0
158			Грицкевичи	10	0,0
159			Красногорки	10	0,0
160			Кучиновщина	10	0,0
161			Лань	10	0,1
162			Леоновичи	10	0,0
163			Микуличи	10	0,0
164			Макаши	10	0,0
165			Несвиж	10	0,0
166			Островки	10	0,0
167			Петуховщина	10	0,0
168			Снов	10	0,0
169			Ст.Новоселки	10	0,0
170			Славково	10	0,0
171			Янчицы	10	0,0
172	Любанский		Веречегош	10	0,0
173			Коммуна	10	0,0
174			Любань	10	0,1
175			М. Городятичи	10	0,0
176			Орлево	10	0,0
177			Озерная	10	0,2
178			Паличная	10	0,1
179			Редковичи	10	0,1
180			Сосны	10	0,0
181			Сорочи	10	0,0
182			Ст. Юрковичи	10	0,2
183			Уречье	10	0,0
184			Чеченск	10	0,0
185			Шепиловичи	10	0,0
186			Яминск	10	0,0
187	Обл. подчинения		Солигорск	10	0,2
188			Марьина Горка	10	0,0
189			Пуховичи	10	0,1
190			Турин	10	0,1
191	Пуховичский		Марьина Горка	10	0,0
192			Пуховичи	10	0,1
193			Турин	10	0,1
194	Смолевичский		Драчково	10	0,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
195			Жодино	10	0,0
196			Зеленый Бор	10	0,2
197			Студенка	10	0,1
198			Смолевичи	10	0,0
199			Усяжа	10	0,0
200	Солигорский	Районного подчин.	Красная Слобода	10	0,4
201			г. Солигорск	10	0,0
202		Гоцкий	Гоцк	10	3,0
203		Гаврильчицкий	Гаврильчицы	10	5,0
204		Долговский	Махновичи	10	0,1
205			Мелковичи	10	0,1
206		Домановичский	Сковшин	10	0,0
207			Домановичи	10	0,2
208			Осово	10	0,0
209		Зажевичский	Березовка	10	0,0
210		Конацевичский	Тесна	10	2,1
211		Краснослободский	Красная Слобода	10	0,2
212		Краснодворецкий	Листопадовичи	10	0,1
213		Новотерушский	Обидемля	10	0,2
214		Хоростовский	Новина	10	1,6
215			Груздово	10	5,0
216			Челонец	10	5,0
217			Хоростово	10	2,0
218		Ясковичский	Пузичи	10	1,2
219			Ясковичи	10	0,3
220			Б. Викоровичи	10	1,4
221	Солигорский		Груздово	10	5,0
222			Челонец	10	5,0
223			Гаврильчицы	10	2,2
224			Загорье	10	0,2
225	Слуцкий		Борки	10	0,0
226			Белевичи	10	0,0
227			Беличи	10	0,0
228			Гацук	10	0,0
229			Греск	10	0,0
230			Исерно	10	0,1
231			Млынка	10	0,0
232			Н. Беличи	10	0,0
233			Чижовка	10	0,0
234			Слуцк	10	0,0
235	Стародорожский		Вертучино	10	0,0
236			Александровка	10	0,0
237			Горки	10	0,0
238			Залужье	10	0,0
239			Положевичи	10	0,0
240			Новый Рабак	10	0,0
241			Старые Дороги	10	0,1
242			Рамичи	10	0,0
243			Шапчицы	10	0,0
244			Щитковичи	10	0,0
245			Языль	10	0,1
246	Столбцовский		Вишневец	10	0,0
247			Засулье	10	0,0
248			Литва	10	0,0
249			Налибоки	10	0,0
250			Столбцы	10	0,0
251			Шашки	10	0,2
252	Узденский		Любяча	10	0,0
253			Занеманец	10	0,0
254			Зеньковичи	10	0,0
255			Жирмоны	10	0,0
256			Борки	10	0,0
257			Войково	10	0,0
258			Литвяны	10	0,0
259			Озеро	10	0,0
260			Теплень	10	0,1
261			Теляково	10	0,0
262			Узда	10	0,0
263	Червенский		Рудня	10	0,0
264			Ляды	10	0,0
265			Червень	10	0,0
266			Хутор	10	0,0
267			Смиловичи	10	0,1
268				10	0,0

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ БССР ЦЕЗИЕМ-137 Ки/км^2)
(Caesium-137)

МОГИЛЕВСКАЯ ОБЛАСТЬ (MOGILEV)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Обл. подчинения		Кричев	18	0,5
2			Осиповичи	10	7,7
3	Костюковичский	Районного подчин.	Костюковичи	16	0,3
4		Белодубровский	Белая Дубрава	16	6,0
5			Боровка	13	2,7
6			Клеевичи	15	15,0
7			Клетки	21	36,3
8			Островок	21	26,5
9			Староселье	12	6,2
10		Белынковичский	Артюхи	10	0,3
11			Белый Камень	10	0,2
12			Белынковичи	10	0,3
13			Большая Крапивня	10	0,3
14			Бони	10	0,3
15			Вишенский	10	0,3
16			Заречье	16	0,2
17			Каничи	10	0,2
18			Кисели	10	0,3
19			Липовка	10	0,4
20			Пасека	10	0,3
21			Соколовский	17	0,3
22			Трусок	10	0,3
23		Бороньковский	Боровая	10	4,3
24			Бороньки	16	0,4
25			Гавриленка	10	0,7
26			Каменка	10	0,5
27			Сигеевка	16	9,7
28			Паньковская Буда	10	1,0
29		Братьковичский	Блудимля	35	12,5
30			Братьковичи	21	16,5
31			Дубровка	21	30,7
32			Колодезская	36	27,0
33			Осов	16	15,1
34			Скалин	21	23,6
35			Хоминка	24	12,6
36			Читовые	18	13,8
37		Горсовет	Василевка	10	0,5
38			Избужар	10	0,3
39			п. Россохи	16	0,2
40			Студенец	16	0,6

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
41			Федоровка	10	0,3
42		Демидовичский	Витунь	12	0,5
43			Вишеньки	10	9,0
44			Городок	10	0,2
45			Демидовичи	10	0,4
46			Осиновка	16	0,4
47			Ручей	10	0,7
48		Деражненский	Ветухна	42	45,0
49			Гайковка	24	44,8
50			Гарь	24	8,4
51			Горбовичи	25	14,1
52			Дережня (Красница)	33	52,3
53			Долгий Лог	21	22,8
54			Дубиец	26	27,0
55			Красная Заря	26	2,0
56			Кривая Нива	21	33,6
57			Люблин	31	5,7
58			Меловка	21	17,7
59			Новая Слобода	16	5,9
60			Носетское	15	3,4
61			Печенеж	21	18,2
62			Поломка	21	9,6
63			Рвенск	20	28,0
64		Забычанский	Галачевка	16	6,4
65			Гумницкое	16	0,6
66			Забычанье	27	6,1
67			Красная Слобода	19	1,0
68			Красный Курган	19	2,5
69			Крупня	16	1,0
70			Мурин Бор	21	0,8
71			Негино	26	4,4
72			Низки	21	0,7
73			Норкино	54	15,0
74			Подгородок	18	0,7
75			П.Забычанье	14	6,0
76			Россохи	10	0,6
77			Хорошовка	21	0,5
78			Высокое	10	0,4
79		Мокровский	Великий Бор	46	14,7
80			Вировка	25	58,3

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
81			Вишни	15	8,7
82			Вороновка	19	38,1
83			Гутка	40	45,2
84			Дубровка	16	3,5
85			Егоровка	16	10,3
86			Жарки	21	10,6
87			Заречье	21	57,9
88			Затишье	45	8,0
89			Ковычецы	19	9,3
90			Ленинский	50	45,2
91			Мамоновка	40	34,3
92			Мокрое	40	36,0
93			Мошевое	14	3,9
94			Озерец	24	44,3
95			Подрайский	17	4,0
96			Раек	17	5,8
97			Углы (Червоный Угол)	20	71,1
98			Шабли	16	6,8
99		Пролетарский	Антоновка	18	0,4
100			Большая Волосковня	10	0,4
101			Волосковня	15	0,3
102			Волынеж	16	0,4
103			Вязовец	16	0,4
104			Затишье	16	0,3
105			Камень	16	0,4
106			Колодезьки	17	1,5
107			Корбаново	16	0,4
108			Лесовой	16	0,5
109			Муравиль	10	0,3
110			Теханичи	10	0,2
111			Черченовка	10	0,2
112			Янгеловка	10	0,4
113		Самотевичский	Видуйцы	31	19,0
114			Киселевка	26	32,0
115			Красномосковский	24	35,0
116			Морозовка	26	27,0
117			Папоротная	19	13,3
118			Провиденец	21	27,6
119			Прудок	21	23,1
120			Самотевичи	32	32,5
121			Силичи	30	16,7
122			Тарасовка	26	21,0
123			Хотимск	26	41,0
124		Селецкий	Журбин	12	0,5

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
125			Колосовка	10	0,3
126			Сафоновка	10	0,3
127			Селецкое	16	0,2
128			Смольки	10	6,3
129			Старая Фроловка	10	0,3
130			Разрытая	10	0,3
131	Климовичский	Районного подчин.	Климовичи	16	1,0
132		Высоковский	Автуховка	10	0,4
133			Высокая Буда	16	1,1
134			Высокое	21	0,9
135			Жевжик	20	0,4
136			Красавичи	20	1,0
137			Красовичская Слобода	13	1,3
138			Новый Строй	19	0,9
139			Торчанка	21	0,6
140			Яновка	21	0,8
141		Галичский	Галичи	10	0,3
142			Мыза	16	0,2
143			Петровка	10	0,4
144			Соколовка	10	0,3
145			Недведь	10	0,3
146		Гусарковский	Блиунг	10	0,3
147			Зеленый Клин	15	0,4
148			Зимницы	10	0,7
149			Свирель	10	0,2
150			Свищево	10	0,4
151			Гусарка	10	0,2
152		Домамеричский	Барсуки	10	0,3
153			Домамеричи	10	0,1
154			Хотовиж	10	0,2
155			Церковище	10	0,4
156		Киселево-Будский	Великий Мох	10	0,6
157			Звенчатка	10	0,4
158			Ивановск	10	0,4
159			Киселева-Буда	10	0,5
160			Ковалевка	10	0,5
161			Старый Дедин	10	0,4
162			Федоровка	10	0,4
163		Лобжанский	Борисовичи	20	4,0
164			Ганновка	45	12,6
165			Городок	16	0,2
166			Грязивец	14	0,4
167			Гута	16	1,4
168			Дубровица	21	8,7

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
169			Игнатовка	55	16,6
170			Заручье	15	0,5
171			Лобжа	10	0,7
172			Новые Жарки	20	0,4
173			Папехинка	16	1,9
174			Подъелье	10	0,5
175			Рудня	10	0,6
176			Селище	32	40,0
177			Синеж	16	0,5
178			Старые Жарки	20	0,5
179		Лозовицкий	Осмоловичи	10	0,2
180			Павловичи	12	0,6
181			Уздеевичи	10	0,5
182			Лозовица	10	0,4
183		Милославичский	Милославичи	12	0,2
184			Переволочня	10	0,4
185			Питер	10	0,4
186			Склимин	10	0,4
187			Совна	10	0,4
188			Старый Стан	10	0,5
189			Титовка	10	0,3
190		Родненский	Васьковка	10	0,3
191			Родня	12	0,2
192			Сидоровка	10	0,5
193			Судилы	10	0,5
194			Халдеевка	10	0,3
195			Якубовка	10	0,4
196		Савиничский	Александровка	44	47,1
197			Будище	25	27,6
198			Горки	21	21,6
199			Городешня 1	26	12,8
200			Городешня 2	21	16,0
201			Грязивец	21	9,7
202			Дережня	31	19,9
203			Замощенье	26	17,8
204			Канчары	39	40,0
205			Кашеновка	39	17,0
206			Кислядь	20	18,0
207			Рысин	21	6,0
208			Савиничи	30	29,2
209			Студенец	21	18,8
210			Титовка	39	40,0
211			Шишковка	17	26,0
212		Тимоновский	Балешин	18	0,4
213			Вознесенск	20	0,5

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
214			Гиреевичи	25	0,5
215			Дорогинь	21	0,5
216			Жадунька	21	0,5
217			Кукуевка	20	0,5
218			Лубянка	21	0,6
219			Медведовка	19	0,4
220			Муравец	21	0,5
221			Плющево	21	0,3
222			Семеновка	21	0,5
223			Спартак	22	0,6
224			Стайки	20	0,7
225			Тимоново	20	0,5
226			Ясная Поляна	22	0,4
227	Краснопольский	Районного подчин.	Краснополье	13	1,4
228		Высокоборский	Александровка 1	30	12,0
229			Александровка 2	26	6,8
230			Антоновка	21	34,9
231			Брилевка	22	6,9
232			Ветухновка	21	8,0
233			Высокий Борок	31	67,0
234			Горезна	35	37,2
235			Горна	26	20,0
236			Гослев	16	36,6
237			Дубеец	25	14,6
238			Железница	16	31,0
239			Желижье	16	65,0
240			Заборье	21	9,4
241			Заречье	38	8,9
242			Какойск	31	21,8
243			Калинина	38	15,4
244			Калиновый Бор	33	36,2
245			Костюковка	35	29,4
246			Красное Знамя	26	15,8
247			Краснозвездный	26	33,5
248			Круторог	21	17,0
249			Лещенка	21	11,5
250			Лещенская Гута	21	12,2
251			Мануйлы	26	60,0
252			Осиновый	41	18,5
253			Осов	30	25,4
254			Палуж 1	38	10,3
255			Палуж 2	32	27,9
256			П. Буглай	26	7,8
257			П. Какойск	16	15,7
258			Поджелезница	21	20,4

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
259			Росомаха 1	21	20,3
260			Росомаха 2	21	20,0
261			Сосновица 1	21	36,6
262			Сосновица 2	21	28,4
263			Сосновский Хутор	23	31,2
264			Степаново	49	26,7
265			Суворовка	21	6,3
266			Шелуховка	16	32,6
267			Широкоувелье	26	22,0
268		Горский	Артехов	21	9,4
269			Бирюли	21	6,0
270			Веселый	24	6,2
271			Горенка	16	6,3
272			Городный	15	5,1
273			Горы	26	7,8
274			Грибы	16	7,4
275			Грозный	22	5,2
276			Грязивец	20	7,1
277			Дерновая	16	6,0
278			Дубровка	21	6,8
279			Загоренье	27	19,5
280			Им. Кирова	13	5,7
281			Ковпита	18	6,0
282			Ленина	24	5,0
283			Леоновка	21	7,1
284			Некрасов	26	5,0
285			Новый Совет	26	8,5
286			Полядки	21	10,5
287			Романов	21	10,5
288			Леоновка	15	7,0
289			Средний	20	5,3
290			Стайки	21	4,7
291		Мхиничский	Буглаи	21	5,6
292			Глыбов	27	7,0
293			Готовец	46	66,0
294			Драгомилово	25	64,0
295			Козелье	28	5,0
296			Лосинка	26	57,4
297			Марьина Буда	27	50,0
298			Мхиничи	22	58,4
299			Новое Житье	31	3,7
300			Победа	34	7,4
301			Романьки	27	6,1
302			Тивецкое	36	9,8
303			Холмы	24	5,4
304			Ячная Буда	33	2,7
305		Новоельнинский	Березяки 1	29	33,8
306			Березяки 2	20	22,1
307			Болин	40	15,4
308			Большой Осов	32	42,9
309			Гацкевич	43	75,9
310			Драготынь	40	31,5
311			Зелени (Красная Заря)	26	46,3
312			Корма-Долгая	19	49,7
313			Корма-Пайки	22	72,7
314			Кривелицк	24	10,8
315			Малый Осов	22	47,0
316			Новая Ельня	58	92,2
317			Новместный	19	8,7
318			Осиновка	22	10,7
319			Папоротки	40	10,0
320			Радилево	35	35,5
321			Репище	33	127,4
322			Ровнище	21	17,8
323			Хатыжин	21	13,3
324			Чернин	24	3,1
325			Якушевка	25	26,7
326		Сидоровский	Городецкая	21	3,5
327			Граковка	18	9,3
328			Ельня	19	24,0
329			Калиновка	12	2,9
330			Кожемякино	12	3,8
331			Колодецкий	12	2,9
332			Луч	32	2,7
333			Лютнянская Буда	15	2,7
334			Малые Хутора	16	3,8
335			Медведовка	12	5,6
336			Нерядовка	28	16,6
337			Софиевка	36	9,4
338			Травна	12	5,9
339			Устиновичи	32	3,9
340			Федоровка	13	4,0
341			Ясенка	14	3,6
342			Яснополье	13	2,3
343			Богдановка	17	11,2
344			Большие Хутора	10	4,2
345			Городок	10	6,7
346			Лютня	10	2,6
347			Михайловский	10	3,9
348			Новая Ферма	10	3,5

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
349			Новая Ясенка	10	3,2
350			Новина	10	1,3
351			Новоселки	10	2,3
352			Сидоровка	10	2,2
353			Турейск	10	1,4
354			Заводок	10	1,8
355		Соболевский	Березуга	23	15,0
356			Боровая	17	38,0
357			Выдренка	26	16,0
358			Горки	21	11,5
359			Городок	51	44,6
360			Дубровка	36	71,0
361			Заводок	68	76,1
362			Ляды	22	9,1
363			Марьинополье	20	9,9
364			Овчинец	28	14,0
365			Петровичи	22	17,6
366			Соболи	47	11,9
367			Старая Буда	16	33,6
368			Струменск	26	8,3
369			Топкое	26	25,4
370			Черня	18	19,4
371		Турьевский	Буходьково	36	6,0
372			Восход	16	4,1
373			Гора	24	5,9
374			Долгая Выгорь	31	5,4
375			Дубровка	19	4,5
376			Клясино	38	4,7
377			Князевка	26	2,5
378			Курганье	27	3,3
379			Ломы	26	7,8
380			Малюшино	26	8,0
381			Непобедимый	37	5,3
382			Почепы	30	2,8
383			Сосновский	28	7,7
384			Станислав	16	3,0
385			Трубильня	27	5,0
386			Турья	36	6,2
387			Хвощи	22	7,0
388			Широкий	37	5,0
389		Яновский	Козелье	27	9,0
390			Курбаки	24	6,0
391			Яновка	15	7,4
392			Ленинский	22	7,6
393			Лесовой	12	5,0
394			Малиновка	21	5,0
395			Передовой	23	6,1
396			Яновка	24	7,4
397			Голузы	10	3,5
398			Калининский	15	3,8
399			Костяговка	10	5,0
400			Бардич	10	2,0
401	Чериковский	Районного подчин.	Чериков	21	6,8
402		Вепринский	Боровая	26	9,8
403			Веприн	21	32,5
404			Гроново	21	7,6
405			Калютино	51	30,1
406			Каменка	44	72,7
407			Клины	26	24,0
408			Лисань	24	32,1
409			Майский	20	8,3
410			Малиновка	39	74,8
411			Новомалиновка	31	63,2
412			Осовец	50	64,0
413			Чудяны	71	146,5
414		Веремейский	Бельгийский	20	4,0
415			Веремейки	14	2,6
416			Городец	14	2,8
417			Зобачев	14	2,5
418			Каменка	14	1,8
419			Колода	20	5,0
420			Корма	14	4,6
421			Косари	13	0,9
422			Красный	20	5,0
423			Ляхи	15	1,7
424			Мосток	14	3,5
425			Новая Белица	14	2,4
426			Норки	13	3,1
427			Селище	14	2,9
428			Старая Белица	14	3,6
429			Холодня	14	3,4
430			Чернышин	14	2,6
431			Юдовка	14	2,6
432			Ясная Заря	20	5,0
433			Ясная Поляна	20	5,0
434		Горсовет	Лимень	28	3,7
435			Высокое	15	0,7
436		Езерский	Баков	21	12,8
437			Вербеж	21	2,3
438			Виноград	21	4,3

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
439			Гривки	22	5,0
440			Езеры	19	5,3
441			Заозерье	22	8,3
442			Звезда	25	5,7
443			Карповский	14	3,3
444			Михлин	23	5,7
445			Новая Слобода	14	4,5
446			Новый Свет	19	3,8
447			Полипень	10	6,4
448			Припечино	22	5,1
449			Ремидовщина	18	6,4
450			Рогалино	25	6,0
451			Ржавец	17	1,8
452			Селище	26	5,4
453			Соколовка	27	5,2
454			Шиманы	23	9,4
455		Лобановский	Васьковка	20	4,1
456			Возрождение	14	1,8
457			Гижня	13	5,1
458			Громобой	14	2,3
459			Долгое	18	7,4
460			Дубровка	14	3,0
461			Еловка	14	1,9
462			Житнев	19	2,5
463			Заря	12	3,0
464			Зеленый Дуб	14	2,3
465			Каменка	14	1,8
466			Лобановка	15	1,5
467			Лобча	13	6,2
468			Октябрь	14	1,4
469			Остров	14	2,0
470			Победа	14	2,0
471			Подбудки	14	2,0
472			Подломье	14	3,1
473			Рынковка	14	4,0
474			Светлый	14	0,9
475			Щетинка	14	2,4
476		Речицкий	Ближняя Речица	26	28,1
477			Гойков	21	11,0
478			Комаровичи	30	23,0
479			Михалин	25	12,3
480			Охорь	20	17,8
481			Победа	21	10,8
482			Речица	26	11,0
483			Степанов	43	16,3

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
484			Торжев	19	16,3
485			Устье	26	12,2
486			Холоблин	26	10,4
487		Сормовский	Анютино	17	3,9
488			Богдановка	26	8,8
489			Богдановка, сан. "Сож"	20	9,6
490			Вымочь	31	11,4
491			Глинь	21	13,0
492			Горки	23	8,0
493			Горки, сан. "Солнышко"	15	6,0
494			Журавель	33	18,0
495			Загурковище	20	5,6
496			Зори	26	15,8
497			Корма	18	9,0
498			Латыщено	16	9,6
499			Лещевино	26	4,5
500			Лютровка	14	1,5
501			Мирогош	23	2,9
502			Монастырек	50	30,8
503			Мостково	18	7,6
504			Палом	10	7,0
505			Турье	25	8,3
506			Удога	42	7,0
507			Шароевка	19	1,5
508			Юный Пахарь	14	2,8
509			Ямки	16	9,6
510		Ушаковский	Бакуновичи	31	29,3
511			Головчицы	26	5,4
512			Драгунские Хутора	21	3,3
513			Дубровка	21	23,3
514			Зябень	20	17,0
515			Князевка	21	12,8
516			Лысовка	21	38,3
517			Михайловка	22	5,2
518			Островы	32	43,0
519			Пиленка	26	15,0
520			Пильня	16	3,9
521			Ушаки	32	18,2
522			Холменка	29	26,8
523			Чериковское	15	2,2
524	Быховский	Районного подчин.	Быхов	16	5,1
525		Борколабовский	Залохвенье	12	6,0
526			Барсуки	10	7,4

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
527			Борколабово	10	5,0
528			Боровка	16	6,8
529			Косичи	10	7,0
530			Липовка	15	3,8
531			Ректа	14	6,6
532			Ходутичи	13	5,0
533		Верхнетощицкий	Великий Лес	10	2,3
534			Верхняя Тощица	12	6,0
535			Виляховка	10	6,0
536			Вишенька	10	1,4
537			Заводчик	10	3,0
538			Истопки	10	6,0
539			Красный Пахарь	10	0,5
540			Липа	10	2,0
541			Нижняя Тощица	10	2,0
542			Первое Мая	10	2,4
543			Порталевка	15	6,0
544			П. им. Ленина	14	3,2
545			П. Калинина	10	2,0
546			П. Рабочий	10	1,2
547			Синеж	10	0,9
548			Тощица	12	2,0
549			Виляховка	14	6,0
550			Истопки	14	6,0
551			Малиновка	20	8,0
552			Михалевка	13	9,0
553			Чернолесье	15	5,0
554		Глухский	Восточная	12	3,0
555			Глухи	12	5,0
556			Новая Слободка	15	3,3
557			Подрябинки	12	1,2
558			Селища	15	2,9
559			Словенщина	14	3,4
560			Студенка	12	1,6
561			Ямнище	12	4,8
562		Городецкий	Городец	18	5,0
563			Гута	11	1,1
564			Коммуна	11	2,0
565			Лубянка	11	1,7
566			Резки	14	2,0
567		Грудиновский	Быново	13	2,6
568			Грудиновка	14	2,0
569			Давыдовичи	14	3,4
570			Перекладовичи	12	1,0
571		Дунайковский	Вьюн	16	2,6

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
572			Вязьма	12	1,4
573			Дунаек	12	1,5
574			Проточное	14	1,3
575			Хомичи	12	1,3
576		Краснослободский	Александров	36	30,1
577			Красная Слобода	10	3,9
578			Липовка	12	3,6
579			Никоновичи	16	3,5
580			Новый Свет	10	2,8
581			Подгорье	13	3,7
582			Поповка	14	5,0
583			Прибор	13	5,0
584			Радьков	13	2,8
585			Радькова Слобода	12	3,2
586			Смольковка	14	2,9
587			Старая Трасна	14	3,5
588			Усохи	12	3,1
589			Хачинка	31	8,9
590		Лудчицкий	Дубровка	12	2,1
591			Идрица	10	2,3
592			Лудчицы	10	1,6
593		Новобыховский	Вотня	12	4,0
594			Земледелие	14	6,7
595			Лазаревичи	15	4,0
596			Новый Быхов	15	3,2
597			Покровский	14	8,0
598			Трилесино	10	4,0
599			Таймоново	16	4,4
600			Яново	10	2,1
601		Обидовичский	Веть	10	5,0
602			Громада	13	2,9
603			Долгое	13	4,0
604			Дорки	10	3,1
605			Заболотное	15	3,5
606			Искань	10	3,0
607			Кошелевка	15	3,2
608			Круглица	10	3,5
609			Кулага	12	3,4
610			Лосевка	10	6,0
611			Обидовичи	13	2,9
612			Палки	12	2,5
613			Погарки	15	3,3
614			Селец	21	5,0
615			Старое Село	15	6,0
616			Забродье	10	2,5

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
617		Следюковский	Воронино	12	2,9
618			Кузьковичи	16	3,9
619			Хатмилье	12	3,6
620			Годылево	12	4,8
621			Латколония	10	4,0
622		Трилесинский	Бовки	10	6,0
623			Виляга	10	6,0
624			Добуша	10	6,0
625			Смолица	10	6,0
626			Трилесино	10	5,0
627		Холстовский	Колос	13	4,3
628			Мокрое	12	4,0
629			Седич	12	5,0
630			Холстово	12	3,2
631			Хутор	12	3,2
632			Сапежинка	10	3,7
633		Черноборский	Золотва	10	1,0
634			Козел	12	4,0
635			Кучин	12	1,6
636			Черный Бор	12	1,0
637			Болоновка	10	2,0
638			Глухская Селиба	12	5,4
639			Стаховщина	12	3,6
640			Чечевичи	13	1,2
641			Сущев	13	2,4
642		Ямницкий	Антополь	10	1,0
643			Выгода	10	1,0
644			Красная Белорусь	12	1,0
645			Подлесье	10	0,2
646			Гальский	12	1,6
647	Кличевский	Бацевичский	Бацевичи	10	0,2
648			Заполье	10	0,2
649		Гонченский	Бобовка	10	0,5
650			Гончанский	12	1,0
651		Долговский	Долгое	10	3,4
652			Ядреная Слобода	10	3,0
653			Должанка	10	6,0
654		Несятский	Черевач	10	1,0
655		Октябрьский	Новый Остров	10	0,3
656		Потокский	Слободка	10	0,2
657			Усакино	10	0,5
658	Кировский	Районного подчин.	Кировск	10	2,5
659		Боровицкий	Боровица	10	0,4
660			Городец	10	0,3
661			Неговля	10	0,1
662		Любоничский	Любоничи	10	0,3
663			Сергеевичи	10	0,2
664		Павловичский	Лещенка	10	1,0
665			Селица	10	0,2
666		Скриплицкий	Вязовка	10	0,4
667			Хвойница	10	2,0
668		Стайковский	Стайки	10	1,0
669	Кричевский	Ботвиновский	Ботвиновка	16	2,1
670			Буланый	10	5,0
671			Вородьково 1	12	3,6
672			Горки	10	6,0
673			Городок	10	5,0
674			Губенщина	21	5,0
675			Малиновка	10	2,7
676			Милятино	10	5,0
677			Осинник	10	5,0
678			Подудога	10	5,0
679			Прусино	12	4,2
680			Ратная	16	6,0
681			Тиньково 1	10	2,2
682			Янов	12	3,6
683			Сетное	12	7,6
684			Верховцы	10	6,6
685		Костюшковичский	Волчас	10	5,0
686			Гуркова Нива	12	3,0
687			Дарливое	12	0,3
688			Дорогая	12	2,6
689			Калинино	16	5,0
690			Костюшковичи	22	6,0
691			Коханов	10	5,0
692			Лущевинка	10	0,5
693			Мальковка	10	5,0
694			Новики	14	6,0
695			Поклады	16	0,5
696			Прыговка	23	5,5
697			Пушкари	12	3,4
698			Свадковичи	10	9,8
699			Сокольничи	16	0,4
700			Хотиловичи	16	1,2
701		Краснобудский	Дяговичи	16	0,4
702			Зарубец	10	0,3
703			Каменка	10	0,5
704			Красная Буда	13	0,3
705			Серебрянный Ручей	15	0,2
706		Лобковичский	Ананичи	16	0,7

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
707			Бель 1	10	0,2
708			Ивановка	10	0,3
709			Кошаны	10	0,3
710		Молятичский	Ермаковка	10	0,4
711			Молятичи	10	0,3
712	Белыничский	Запольский	Другчаны	14	3,0
713			Замочулье	16	2,0
714			Межонка	13	2,0
715			Падевичи	13	1,0
716			Рубеж	13	4,0
717			Сеньков	16	3,0
718			Стодолище	12	4,0
719			Аксеньковичи	12	0,5
720		Ланьковский	Искра	10	1,0
721		Лебедянский	Борок	10	6,0
722		Мошаницкий	Большая Мошаница	16	4,0
723			Вольница	13	2,0
724			Дробовка	12	3,0
725			Заболотье	13	3,0
726			Лисовка	10	5,0
727			Малая Мошаница	14	3,0
728			Осливка	12	1,0
729			Рудня	17	3,1
730			Секерка	13	2,2
731		Техтинский	Осовец	13	1,0
732			Курганье	10	5,0
733			Молотовка	10	5,0
734			Поливники	13	2,0
735			Прибор	12	0,3
736	Могилевский	Дашковский	Дашковка	16	1,9
737			Бовшево	10	9,0
738			Межисятки	10	3,0
739			Стайки	10	6,0
740			Досова-Селиба	12	5,0
741		Заводослободский	Поплавщина	12	7,0
742			Репище	12	5,0
743		Маховский	Дубровка	10	8,0
744	Хотимский	Районного подчин.	Хотимск	16	0,2
745		Батаевский	Ветка	10	0,3
746			Дубровка	10	0,2
747			Еленовка	10	0,2
748		Беседовичский	Варваровка	16	0,3
749		Боханский	Боханы	16	0,3
750		Великолиповский	Еловец	16	0,2
751			Липовка	20	9,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
752		Забельшинский	Таклевка	10	0,4
753		Тростинский	Тростино	16	0,2
754			Мосток	10	0,3
755	Чаусский	Районного подчин.	Чаусы	10	2,0
756		Антоновский	Антоновка	15	1,6
757			Головенчицы	13	1,9
758			Зеленая Роща	10	6,0
759			Залесье	12	1,5
760			Хоменки	13	6,0
761			Юшковичи	14	5,0
762			Красная Буда	10	5,0
763			Усушек	12	7,0
764		Благовичский	Благовичи	18	1,6
765		Войниловский	Войнилы	16	0,5
766			Копани	13	1,9
767			Любавино	12	1,0
768		Волковичский	Волковичи	13	2,3
769			Александров	10	10,0
770			Большой Грязивец	10	10,0
771			Грязивец	13	10,0
772			Долгий Мох	16	7,0
773			Малый Грязивец	19	9,0
774			Победа	10	5,0
775			Сутоки	15	11,0
776			Захарполье	13	7,0
777			Зарестье	10	5,0
778			Черенки	12	7,0
779			Красная Поляна	14	8,0
780		Горсовет	Заболотье	18	1,0
781		Дужевский	Заречье	13	3,5
782			Кононовка	12	2,1
783			Кузьминичи	13	3,6
784			Полоево	12	1,7
785			Роман-Вина	10	5,0
786			Скоклево	12	2,0
787			Теплое	13	1,1
788		Желивский	Александровка	10	5,8
789		Прудковский	Рыминка	10	2,8
790			Голочевка	10	5,0
791		Путьковский	Быново	12	1,2
792			Гатище	12	2,9
793			Ольховка	12	2,0
794			Осиновка	12	2,0
795			Прилеповка	12	1,8
796			Путьки	13	3,7

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
797			Ребятки	12	6,7
798			Чигриновка	12	1,1
799			Нешковка	13	8,0
800		Темровичский	Темровичи	15	0,3
801	Славгородский	Районного подчин.	Славгород	17	7,1
802		Баханский	Бахань	25	12,8
803			Большая Зимница	20	8,0
804			Вишь	13	5,4
805			Добрый Дуб	25	16,3
806			Затишье	12	5,0
807			Зеленая Роща	10	5,2
808			Малая Зимница	18	7,0
809			Малые Борки	12	6,7
810			Онилино	10	6,0
811			Смолигов	12	6,1
812			Тишь	12	6,0
813			Труд	14	5,0
814			Борки	15	7,8
815		Васьковичский	Барсуковка	26	11,1
816			Безуевичи	20	5,5
817			Васьковичи	20	8,0
818			Гайшин	25	14,6
819			Гончаровка	21	7,2
820			Красный Восход	22	12,3
821			Людково	21	7,7
822			Поповка	20	6,1
823			Рудня	29	8,5
824			Селище	26	18,0
825			Tереховка	25	5,0
826			Уречье 1	25	8,0
827			Уречье 2	21	10,3
828			Чечеровка	20	11,0
829			Шеломы	24	10,9
830			Ясеновец	21	5,7
831		Гиженковский	Александровка 1	35	10,3
832			Александровка 2	40	13,8
833			Березовка	13	4,5
834			Гиженка	24	9,3
835			Гиженковское лес-во	11	1,5
836			Заболотье	26	9,4
837			Красный Октябрь	25	9,3
838			Летяги	13	6,0
839			Любаны	14	5,0
840			Телеши	14	5,0
841			Тросливка	14	5,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
842			Усохи	29	11,4
843			Ходорово	19	15,0
844			Дашковка	11	5,6
845			Заглинное	11	3,8
846			Закрупец	16	3,3
847		Горсовет	Завод Вировая	25	16,2
848			Кабина Гора	24	9,0
849			Кургановка	26	6,5
850			Михайлов	21	13,0
851			Новая Слобода	24	9,4
852			Силино Поле	25	19,7
853		Каменковский	Благодать	21	10,4
854			Дубно	43	13,1
855			Казаковка	20	6,0
856			Клины	21	17,7
857			Новая Каменка	21	5,0
858			Старая Каменка	21	7,8
859		Кульшичский	Дубровка	31	16,0
860			Жерелы	26	27,3
861			Заполянье	35	54,8
862			Куликовка 1	55	36,5
863			Куликовка 2	55	43,3
864			Кульшичи	34	16,8
865			Курганье	26	14,5
866			Приволье	19	6,3
867			Пчельня	24	21,7
868			Ржавка 1	26	6,6
869			Ржавка 2	23	8,7
870			Рябиновка	25	12,4
871			Серковка	32	13,8
872		Лопатичский	Азаричи	11	1,8
873			Железинка	12	2,9
874			Иванищевичи	16	6,5
875			Кошелев	34	22,3
876			Красная Слобода	30	19,6
877			Лесная	12	5,1
878			Лопатичи	11	1,8
879			Машецкая Слобода	14	5,8
880			Рабовичи	11	6,0
881			Улуки	11	1,6
882			Устанное	11	1,2
883			Хоронево	11	1,3
884			Чиковка	16	1,6
885		Свенский	Вышковка	12	7,0
886			Дальний	14	7,0

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
887			Дубовый Лог	19	9,0
888			Лебедевка	23	6,6
889			Липник	14	8,0
890			Прудок	21	9,6
891			Ректа	20	7,0
892			Ректа Михайловка	18	8,0
893			Роги	30	17,0
894			Свенск	20	10,0
895			Славня	18	8,0
896			Сосновица	23	7,0
897			Черняковка	14	9,0
898			Перегон	15	12,0
899		Старинковский	Агеево	43	12,6
900			Восход	45	12,1
901			Добрянка	21	19,7
902			Кремянка	21	10,0
903			Сергеевка	39	14,1
904			Станки	44	12,2
905			Старинка	21	20,1
906			Сычин	39	9,5

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ БССР СТРОНЦИЕМ-90 (Ки/км^2)

(Strontium-90)

ГОМЕЛЬСКАЯ ОБЛАСТЬ (GOMEL)

№	Район	Населенный пункт	Ки/км^2
1	Гомельский	Бобовичи	0,52
2		Большевик	0,50
3		Будатин	0,60
4		Водопой	0,49
5		В.Грива	0,30
6		Глыбоцкое	0,50
7		Гомель	0,35
8		Грабовка	0,30
9		Дикаловка	0,05
10		Журавлевка	0,26
11		Забияка	0,40
12		Ивановка	0,60
13		Калинино	0,40
14		Климовка	0,43
15		Климовский	0,30
16		Марковичи	0,31
17		Михайловка	0,05
18		Михайловск	0,26
19		Новая Гута	0,10
20		Никольск	0,26
21		Осовцы	0,45
22		Островы	0,42
23		Поколюбичи	0,35
24		Прудок	0,30
25		Пролетарий	0,28
26		Рандовка	0,33
27		Ржавец	0,14
28		Рудня	0,06
29		Рудня Жигальская	0,55
30		Роги	0,70
31		Светиловичи	0,13
32		Скиток	0,08
33		Тереничи	0,61
34		Улуковье	0,12
1	Брагинский	Алексеевка	2,60
2		Александровка	1,30
3		Асаревичи	0,80
4		Бакуны	1,30
5		Бересневка	0,70

№	Район	Населенный пункт	Ки/км^2
6		* Богуши	4,30
7		Брагин	2,10
8		Братский	3,50
9		Бурки	0,70
10		Березки	1,00
11		Волоховщина	3,00
12		* Вельмов	0,20
13		Верхние Жары	1,50
14		** Выгребная Слобода	3,20
15		Вязок	1,70
16		Великий Лес	0,05
17		Вялье	1,50
18		* Верховня Слобода	0,90
19		Голубовка	0,90
20		Городище	0,92
21		Гдень	1,60
22		* Глуховичи	4,60
23		Громкий	1,30
24		Грушное	1,70
25		Двор-Савичи	1,50
26		Дублин	0,73
27		Дубровка	0,20
28		Дубровное	0,30
29		** Жердное	1,90
30		Жиличи	0,12
31		* Залесье	3,00
32		Заречье	1,10
33		Иванки	2,40
34		* Ильичи	2,80
35		Ковали	2,00
36		* Козелужцы	3,50
37		Калинин 1	2,90
38		Калининский	1,20
39		Красное	1,10
40		* Колыбань	1,70
41		Кавака	2,10
42		Каманов	0,90
43		Комарин	1,00
44		* Капоренка	2,30
45		Красное Поле	1,20
46		Галки	0,43
47		Карловка	1,20
48		Косачев	0,04
49		Котловица	1,20
50		Катичев	1,80
51		Кирово	1,20
52		Кононовщина	1,70
53		* Красная Гора	3,00
54		Красная Горка	2,00
55		* Круг-Рудка	3,80
56		** Крюки	11,00
57		** Кулажин	21,00
58		* Ленинец	4,00
59		Ленинск	4,00
60		Ленинский	0,30
61		* Ляды	1,50
62		Новые Ляды	0,90
63		Старые Ляды	1,00
64		Людвинов	0,90
65		Маложин	0,40
66		Малейки	2,80
67		Маритон	1,00
68		Микуличи	0,95
69		Михалов	1,63
70		Михновка	0,60
71		** Нежихов	2,60
72		Нижние Жары	1,80
73		Новая Иолча	0,90
74		Новый Мокрец	1,00
75		* Новый Степанов	3,70
76		Новые Храковичи	0,42
77		Нудичи	3,90
78		Пожарки	1,40
79		Пасека	1,00
80		* Посудово	2,60
81		Переносы	0,50
82		** Пересатинец	11,00
83		Петрицкое	0,70
84		* Петьковщина	2,40
85		* Печи	1,70
86		* Пирки	2,10
87		Просмычи	1,80
88		* Пристанское	4,90
89		* Пучин	3,60
90		* Осинник	1,60
91		* Остроглялы	1,00

* Зона отселения
** Зона отчуждения

№	Район	Населенный пункт	Ки/км^2
92		* Рафалов	3,50
93		Рыжков	0,70
94		* Савичи	2,20
95		Садовый	2,10
96		* Соболи	2,30
97		Скородное	0,90
98		* Сперижье	2,80
99		Старая Иолча	0,70
100		Старый Мокрец	0,60
101		Старые Юрковичи	1,40
102		* Сувиды	2,10
103		Стежерное	1,80
104		Теклинов	0,80
105		Углы	0,50
106		* Хатуча	2,20
107		Целуйки	1,20
108		Чемерисы	1,00
109		* Чикаловичи	2,10
110		* Чернев	1,90
111		Шкураты	1,60
112		Щербины	1,80
113		* Ясени	1,70
114		* Ясменцы	2,00
115		Новый Путь	0,50
116		Селец	0,90
117		Рудня Журавлева	0,40
1	Наровлянский	Д.Александровка	0,80
2		* Антонов	0,60
3		Борисов	1,10
4		** Борщевка	13,70
5		* Боровичи	1,30
6		* Белобережная Рудня	1,40
7		** Белая Сорока	1,20
8		* Белый Берег	0,60
9		Братская	0,46
10		Будки	0,38
11		* Бук	3,20
12		* Березовка	4,10
13		Братская	0,38
14		* Вепры	8,00
15		Вербовичи	0,92
16		* Вяжище	1,49
17		Габрилеевка	0,61
18		Гажин	0,62
19		* Гамарня	0,28

№	Район	Населенный пункт	Ки/км^2
20		Головчинская Буда	0,30
21		Головчицы	0,55
22		Грушевка	1,09
23		* Гридни	0,66
24		Гута	0,75
25		* Данилеевка	1,64
26		* Довляды	4,70
27		* Дворище	1,10
28		* Дерновичи	2,50
29		Демидов	0,54
30		Дезержинск	1,60
31		* Дубрава	1,60
32		Дятлик	0,75
33		Завойть	0,86
34		Заракитное	1,19
35		Калиничи	0,53
36		* Карповичи	2,00
37		Конотоп	1,35
38		Кирово	1,00
39		Красновка	0,67
40		Красновская Буда	0,50
41		Красный Борец	0,39
42		Красный Луч	0,09
43		Красный Остров	0,20
44		Ласка	0,55
45		* Ленинский Поселок	0,80
46		* Лисава	1,20
47		* Лиховня	0,47
48		Лубень	0,93
49		Майдан	1,43
50		Москалевка	1,60
51		* Михайловка	1,16
52		* Надточаевка	8,88
53		Наровля	0,9
54		Ничипоровка	0,8
55		* Новый Майдан	2,29
56		* Окопы	1,2
57		* Осиновка	4,64
58		Перемога	0,15
59		* Радомля	0,92
60		Романовка	1,3
61		* Рожава	8,04
62		Смолегов	1,0
63		Смолеговская Рудня	0,7
64		Свеча	0,65
65		* Тешков	1,01

№	Район	Населенный пункт	Ки/км^2
66		* Тихин	0,77
67		* Углы	1,22
68		Физинки	0,57
69		Хаменки	1,08
70		* Хатки	1,3
71		Хильчиха	0,83
72		* Хутор Лес	1,1
73		* Чапаевка	0,96
74		Чехи	0,69
75		* Ясенок	0,6
76		Буда	0,14
1	Хойникский	Алексичи	2,21
2		* Бабчин	2,1
3		** Борщевка	13,4
4		Борисовщина	1,7
5		Бересневка	1,46
6		Буда	0,92
7		Будовник	0,71
8		Велетин	1,68
9		* Воротец	2,36
10		Вить	1,44
11		Великий Бор	1,50
12		Высокая	2,29
13		* Гряда	8,8
14		Глинище	1,19
15		* Гнезденка	4,4
16		Губаревичи	2,1
17		* Дроньки	2,7
18		Езефов	1,76
19		Загалье	1,6
20		Загальская Слобода	1,37
21		Застенок	0,50
22		Звеняцкое	1,80
23		Ивановка	2,80
24		Карпиловка	0,94
25		* Кожушки	2,56
26		Козелужье	0,40
27		Кореневка	1,87
28		Корчевое	0,50
29		Кливы	1,09
30		** Красноселье	33,50

№	Район	Населенный пункт	Ки/км^2
31		Красный Пахарь	0,67
32		Красная Заря	1,14
33		Куровое	0,66
34		Ломачи	2,63
35		Ленино	2,60
36		Листвин	0,37
37		** Молочки	25,00
38		** Масаны	70,90
39		Мокиш	2,54
40		Нариманов	0,52
41		Настоле	1,40
42		Небытов	0,88
43		Новоселки	1,97
44		* Ново-Покровск	3,92
45		* Новопокровка	3,48
46		* Новокухновщина	3,52
47		Омельковщина	0,70
48		* Оревичи	11,40
49		Партизанская	0,66
50		** Погонное	10,00
51		Поселичи	2,57
52		Поташня	1,10
53		Пикулиха	3,30
54		Рабец	0,46
55		** Радин	16,20
56		Рашев	0,50
57		Рудаков	1,83
58		Рудное	3,00
59		Слобожанка	2,20
60		Смирнов	1,40
61		Старч	1,65
62		Стреличево	2,12
63		Судков	1,40
64		Тульговичи	2,6
65		Туневщина	0,8
66		** Уласы	2,6
67		* Хвощевка	1,68
68		Хвойное	1,95
69		Хвойная Поляна	2,0
70		Храпков	1,5
71		Хойники	0,93
72		** Чамков	10,4
73		Чехи	1,78

* Зона отселения
** Зона отчуждения

№	Район	Населенный пункт	Ки/км^2
74		Червоный Рог	2,6
75		Красное Озеро	1,38
76		Пос. им. Ленина	2,6
1	Ветковский	Акшинка	0,5
2		Амельное	0,7
3		Бартоломеевка	1,75
4		Барченки	0,96
5		Борисневка	0,02
6		Беседь	0,7
7		Борьба	1,0
8		Борщевный	0,06
9		Быковец	1,0
10		Булановы	1,4
11		Великоборье	0,22
12		В. Бор	0,3
13		Ветка	1,0
14		Вербочки	0,26
15		Воробьевка	1,6
16		Воробьевка сев. р-н	1,6
17		Восток	0,96
18		Габровка	0,6
19		Глыбовка	0,5
20		Гута	1,2
21		Гарусты	0,8
22		Горелое болото	0,39
23		Гибки	0,23
24		Н. Громыки	0,8
25		Ю.В. Н. Громыки	1,37
26		Сев. Н. Громыки	2,7
27		Громыки	0,9
28		Говисмы	1,7
29		М. Грязивец	0,06
30		Даниловичи	1,1
31		Домашнее	1,10
32		Железники	0,45
33		Заречье	0,90
34		Затишье	0,02
35		Зимнище	0,10
36		Ириновка	0,66
37		Иванькин	0,76
38		Купреевка	0,55
39		Коновалово	0,20
40		Контуровка	0,30
41		Косицкое	0,86
42		Красный путь	1,60
43		Калинин	0,21
44		Красный Угол	0,90
45		Колбавка	0,28
46		Кирпичный з-д	0,16
47		Ковалево	0,81
48		Крушинник	0,45
49		Куты	0,28
50		Каничев	1,50
51		Лядо	0,40
52		Лазаревский	0,21
53		Лески	1,20
54		Лута	0,87
55		Линовка	0,09
56		Маяк	1,58
57		Некрасово	0,50
58		Новиловка	1,70
59		Новоселки	0,46
60		М. Немки	0,12
61		Неглюбка	0,22
62		Новоивановка	0,74
63		Однополье	0,40
64		Осово	0,61
65		Подлоги	0,46
66		Побутье	0,66
67		Первомайский	1,20
68		Перевесье	0,30
69		Передовец	0,36
70		Петрополье	0,60
71		Потесы	0,76
72		Пролетарский	0,90
73		Попсуевка	1,50
74		Павелевка	0,31
75		Перелевка	0,1
76		Полесье	0,11
77		Присно	0,45
78		Пыхань	0,8
79		Петуховка	0,34
80		Подречье	1,62
81		Репище	0,4
82		Романвино	0,06
83		Расуха	0,17
84		Рудня	0,22
85		Рудня Столбуновская	0,39
86		Радуга	0,7
87		Речки	0,9
88		Рудня-Шлягина	0,6

№	Район	Населенный пункт	Ки/км^2
89		Романов Лес	0,39
90		Рыславль	0,94
91		Рудня-Гулева	1,3
92		Ст. Село	1,1
93		Селицкое	1,2
94		Старч	0,85
95		Слобода	0,52
96		Симоновка	0,34
97		Синицыно	0,38
98		Светиловичи	0,3
99		Сивинка	0,8
100		Старое Закрутье	0,9
101		Старые Громыки	0,9
102		Столбун	0,17
103		Селядочка	0,13
104		Тарасовка	0,5
105		Тумарин	0,7
106		М. Тарасовка	0,88
107		Тана	0,68
108		Тивино	0,43
109		Усохи	0,36
110		Ухово	1,1
111		Федоровка	0,5
112		Хальч	0,5
113		Хизы	1,5
114		Чистые Пути	0,64
115		Шейки	0,6
116		Шеретин	0,8
117		Шона	0,68
118		Шедотин	0,83
119		Юрковичи	0,70
120		Яново	0,22
121		Ягодное	0,80
1	Кормянский	Антоновка	0,30
2		Александровка	0,50
3		Берестовец	0,38
4		Барсуки	0,14
5		Богдановичи	0,17
6		Буда Боровая	0,15
7		Буда Песовая	0,29
8		Боровая Глинка	0,10
9		Бакунино	0,43
10		Боровино	0,33
11		Болев	0,11
12		Буда Сверская	0,07
13		Васильевка	0,23
14		Вашковичи	0,13
15		Высокая	0,22
16		Верцовка	0,058
17		Бервены	0,60
18		Волынцы	0,15
19		Высокая	0,40
20		Выношевка	0,12
21		Вощанки	0,17
22		Вознесенск	0,13
23		Городок	0,35
24		Дубровица	0,25
25		Дубролет	0,20
26		Жданово	0,09
27		Жауница	0,52
28		Задубье	0,14
29		Золотомино	0,50
30		Зятьковичи	0,10
31		Заболоцкое	0,12
32		Енцы	0,10
33		Косельский прудок	0,19
34		Косель	0,28
35		Кураковщина	0,40
36		Колосово	0,13
37		Казимирово	0,13
38		Корсунь	0,22
39		Кляпинская Буда	0,29
40		Камоды	0,41
41		Кучин	0,10
42		Костюковка	0,60
43		Корма	0,20
44		Курганье	0,32
45		Курганица	0,15
46		Коротьки	0,22
47		Луначарский	0,10
48		Лысая Гора	0,05
49		Лебедевка	0,12
50		Лабыревка	0,40
51		Литвиновичи	0,11
52		Лужок	0,10
53		Лозовица	0,56
54		Маленик	0,11
55		Малашки	0,14
56		Михеевка	0,11
57		Моторовка	0,11

№	Район	Населенный пункт	Ки/км^2
58		Н. Млын	0,22
59		Норковщина	0,25
60		Новоселки	0,07
61		Зеньковина	0,34
62		Н. Россохи	0,25
63		Никольский	0,14
64		Остров	0,22
65		Октябрь	0,30
66		Осов	0,15
67		Октябрево	0,50
68		Петровичи	0,08
69		Парбыльники	0,10
70		Полесье	0,26
71		Россохи	0,27
72		Радец	0,38
73		Рудня	0,35
74		Ст. Зеньковина	0,23
75		Сапожки	0,60
76		Скартынь	0,25
77		Сырск	0,18
78		Селиновка	0,31
79		Слобода	0,20
80		Семеновка	0,07
81		Салобута	0,70
82		Студенец	0,20
83		Струмень	1,20
84		Труд	0,08
85		Тараховка	0,10
86		Хлевно	0,90
87		Чамышель	0,25
88		Шамалец	0,10
89		Ясень	0,36
90		Яновка	0,08
1	Добрушский	Антоновка	0,01
2		Большой Лес	0,40
3		Васильевка	0,40
4		Вылево	0,80
5		Волна	1,00
6		Дубовый Лог	0,90
7		Млынок	0,80
8		Добруш	0,28
9		Демьянки	0,36
10		Иваки	0,18
11		Иговка	0,10

№	Район	Населенный пункт	Ки/км^2
12		Кр. Знамя	0,75
13		Красная Буда	0,05
14		Корма	0,75
15		Круговка	1,20
16		Леонтьево	1,00
17		Ленино	0,18
18		Морозовка	0,77
19		Марьино	0,42
20		Нов. Крупец	0,06
21		Николаевка	0,10
22		Очесо-Рудня	0,70
23		Перерост	0,20
24		Степь	0,10
25		Ст. Крупец	0,10
26		Уть	0,04
27		Уборок	0,40
28		Хорошевка	0,55
1	Ельский	Богутичи	0,15
2		Вишенки	0,10
3		Гатин	0,30
4		Городище	0,80
5		Гриши	0,30
6		Даниловка	0,30
7		Ельск	0,15
8		Забозье	0,30
9		Зеленый Бор	0,40
10		Заширье	0,10
11		Кр. Знамя	0,50
12		Кр. Пильщик	0,60
13		Козлы	0,30
14		Калиновое	0,13
15		Кочищи	0,06
16		Кузьмичи	0,33
17		Муты	0,10
18		Млынок	0,30
19		Медведное	0,15
20		Некрашевка	0,50
21		Нов. Рудня	0,30
22		Николаевка	0,08
23		Особы	0,20
24		Половки	0,20
25		Павловка	0,05
26		Прачемышля	0,08
27		Роза Люксембург	0,20

№	Район	Населенный пункт	Ки/км^2
28		Серые	0,20
29		Словечно	0,50
30		Ст. мост	0,30
31		Скородное	0,15
32		Ст. Высокое	0,06
33		Шарин	0,80
34		Шатуны	0,10
35		Шишки	0,70
36		Чертень	0,20
1	Калинковичский	Березовка	0,35
2		Водовичи мал.	0,70
3		Вел. Автюки	0,04
4		Воротынь	0,33
5		Денисовичи	0,20
6		Замостье	0,70
7		И.-Фабиановка	0,20
8		Капличи	0,40
9		Крюковичи	0,05
10		Калинковичи	0,40
11		Крышичи	0,30
12		Клинск	0,02
13		Лиличи	0,10
14		Мутижар	0,90
15		Новоселки	0,30
16		Нахов	0,50
17		Огородники	0,15
18		Обуховщина	0,30
19		Прудок	0,25
20		Руденька	0,12
21		Слободка	0,30
22		Сельцы	0,04
23		Селище	0,10
24		Савичи	0,80
25		Торочичи	0,24
26		Ужинец	0,80
27		Хобное	0,70
28		Юровичи	0,50
1	Буда-Кошелевский	Александровка	0,43
2		Антоновка	0,15
3		Барановка	0,13
4		Боевой	1,00
5		Бурдово	0,15
6		Бурлак	1,20
7		Буда-Кошелево	0,50

№	Район	Населенный пункт	Ки/км^2
8		Вел. Мох	0,49
9		Весел. Курган	0,40
10		Весел. Пахарь	0,80
11		Возрождение	0,10
12		Восход	0,30
13		Высокая Грива	0,14
14		Герой	0,70
15		Головачи	0,60
16		Дербичи	0,35
17		Долгий	0,30
18		Долина	0,20
19		Дубровка	0,10
20		Дубовица	0,40
21		Дуравичи	0,40
22		Забабье	0,02
23		Залуневье	0,30
24		Застенный	0,50
25		Зимник	0,34
26		Зорька	0,11
27		Красница	0,43
28		Красногорский	0,20
29		Кр. Лужок	0,15
30		Кр. Октябрь	0,45
31		Кулешовка	0,60
32		Лукьяновка	0,90
33		Луч	0,87
34		Лучиничи	0,20
35		Любица	0,20
36		Михалевка	0,48
37		Надеждино	0,54
38		Никольск	0,80
39		Новая Гута	0,70
40		Потаповка	0,27
41		Пытьковка	0,41
42		Семеновка	0,53
43		Славенец	0,10
44		Слободка	0,40
45		Солиановка	0,07
46		Староселье	0,30
47		Струки	0,16
48		Хмельное	0,19
49		Хорошевка	0,60
50		Чеботовичи	0,09
51		Череповка	0,45
52		Чернятин	0,14
53		Якимовка	0,20

№	Район	Населенный пункт	Ки/км^2
1	Житковический	Борки	0,02
2		Житковичи	0,06
3		Люденевичи	0,06
1	Лельчицкий	Буйновичи	0,30
2		Вязовая	0,11
3		Вороново	0,75
4		Гребени	0,20
5		Запесочное	0,50
6		Кавыжев	0,15
7		Лохница	0,30
8		Лельчицы	0,04
9		Мехач	0,04
10		Николовичи	0,03
11		Обидовичи	0,05
12		Рубеж	0,23
13		Руднище	0,06
14		Синицкое Поле	0,55
15		Симоновичи	0,10
16		Стодоличи	0,12
17		Усов	0,40
18		Хачинка	0,12
1	Рогачевский	Кистени	0,08
2		Новоселки	0,60
3		Стреньки	0,07
4		Ходосовичи	0,10
1	Лоевский	Бывальки	0,30
2		Белый Колодец	0,30
3		Буда Петрицкая	1,00
4		Вышков	0,43
5		Вышков-Бурицкое	0,60
6		Громыки	0,70
7		Колпень	0,10
8		Лоев	0,30
9		Малиновка	0,50
10		Михалевка	0,60
11		Рудня-Удалевская	0,30
12		Ручаевка	0,60
13		Скиток	0,09
14		Уборок	0,30

№	Район	Населенный пункт	Ки/км^2
1	Чечерский	Алеасеевка	0,34
2		Бобровский	0,15
3		Будице	0,20
4		Болтово	1,10
5		Брилево	0,10
6		Волосовичи	0,03
7		Высокая Грива	0,25
8		Восход	0,40
9		Городовка	0,10
10		Дубок	0,25
11		Дубровка	1,20
12		Дружбичи	0,15
13		Дудачская Рудня	0,00
14		Дудачи	0,80
15		Загорье	0,20
16		Залавье	0,20
17		Заручье	0,15
18		Ивановка	0,30
19		Крутое	0,70
20		Кураки	0,12
21		Кораблище	0,18
22		Красный	0,7
23		Канавы	1,0
24		Лукомские поплавы	0,62
25		Лесная Поляна	1,0
26		Медвежье	0,55
27		Михайловский	0,45
28		Мотневичи	0,06
29		Науховичи	0,3
30		Никольск	0,14
31		Нов. Холочье	0,5
32		Нов. Залесье	0,1
33		Нов. Захарполье	0,09
34		Осиновка	0,15
35		Отор	0,5
36		Осиновская Гута	0,15
37		Подигрушка	0,15
38		Подосовье	0,26
39		Передовик	0,06
40		Пролетарский	0,5
41		Поскубовка	0,7
42		Поплавы	0,7
43		Раков Лог	0,27
44		Репище	0,12
45		Ровковичи	0,3
46		Салтановка	0,2

№	Район	Населенный пункт	Ки/км^2
47		Слободка	0,34
48		Самсоновка	0,6
49		Ср. Малыничи	0,5
50		Себровичи	0,8
51		Светлая Роща	0,12
52		Сойки	0,6
53		Холочье	0,6
54		Чечерск	0,7
55		Шепотовичи	0,3
56		Юный	0,16
57		Яцковщина	0,07
1	Жлобинский	Антоновка	0,14
2		Бобовка	0,22
3		Белица	0,25
4		Дубровка	0,2
5		Жлобин	0,1
6		Кабановка	0,06
7		Луки	0,06
8		Липа	0,5
9		Нов. Марковичи	0,07
10		Папоротное	0,1
11		Ректа	0,1
12		Ст. Рудня	0,2
13		Стрешин	0,3
14		Цупер	0,1
15		Цупер	0,1
16		Щедрин	0,02

№	Район	Населенный пункт	Ки/км^2
1	Петриковский	Бринев	0,06
2		Велавск	0,15
3		Грабов	0,05
4		Коржевка	0,06
5		Копаткевичи	0,11
6		Копцевичи	0,11
7		Петриков	0,06
8		Снядин	1,0
1	Речицкий	Вышемир	0,3
2		Василево	0,25
3		Заспа	0,55
4		Короватичи	0,35
5		Крынки	0,2
6		Лиски	0,15
7		Макановичи	0,35
8		Малодуша	0,45
9		Нов. Барсук	0,8
10		Озерщина	0,16
11		Речица	0,25
12		Свиридовичи	0,24
1	Мозырский	Барбаров	0,4
2		Березовка	0,1
3		Лубня	0,18
4		Михалки	0,24
5		Мозырск	0,14
6		Ниж. Мозырск	0,45

Данные согласованы с АН БССР и Агропромом БССР.

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ БССР СТРОНЦИЕМ-90

(Strontium-90)

МОГИЛЕВСКАЯ ОБЛАСТЬ (MOGILEV)

№	Район	Населенный пункт	Ки/км^2
1	Славгородский	Березовка	0,02
2		Барсуковка	0,04
3		Безуевичи	0,11
4		Большая Зимница	0,02
5		Бохань	0,43
6		Восход	0,15
7		Васьковичи	0,17
8		Гиженка	0,07
9		Гайшин	0,20
10		Гончаровка	0,15
11		Добрянка	0,21
12		Железинка	0,05
13		Завод Вировая	0,13
14		Кульшичи	0,15
15		Кремянка	0,32
16		Куликовка 1	0,40
17		Куликовка 2	0,45
18		Красная Слобода	0,12
19		Курганы-Рябиновка	0,11
20		Лебедевка	0,25
21		Михайлов	0,20
22		Нов. Каменка	0,19
23		Поповка	0,24
24		Ржавка 2	0,10
25		Рудня	0,43
26		Роги	0,17
27		Ректа	0,16
28		Серковка	0,05
29		г. Славгород	0,17
30		Силино Поле	0,10
31		Свенск	0,20
32		Телеши	0,15
33		Труд	0,06
34		Тереховка	0,20
35		Уречье 1	0,40
36		Уречье 2	0,27
37		Ходорово	0,79
38		Чечеровка	0,18
39		Шеломы	0,18
40		Ясеновец	0,2

№	Район	Населенный пункт	Ки/км^2
1	Краснопольский	Антоновка	0,25
2		Березняки 1	0,45
3		Высокий Борок	1,2
4		Выдренка	0,23
5		Гослев	0,05
6		Готовец	0,82
7		Граковка	0,20
8		Горки	0,13
9		Дубровка	0,68
10		Драгомилово	0,43
11		Želижье	0,35
12		Заводок	0,6
13		Заречье	0,95
14		Князевка	0,1
15		Краснополье	0,1
16		Корма Долгая	0,2
17		Корма Пайки	0,8
18		Лосинка	0,4
19		Мхиничи	0,67
20		Марьина Буда	0,46
21		Мал. Осов	0,7
22		Медведовка	0,7
23		Мал. Хутор	0,1
24		Мануйлы	0,52
25		Новый Свет	0,15
26		Непобедимый	0,5
27		Новоельня	1,4
28		Осиновый	0,17
29		Палуж 2	0,25
30		Поджелезница	0,2
31		Какойск	0,24
32		Победа	0,2
33		Петровичи	0,27
34		Росомаха 1	0,16
35		Росомаха 2	0,35
36		Репище	0,48
37		Радилево	0,43
38		Сосновича 1	0,32
39		Соболи	0,26
40		Ст. Буда	0,63

№	Район	Населенный пункт	Ки/км^2
41		Турейск	0,16
42		Топкое	0,32
43		Хатыжин	0,5
44		Широкоувелье	0,38
45		Шелуховка	0,31
46		Якушовка	0,54
1	Чериковский	Бакуновичи	0,71
2		Боровая	0,15
3		Веремейки	0,17
4		Веприн	0,56
5		Езеры	0,10
6		Глинь	0,40
7		Дубровка	0,60
8		Драгунские Хутора	0,27
9		Кожемякино	0,50
10		Комаровичи	0,70
11		Клины	0,52
12		Каменка	0,18
13		Лобановка	0,07
14		Малиновка	0,90
15		Монастырек	0,93
16		Михайловка	0,16
17		Осовец	0,60
18		Пильня	0,02
19		Рогалино	0,10
20		Ушаки	0,25
21		Чериков	0,10
22		Чудяны	0,80
1	Костюковичский	Бороньки	0,13
2		Боровня	0,3
3		Братьковичи	0,4
4		Ветухна	0,6
5		Видуйцы	0,58
6		Вировка	0,64
7		Вишни	0,24
8		Вороновка	0,5
9		Вишеньки	0,3
10		Гайковка	0,84
11		Гутка	0,24
12		Дережня	0,7
13		Дубровка	0,57
14		Журбин	0,07
15		Забычанье	0,04
16		Киселевка	0,54

№	Район	Населенный пункт	Ки/км^2
17		Красномосковский	0,44
18		Костюковичи	0,01
19		Кавычецы	0,12
20		Крупня	0,1
21		Красная Заря	0,1
22		Кривая Нива	0,33
23		Клетки	0,4
24		Колодезская	0,41
25		Красница	1,11
26		Люблин	0,18
27		Меловка	0,2
28		Мамоновка	0,3
29		Мокрое	0,8
30		Морозовка	0,36
31		Норкино	0,19
32		Носетская	0,13
33		Озерец	0,80
34		Осов	0,42
35		Островок	0,34
36		Поломка	0,08
37		Прудок	0,46
38		Провиденец	0,43
39		Папоротное	0,35
40		Печенеж	0,33
41		Ревнск	0,40
42		Россохи	0,15
43		Скамен	0,77
44		Самотевичи	0,80
45		Студенец	0,10
46		Силичи	0,17
47		Сельхозхимия	1,35
48		Тарасовка	0,44
49		д. Хотимск	0,55
50		м. Хотимск	0,57
51		Читовичи	0,50
1	Климовический	Александровка	0,27
2		Городок	0,20
3		Замощенье	0,20
4		Зеленый Клин	0,08
5		Климовичи	0,12
6		Нов. Жарки	0,13
7		Подьелье	0,04
8		Сивиничи	0,47
9		Старые Жарки	0,13

№	Район	Населенный пункт	Ки/км^2
1	Кричевский	Ботвиновка	0,12
2		Ивановка	0,14
3		Кричев	0,10
4		Луты	0,06
5		Красная Буда	0,03
6		Хотиловичи	0,17
1	Хотимский	Хотимск	0,03

№	Район	Населенный пункт	Ки/км^2
1	Быховский	Александров	0,37
2		Искань	0,08
3		Никоновичи	0,04
4		Обидовичи	0,02
1	Чаусский	Грязивец	0,03
2		Кузьминичи	0,05
3		Рыминка	0,04
4		Чаусы	0,02

Данные согласованы с АН БССР и Агропромом БССР.

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ РСФРС ЦЕЗИЕМ-137 (Ки/км^2)
(Caesium-137)

БРЯНСКАЯ ОБЛАСТЬ (BRYANSK)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Обл. подчинения		Дятьково	11	1,00
2			Клинцы	12	2,20
3			Новозыбков	15	16,23
4	Гордеевский	Гордеевский	Васильевка	11	9,53
5			Великий Бор	11	7,0
6			Гордеевка	20	25,00
7			Дальний Клин	11	10,00
8			Зеленый Клин	16	9,23
9			Новый Великий Бор	11	10,16
10			Поконь	11	11,07
11			Смелый	11	11,56
12		Заводо-Корецкий	Жовнец	10	7,78
13			Заводо-Корецкий	12	8,93
14			Медведовка	15	10,90
15			Муравинка	10	10,35
16			Чиховка	11	12,92
17			Шамры	10	9,00
18		Казаричский	Белица	7	3,33
19			Даниловка	8	4,68
20			Дубровка	6	4,10
21			Казаричи	8	5,12
22			Марс	7	3,59
23			Станок	7	3,32
24			Федоровка	8	2,40
25			Черный Ручей	12	7,75
26		Кожановский	Безбожник	13	22,32
27			Дягов	13	20,10
28			Ермаки	11	14,66
29			Зайцево	11	19,11
30			Засечный	10	18,43
31			Кожаны	14	41,00
32		Петровобудский	Криштопов Ручей	16	28,98
33			Малоудебное	15	20,44
34			Осов	16	13,65
35			Перетин	17	17,18
36			Петрова-Буда	15	15,75
37			Революционный Свет	17	18,48
38		Рудневоробьевский	Новоновицкое	15	21,33
39			Поповка	15	22,35
40			Рудня-Воробьевка	14	19,14

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
41			Староновицкое	15	24,32
42			Ширяевка	15	27,49
43		Смяльчский	Владимировка	17	23,21
44			Залиповье	20	20,69
45			Новый Свет	12	16,68
46			Смяльч	15	17,18
47			Сугродовка	18	18,81
48		Старополонский	Дмитриевка	12	4,92
49			Дубровное	10	13,36
50			Зеленый Рог	9	9,20
51			Нежча	8	5,49
52			Петроковка	8	7,66
53			Старая Полона	10	6,31
54			Удел	7	7,29
55		Струговобудский	Алес	7	1,53
56			Белица	7	1,92
57			Березина	10	10,55
58			Глинное	10	4,51
59			Займище	10	5,51
60			Ивановка	7	1,37
61			Колыбели	10	11,14
62			Красный Борец	10	13,89
63			Новоселье	10	11,40
64			Стругова Буда	9	8,96
65			Струговка	8	8,12
66		Творишинский	Горовой	11	16,80
67			Ипуть	10	10,08
68			Крещенский	12	11,91
69			Михайловка	14	16,87
70			Никитовка	11	8,28
71			Соколки	10	8,84
72			Степана Разина	13	20,62
73			Творишино	13	14,39
74		Уношевский	Антоновка	14	20,78
75			Голынщина	8	15,89
76			Паломы-Сукрым	10	27,28
77			Покровка	12	21,07
78			Роговец	9	28,81
79			Уношево	12	12,29
80			Федоровка	12	12,67

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
81			Хармынка	13	17,69
82			Черетовка	10	6,90
83		Ямновский	Алисовка	10	12,20
84			Андреевка	9	7,68
85			Кузнецы	11	10,77
86			Лозовка	9	5,29
87			Ямное	10	6,22
88	Дятьковский	Большежуковский	Большая Жуковка	6	0,84
89			Любыш	6	1,06
90			Малая Жуковка	6	0,80
91			Романовка	6	1,24
92			Хизовка	6	2,11
93		Псурский	Верещевка	7	2,37
94			Ольшаница	7	3,64
95			Псурь	7	4,68
96			Ж/д. ст. Верещевка	6	0,89
97			Псурский	6	3,25
98	Злынковский	Районного подчин.	Злынка	16	26,79
99			Вышков	16	34,71
100		Большещербиничский	Большие Щербиничи	14	13,16
101			Вилы	12	12,35
102			Гребельки	9	10,11
103			Добрынь	9	11,10
104			Еловка	9	11,55
105			Зеленая Роща	13	11,41
106			Малые Щербиничи	14	9,56
107			Петрятинка	10	8,02
108			Свисток	8	13,22
109			Шурубовка	11	9,33
110			Чумаки	7	10,13
111		Карпиловский	Андреевка	7	13,10
112			Вишенки	14	11,18
113			Карпиловка	15	11,78
114			Красный Октябрь	7	13,10
115			Новолюбин	9	8,95
116			Озерище	16	14,60
117			Петровка	18	18,09
118			Сосновый Бор	14	11,44
119		Денисковичский	Денисковичи	16	16,33
120			Колодецкий	14	15,31
121			Лысые	16	14,16
122			Нетеша	14	13,42
123			Федоровка	15	12,33
124		Добродеевский	Добродеевка	21	28,68
125			Заречье	13	40,26

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
126			Камень	11	37,77
127			Красные Орлы	9	28,67
128			Красный Камень	11	32,33
129			Любин	14	24,99
130			Медвежье	16	34,64
131			Саньково	11	46,53
132			Советский Лог	14	38,49
133			Чехов	13	41,75
134		Кожановский	Барановка	8	2,73
135			Кожановка	9	1,72
136			Серовка	7	0,61
137		Роговский	Вербовка	7	6,55
138			Добрынька	8	14,14
139			Новобежков	9	5,39
140			Рогов	13	7,32
141			Софиевка	13	17,06
142			Стрела	9	6,82
143		Спиридоновобудский	Азаричи	8	2,56
144			Спиридонова Буда	15	11,04
145	Климовский	Районного подчин.	Климово	10	10,04
146		Брахловский	Брахлов	6	4,61
147			Горки	6	3,93
148			Куничев	6	4,21
149			Любечане	6	3,43
150			Манев	6	2,28
151			Октябрь	6	4,35
152			Оптени	6	2,89
153			Соловской	6	4,99
154			Тымайловка	6	4,18
155		Вишневский	Вишневый	6	5,89
156			Курганы	6	9,57
157			Михайловка	6	0,47
158			Янковское	6	1,07
159		Воробьевский	Важица	11	15,61
160			Воробьевка	7	6,60
161			Глубочка	10	14,20
162			Грецковка	10	8,92
163			Гуков	8	7,51
164			Добрынь	9	8,45
165			Корытенко	8	7,53
166			Ломанка	10	13,32
167			Новосергеевка	12	12,49
168			Ольховка	8	8,32
169			Павловка	8	5,40
170			Холуповка	10	9,46

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
171		Гетманобудский	Гетманская Буда	9	5,55
172			Крапивна	6	5,64
173		Истопский	Истопки	6	3,81
174			Засновье	6	5,24
175			Карнатное	6	4,80
176			Лужи	6	4,10
177			Первомайский	6	6,17
178			Петровский	6	5,24
179			Шамовка	6	4,39
180		Каменский	Плавна	6	7,90
181			Бурный	6	4,02
182			Крушинник	6	5,68
183			Курозново	6	5,40
184			Май	6	4,01
185			Пруска	7	6,62
186			Рудня	6	8,25
187			Чернятино	6	11,80
188			Честный	6	3,77
189			Каменка	6	4,06
190		Каменскохуторской	Каменский Хутор	6	6,27
191			Луговой	6	4,82
192			Красный Бор	6	5,28
193			Красный Став	6	4,05
194			Скачок	6	3,40
195			Уборки	6	1,62
196		Кирриллоский	Березовка	6	2,19
197			Боровка	6	1,72
198			Кирилловка	6	0,39
199			Новокирилловка	6	1,36
200			Шумиловка	7	6,59
201		Куршановичский	Куршановичи	7	10,39
202			Ольховка	6	6,36
203			Соловьевка	6	10,96
204			Старый Городок	6	5,50
205			Ясеновка	6	7,06
206			Дубрава	6	6,55
207		Лакомобудский	Лакомая Буда	7	10,93
208			Лужки	7	9,34
209			Побожеевка	6	10,25
210		Лобановский	Лобановка	6	6,19
211			Могилевцы	6	7,05
212			Плужин	6	4,60
213		Митьковский	Передовик	6	5,71
214			Черная Криница	6	10,92
215			Хохловка	6	12,10

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
216		Новоропский	Ирпа	6	4,80
217			ж/д. ст. Новоропск	6	4,74
218			Новоропская ПМК	6	4,25
219			Новый Ропск	6	3,83
220			Рубеж	6	3,42
221			Старый Ропск	6	4,42
222		Новоюрковичский	Вербовый Выгор	6	0,17
223			Гладкий	6	0,15
224			Круча	6	0,72
225			Новые Юрковичи	6	0,18
226			Новый Свет	6	0,25
227			Светлый	6	0,20
228			Синявка	6	0,12
229			Черноземный Городок	6	0,14
230			Жеведа	6	0,16
231		Сачковичский	Великие Пожни	6	7,29
232			Добречка	6	4,22
233			Дохновы	6	4,51
234			Сачковичи	6	8,40
235			Городище	6	7,00
236			Содок	6	5,57
237		Староюрковичский	Зеленый Гай	6	0,61
238			Зеленый Кут	6	4,16
239			Ивановка	6	2,31
240			Рудня Цата	7	3,55
241			Рябиновка	6	0,42
242			Старые Юрковичи	6	2,15
243		Сушановский	Бровничи	6	3,74
244			Красные Ляды	6	5,17
245			Малинник	6	4,49
246			Погары	6	3,85
247			Прогресс	6	3,81
248			Сушаны	6	3,19
249			Шелковский	6	3,00
250			Рясенка	6	6,52
251		Сытобудский	Великогайский	6	4,67
252			Рубежное	7	7,70
253			Сытая Буда	6	10,05
254		Хороменский	Красное	6	0,19
255			Раковка	1	0,20
256			Хоромное	6	0,34
257			Корябин	6	0,15
258		Чернооковский	Чернооково	6	4,11
259			Бабки	6	6,04

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
260			Полхов	6	3,47
261		Чолховский	Борьба	6	9,90
262			Быстра	7	4,95
263			Вага	7	4,85
264			Марковщина	7	6,42
265			Новополье	6	5,70
266			Фоевичи	9	7,53
267			Челхов	9	6,00
268			Стрела	6	8,77
269		Чуровичский	Чуровичи	7	8,13
270			Бугровка	7	8,95
271			Вознесенск	6	7,11
272			Ново-Варин	7	8,09
273			Перекоп	6	13,54
274			Петрова Гута	6	0,90
275			Ягодное	6	2,88
276			Хороменские Хутора	6	0,42
277		Климовский поссовет	Покровское	6	13,69
278			Климово	6	9,70
279	Клинцовский	Ардонский	Ардонь	7	1,55
280			Ивановка	7	3,70
281			Любвин	7	3,90
282		Великотопальский	Великая Топаль	8	9,07
283			Дровосеки	7	7,10
284			Дубрава	7	5,45
285			Засновье	7	7,75
286			Киров	8	8,32
287			Красная Лоза	7	6,00
288			Красный Клин	8	6,50
289			Красный Мост	7	10,05
290			Красный	7	7,35
291			Круглое	7	5,35
292			Малая Топаль	8	5,46
293			Поляна	7	4,85
294		Гулевский	Вольница-1	7	8,00
295			Вольница-2	8	10,53
296			Гастенка	13	12,16
297			Гулевка	7	8,38
298			Калинина	7	9,70
299			Каменка	8	23,87
300			Каменуха	8	10,63
301			Красное Заречье	7	9,20
302			Красный Мост	10	12,38
303			Морозовщина	9	9,70
304			Особцы	9	8,39
305			Первомайский	8	8,30
306			Роща	7	7,75
307			Сосновый	8	11,57
308			Станилов	10	11,14
309			Туросна	11	10,92
310		Гутокорецкий	Андреевка-Пичевая	7	10,35
311			Буян	7	12,40
312			Ганновка	7	14,50
313			Гута-Корецкая	9	13,87
314			Заречье	8	8,47
315			Земница	10	12,22
316			Знание	3	13,00
317			Кожухово	7	16,25
318			Лядовка	7	12,65
319			Новая Андреевка	12	13,90
320			Новый Рассвет	12	17,03
321			Прохоровка	7	20,00
322			Сазоновка	7	10,75
323			Торфопредприятие Ректа	7	9,20
324			Унеча	14	15,68
325			Фанзоновщина	8	15,16
326		Душкинский	Видочка	6	1,90
327			Душкино	8	4,74
328			Запорожец	7	4,30
329			Кирковка	7	6,25
330			Медведево	8	7,38
331			Пчела	6	1,60
332			Стражев	7	1,90
333		Киваевский	Бутовск	8	8,67
334			Киваи	9	9,10
335			Кневичи	7	4,70
336			Красный Пахарь	7	8,40
337			Оболешево	7	5,90
338			Побережье	7	7,35
339		Коржовоголубовский	Волна	7	0,55
40			Вьюнка	7	1,90
341			Коржовка-Голубовка	7	2,00
342			Красная Заря	7	1,82
343			Лукьяновка	7	1,75
344			Мизиричи (психоинт.)	7	1,80
345			п. Вьюнка	7	1,55
346			Робчик	7	0,50
347			Сухопаровка	7	2,20

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
348		Лопатенский	Лопатни	9	6,55
349			Маковье	7	6,80
350		Мартьяновский	Авсеенково	8	2,03
351			Кабановка	7	3,15
352			Калинин	7	4,70
353			Ляды	7	6,10
354			Марьтьяновка	8	2,60
355			Окоп	6	3,70
356			Раскоса	7	6,80
357			Рощин	6	5,40
358			Сергеевка	6	4,90
359			Смотрова-Буда	8	6,03
360			Якубовка	9	3,00
361		Ольховский	Ольховка	14	9,03
362			Тулуковщина	13	8,58
363			Туренев	8	8,38
364		Павличский	Зараманье	7	0,95
365			Павличи	7	1,35
366			Сурецкий Муравей	7	1,55
367		Первомайский	Ивановщина	7	6,80
368			Клубничный	9	12,46
369			Первое Мая	8	8,00
370			Рудня Голубовка	11	10,14
371			Теремошка	12	13,63
372			Токаревщина	7	4,95
373		Песчанский	Березовка	9	5,15
374			Песчанка	7	2,75
375			Суббовичи	7	2,10
376		Рожновский	Веприн	16	26,48
377			Голота	13	16,88
378			Горелая Сосна	8	21,03
379			Дробница	10	23,22
380			Красный Луч	11	28,65
381			Кузнец	18	23,79
382			Лесновка	12	16,64
383			Новый Мир	11	22,82
384			Поплавы	12	14,44
385			Рожны	17	10,76
386			Старая Комаровка	8	14,77
387			Улетовка	13	29,10
388			Чахов	12	27,66
389			Ягодка	8	19,83
390		Смолевичский	Белая Криница	7	1,85
391			Близна	7	3,85
392			Борки	7	1,94

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
393			Меляковка	7	4,05
394			Смолевичи	9	2,87
395			Чемерна	9	3,10
396		Сосновский	Воровского	7	1,25
397			Гроза	6	0,40
398			Заря	7	2,80
399			Затишье	7	1,60
400			Кожушье	7	1,90
401			Новоельнинский	6	0,60
402			Павловский	6	0,95
403			Рудня Тереховка	7	1,65
404			Свердлов	6	0,60
405			Свобода	6	0,40
406			Сосновка	7	1,55
407		Ущерпский	Борозенщина	12	12,41
408			Веселая Роща	10	15,64
409			Кипень Рожновский	13	17,08
410			Кипень Ущерпский	13	18,84
411			Колпины	14	19,46
412			Корьма	11	14,67
413			Красная Криница	11	14,92
414			Новая Комаровка	12	15,51
415			Новая Речица	11	18,18
416			Писаревка	13	18,42
417			Свисток	12	16,89
418			Ущерпье	18	18,00
419	Красногорский	Районного подчин.	Красная Гора	15	6,23
420			Мирный	15	33,28
421		Батуровский	Батуровка	11	24,81
422			Высокий Бор	7	15,45
423			Дубенец	16	15,61
424			Краснодубровск	11	11,17
425			Крыловка	8	26,34
426			Новопавловка	11	17,40
427		Верхличский	Верхличи	8	2,93
428			Столбунка	9	23,75
429			Яминец	12	12,26
430		Заборский	Борки	12	70,61
431			Буковец	12	76,75
432			Гущи	11	48,49
433			Долгое	9	45,96
434			Заборье	17	68,18
435			Ковали	12	81,14
436			Озерщина	9	50,28
437			Прохоренки	9	74,35

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
438			Тугани	15	60,23
439		Колюдовский	Буда	6	3,20
440			Даниловка	6	4,30
441			Ивановка	6	2,00
442			Калинин	6	3,50
443			Каменка	6	2,80
444			Колюды	8	3,30
445			Краснопавловка	6	1,80
446			Непобедимый	6	2,40
447			Новоковалевка	6	2,00
448			Обруб	7	2,25
449			Прудки	6	5,70
450		Кургановский	Березовка	15	31,91
451			Криничное	14	9,85
452			Кургановка	13	4,69
453			Кустовка	11	2,18
454			Малиновка	8	7,62
455			Михалевка	10	27,38
456			Николаевка	31	50,70
457			Новоалександровка	16	48,21
458			Новомихалевка	17	22,89
459			Рубаны	13	20,02
460			Ямище	13	59,81
461		Летяховский	Красный Городок	7	1,45
462			Летяхи	7	3,25
463		Лотаковский	Ермолинка	7	4,95
464			Залесье	7	4,85
465			Заречье	7	4,60
466			Ивановка	7	8,05
467			Кибирщина	7	7,50
468			Лотаки	7	5,20
469		Любовшанский	Кашковка	7	3,40
470			Любовшо	8	3,57
471		Макаричский	Дубовец	7	4,60
472			Макаричи	7	13,82
473			Палужская Рудня	7	6,05
474		Медведевский	Александровский	11	14,11
475			Вяжновка	13	13,75
476			Малев	11	18,84
477			Медведи	17	11,91
478			Новая Жизнь	9	14,52
479			Новодрожжинск	14	27,19
480		Морозовский	Александровка	13	41,03
481			Гасанова Слобода	9	5,50
482			Комары	9	3,53
483			Козловка	9	4,43
484			Ларневск	11	5,90
485			Морозовка	11	6,93
486			Никольск	11	3,83
487			Тислянки	9	4,00
488			Чиграй	15	28,53
489		Перелазский	Ковалевка	6	3,20
490			Перелазы	8	2,93
491			Сеятель	6	7,20
492		Селецкий	Великоудебное	13	16,94
493			Поляны	10	6,83
494			Селец	11	14,72
495		Увельский	Байлуки	12	20,91
496			Барсуки	16	22,62
497			Городок	13	13,30
498			Заозерье	11	25,66
499			Лесной	14	23,94
500			Подславушка	12	19,60
501			Увелье	17	28,61
502			Устье	7	24,35
503		Фошнянский	Боровка	6	1,70
504			Деньгубовка	7	6,70
505			Дубрежка	7	4,75
506			Зеленая Дубровка	7	8,85
507			Красная Пересвица	7	7,40
508			Красное	6	5,20
509			Красный Камень	8	13,47
510			Новодубровка	8	7,90
511			Труд	11	4,10
512			Фошное	7	3,90
513		Яловский	Городечня	13	11,50
514			Яловка	16	46,61
515		Красногорский	Даниловка	9	5,79
516		Посс.	Завалище	7	2,74
517			Новая Москва	9	6,35
518			Щедрин	9	3,43
519	Новозыбковский	Верещакский	Верещаки	16	17,03
520			Грозный	11	23,13
521			Махоновка	11	14,62
522			Несвоевка	13	15,28
523			Рассадники	11	27,42
524			Триголов	11	16,19
525		Внуковичский	Борщевка	10	20,90
526			Внуковичи	13	14,55
527			Дедовский	11	16,71

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
528			Калиновка	14	15,53
529			Клюков Мох	11	22,58
530			Красная Заря	13	28,50
531			Любин	8	13,01
532			Пеньки	13	13,37
533			Синий Колодец	14	14,48
534			Синявка-1	13	13,89
535		Деменский	Барки	12	26,30
536			Вертебы	9	22,22
537			Воронова Гута	11	8,20
538			Гремучка	10	28,81
539			Гута	14	30,22
540			Деменка	14	28,32
541			Калинин	9	31,05
542			Кривой Сад	11	31,65
543			Муравинка	12	28,78
544			Орел	12	41,28
545			Павловка	12	27,61
546			Перевоз	12	28,20
547			Рудня	9	23,65
548			Савичка	11	26,34
549			Свидерки	10	24,14
550			Сенное	11	33,19
551			Столпенко	12	42,55
552			Филиал ВИУА	9	31,71
553			Хутор Дармоедов	6	24,80
554			Поселок им.Калинина	6	27,40
555			Косматая Гора	6	30,03
556		Замишевский	Величка	17	17,48
557			Дружба	11	17,19
558			Замишево	16	16,19
559			Крутоберезка	16	13,41
560			Мамай	14	17,21
561			Тростань	14	14,51
562			Шитиков Лог	16	13,40
563			Горянск	6	20,02
564		Каташинский	Каташин	14	9,70
565			Красный Гай	10	10,72
566			Курганье	10	6,70
567		Катичский	Вихолка	12	19,65
568			Журавка	12	20,94
569			Катичи	12	14,89
570			Корчи	12	15,68
571			Михайловка	8	17,20
572			Новые Катичи	11	15,01
573		Манюковский	Белый Колодец	18	12,79
574			Борок	9	11,57
575			Заверша	7	13,15
576			Злотницкий	16	9,64
577			Красная Московщина	13	9,98
578			Красный Остров	9	7,62
579			Манюки	10	10,56
580			Манюки ж/д. ст.	6	8,60
581			Писарка	12	14,77
582			Савкин Хутор	6	13,30
583			Подрузный	7	13,00
584			Уступы	6	9,81
585		Новобобовичский	Борец	9	37,29
586			Новые Бобовичи	18	25,78
587			Победа	9	19,30
588			Подлесье	9	24,19
589		Новоместский	Белимовка	9	21,59
590			Борок	10	42,52
591			Глыбочка	10	42,76
592			Граница	7	32,90
593			Дыбовка	8	16,06
594			Карна	11	26,96
595			Макусы-1	9	28,53
596			Макусы-2	8	23,69
597			Мошок	9	37,81
598			Новая Деревня	8	32,67
599			Новое Место	18	26,19
600			Озерище	7	20,10
601			Селицкое	8	24,51
602			Шеломы	14	20,43
603		Святский	Бабаки	11	57,60
604			Новоалексеевка	7	61,70
605			Святск	17	47,64
606		Сновский	Великие Ляды	11	22,95
607			Данченкова Слобода	11	9,59
608			Дубровка	16	19,97
609			Заречье	11	9,78
610			Новые Файки	12	15,81
611			Паломы	11	23,33
612			Сновское	16	10,77
613		Старобобовичский	Булдынка	11	21,95
614			Гатка	9	22,22
615			Гривка	11	24,65
616			Старые Бобовичи	13	26,58
617			Ясная Поляна	11	27,46

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
618			Подипуть	7	43,48
619		Старовышковский	Гривка	9	30,87
620			Колодезский	13	30,32
621			Курганье	11	19,48
622			Прудовка	11	33,28
623			Старый Вышков	13	35,19
624			Горка	7	20,73
625		Старокривецкий	Александровка	8	11,40
626			Дягель	8	7,18
627			Замлынье	6	8,00
628			Засновье	7	13,35
629			Малый Кривец	9	9,90
630			Отрадное	9	5,71
631			Скоробогатая Слобода	10	8,78
632			Старый Кривец	8	6,81
633		Старорудняиский	Машкинский	11	23,23
634			Полек	9	19,25
635			Синявка-2	14	17,22
636			Старая Рудня	12	16,93
637			Халевичи	12	26,65
638			Ягодное	12	32,35
639	Стародубский	Районного подчин.	Стародуб	6	1,90
640		Алейниковский	Алейниково	6	2,76
641			Ламаковка	6	2,97
642			Стратива	6	2,70
643		Воронокский	Васильевка	6	2,40
644			Воронок	6	1,38
645			Лужки	6	3,61
646		Дохновичский	Дохновичи	6	2,35
647			Забава	6	1,44
648			Иванчиковский	6	1,80
649			Суходолье	6	2,56
650		Елионский	Елионка	6	4,16
651			Елеоночка	6	2,69
652			Солова	6	4,25
653		Занковский	Березовка	6	1,54
654			Занковка	6	2,00
655			Малышкино	6	4,97
656			Красный	6	2,75
657			Плоцкое	6	3,37
658			Соколовка	6	4,02
659		Запольско-Халеевич	Запольские Халеевичи	6	1,94
660			Литовск	6	3,63
661			Селище	6	0,22
662			Старые Халеевичи	6	3,47
663			Ярцево	6	2,89
664		Каменский	Камень	6	4,36
665			Крюков	6	3,35
666			Логоватое	6	3,71
667			Чубковичи	6	3,26
668		Картушинский	Картушино	6	0,62
669			Ковалевщина	6	1,81
670			Красный Дуб	6	1,90
671			Обуховка	6	2,38
672			Таврика	6	1,81
673		Краснооктябрьский	Десятуха	6	0,69
674			Кирпичики	6	1,15
675			Невструево	6	0,73
676			Горислово	6	0,97
677		Мишковский	Мишковка	6	1,47
678			Мирный	6	1,90
679			Стодолы	6	1,55
680			Тарасовка	6	2,78
681			Хомутовка	6	2,38
682		Мохоновский	Мадеевка	6	1,89
683			Остроглядово	6	1,53
684			Сергеевск	6	1,19
685			Прокоповка	6	2,84
686			Рябцево	6	1,46
687		Нижневский	Белоусов	6	3,99
688			Березовка	6	5,52
689			Истровка	6	6,15
690			Криницы	6	6,66
691			Нижнее	6	7,52
692			Ойстрица	6	8,81
693		Новомлынский	Буда Корецкая	6	2,01
694			Новомлынка	6	2,83
695			Озерное	6	1,77
696			Приваловка	6	2,54
697		Понуровский	Буда Понуровская	6	2,24
698		Пятовский	Днепровка	6	0,90
699			Осколково	6	1,06
700			Пятовск	6	0,85

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ РСФСР ЦЕЗИЕМ-137 (Ки/км^2)
(Caesium-137)

КАЛУЖСКАЯ ОБЛАСТЬ (KALUGA)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Обл. подчинения		Людиново	10	2,05
2	Думиничский	Хотьковский	Хотьково	7	2,36
3			Клинцы	6	2,39
4		Чернышевский	Чернышево	6	0,87
5	Жиздринский	Районного подчин.	Жиздра	9	2,35
6		Кореневский	Дубровка	7	2,62
7			Коренево	6	3,60
8			Улемль	7	3,78
9			Болвинское лес-во	6	9,86
10			Иночка	6	2,98
11			Кресты	6	2,87
12			Рассветы	6	3,68
13		Овсорокский	Овсорок	6	2,55
14			Судимир	7	4,36
15			Таборы	7	3,25
16		Огорский	Березовка	7	1,66
17			Гололобовка	7	1,48
18			Митинка	7	1,50
19		Петровский	Зикеево	9	2,61
20			Фомин	9	2,39
21			Петровка	6	1,93
22			Студенец	6	0,97
23		Полюдовский	Полюдово	7	1,48
24			Белые Ямы	6	6,29
25			Гранки	6	3,86
26			Рассвет	7	7,59
27			Турьевка	6	7,42
28			Щигры	7	5,01
29		Советский	Коллективизатор	7	2,48
30			Полом	6	5,34
31			Высокий Холм	7	6,46
32			Комиссаровский	6	10,16
33			Мурачевка	7	3,01
34			Овсорочки	6	5,36
35			Озерская	7	6,02
36			Потье	6	4,41
37		Улемецкий	Калинино	7	2,36
38			Павловка	6	2,68
39			Улемец	6	2,06
40			Стайки	6	2,07
41		Ульяно-Ленинский	Ж/д. ст. Судимир	6	4,04
42			Поляна	7	5,59
43			Белый Колодец	6	7,45
44			Винский	6	5,00
45			Младенск	5	3,03
46			Плотавец	6	6,96
47		Яровщинский	Яровщина	7	4,86
48			Авдеевка	6	7,45
49			Песочня	6	7,88
50			Орля	6	6,06
51			Сосновка	6	6,62
52	Людиновский	Войловский	Думлово	6	1,92
53		Куяво-Кургановский	Куява	1	1,61
54			Ж/д. ст. Куява	7	2,00
55	Ульяновский	Районного подчин.	Дудоровский	7	6,88
56		Афанасовский	Афанасово	7	8,56
57			Александровка	7	8,20
58			Хоревка	7	8,81
59			Бобровка	6	8,10
60			Минин	6	9,76
61			Петуховка	6	7,79
62			Федоровка	6	9,86
63		Волосово-	Белый Камень	6	0,25
64		Дудинский	Перестряж	6	2,07
65			Слободка	1	4,20
66		Вязовенский	Вяльцево	6	2,12
67			Малая Вязовенка	6	0,55
68			Холмищи	6	3,40
69		Кирейковский	Кирейково	7	4,36
70		Крапивенский	Крапивна	7	5,86
71			Веснины	6	9,80
72			Косовка	7	2,56
73			Красногорье	6	5,89
74			Ломна	6	5,82
75			Любовка	6	9,96
76			Подкопаевский	6	9,84
77		Медынцевский	Дудорово	6	4,03
78			Медынцево	6	4,15
79			Старица	6	5,80
80		Мойловский	Кцынь	7	3,54

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
81			Мойлово	6	2,30
82		Озеренский	Железница	6	1,90
83			Богдановский	6	3,77
84		Паневский	Дубна	7	2,58
85			Дудино	6	0,52
86			Жильково	6	0,60
87			Никитское	6	0,50
88			Починок	6	2,27
89			Гурово	6	1,07
90		Уколицкий	Сорокино	7	3,55
91			Песоченка	6	7,54
92			Уколица	6	4,07
93		Ульяновский	Дурнево	7	4,63
94			Дебри	6	4,24
95			Ульяново	7	3,34
96			Обухово	6	4,00
97			Речица	6	4,62
98			Сеничкин	6	5,02
99		Ягоднинский	Горицы	6	9,08
100			Мелехово	11	6,60
101			Ногая	6	9,60
102			Сопово	6	4,41
103			Шваново	6	6,75
104			Ягодная	6	5,38
105		Дудоровский	Зеленый	6	8,02
106			Кудеяр	7	9,49
107			Мартынка	7	10,99
108	Хвастовичский	Районного подчин.	Еленский	7	2,54
109		Берестнянский	Берестна	7	8,25
110			Высокое	6	7,21
111			Катуновка	6	7,13
112			Колодяссы	7	8,55
113			Красненский	6	8,04
114			Павловка	6	5,48
115		Воткинский	Буда	7	3,63
116			Вечность	7	3,20
117			Воткино	7	5,04

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
118			Почаевка	7	7,07
119			Красная Горка	6	6,28
120			Черная Речка	6	4,64
121			Ястребиха	6	5,83
122		Кленовский	Тросна	6	1,54
123			Клен	7	1,51
124		Красненский	Красное	7	2,19
125			Новохвастовичи	6	2,82
126			Фомин Верх	6	3,36
127		Кудрявецкий	Кудрявец	6	1,63
128			Теребень	6	1,54
129				6	1,40
130		Ловатский	Барановка	7	3,77
131			Ловать	7	8,56
132			Меховая	6	7,34
133			Фролово	6	7,55
134		Милеевский	Милеево	7	4,07
135			Ловатянка	6	11,49
136			Мокрые Дворики	6	5,51
137			Рессета	6	7,68
138			Харитоновка	6	5,10
139		Пеневичский	Пеневичи	6	0,80
140		Подбужский	Владимировка	7	2,93
141			Ильинка	7	1,37
142			Подбужье	6	1,45
143			Холм	7	1,14
144		Нехочский		6	9,20
145				6	6,50
146		Слободский	Долгое	6	1,51
147			Клетно	6	0,80
148			Семеновский	6	1,33
149			Сергеевка	6	2,01
150			Хизна	7	1,66
151		Стайковский	Стайки	6	0,59
152		Хвастовичский	Хвастовичи	7	2,01
153		Еленский	Долина	7	6,21
154			Глебовка	6	3,10

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ РСФСР ЦЕЗИЕМ-137 (Ки/км^2)
(Caesium-137)

ОРЛОВСКАЯ ОБЛАСТЬ (ORLOV)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Болховский	Районного подчин.	Болхов	6	5,00
2		Багриновский	Дубровский	6	2,20
3			Фатнево	6	5,40
4		Бориловский	Сухочево	6	1,60
5		Боровский	Игино	6	3,80
6		Герасимовский	Шпилева	6	6,50
7		Красниковский	Вытебеть	6	1,90
8			Красниково	6	4,70
9		Медведковский	Дворики	6	3,98
10			Подлесная Слобода	6	3,62
11		Михневский	Репнино	6	4,20
12		Однолуцкий	Черногрязка	6	2,30
13		Сурьянинский	Руднево	6	4,10
14		Хуторской	Верхняя Радомка	6	5,80

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ РСФСР ЦЕЗИЕМ-137 (Ки/км^2)
(Caesium-137)

ТУЛЬСКАЯ ОБЛАСТЬ (TULA)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Обл. подчинения		Богородицк	6	2,60
2			Кимовск	6	1,50
3	Арсеньевский	Районного подчин.	Арсеньево	6	3,10
4		Аранский	Араны	6	5,60
5			Нагорный	6	5,06
6			Огневой	6	6,27
7		Белоколодезский	Дубрава	6	3,47
8			Железница-Жизневский	6	4,50
9			Железница-Обрезково	6	3,80
10			Заречье	6	4,38
11			Ивановка-2	6	6,40
12			Троицкое	6	4,66
13		Ясенковский	Выковка	6	4,54
14			Вязок	6	3,01
15			Елизаветино-Блиновка	6	2,76
16			Красноармеец	6	5,06
17			Красное	6	6,37
18			Кологреевка	6	5,30
19			Сычовка	6	2,65
20			Черный Верх	6	5,44
21			Шмелевка	6	3,49
22			Ясенки	6	2,30
23		Голубоченский	Андрияновский	6	4,73
24			Батурский	6	3,69
25			Красный	6	4,72
26			Нижние Ростоки	6	5,46
27			Поляны	6	5,46
28			Протасово	6	4,88
29			Средние Ростоки	6	5,75
30			Фурсово	6	4,45
31		Бобровский	Большая Борщевка	6	4,68
32			Боброво	6	4,72
33			Большое Захарово	6	5,03
34			Варварино	6	4,50

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
35			Еврееново	6	5,67
36			Малое Захарово	6	5,00
37			Нариманово	6	3,57
38			Прилепы	6	4,58
39			Савенки	6	4,92
40			Уч. пост. Арсеньево	6	3,61
41			Воробьевский	6	5,99
42		Истинский	Гамово	6	2,77
43			Дертихино	6	6,73
44			Звягино	6	4,88
45		Кузменский	Красноселье	6	5,56
46			Кузменки	6	5,80
47		Литвиновский	Литвиново	7	5,30
48			Астахово	6	4,94
49			Байдино	6	4,66
50			Гремячки	6	5,31
51			Круг-Ливаново	6	4,84
52			Круг-Страхово	6	4,75
53			Савенково	6	6,07
54			Синяково	6	4,84
55			Юрково	6	5,08
56		Мокровский	Мокрое	7	7,52
57			Верхние Лучки	6	4,45
58			Часовня	6	6,34
59		Манаевский	Манаенки	7	3,19
60			Центральный	6	2,40
61			Андрейкинский	6	2,51
62			Миново	6	5,29
63		Меркуловский	Быковский	6	3,76
64			Меркулово	6	5,54
65			Парахино	6	3,54
66			8-е Марта	6	4,27
67		Стрикинский	Дебрицы	6	3,41
68			Дерюжкино	6	4,09
69			Колодези	6	4,71
70			Корытинка	6	3,96
71			Мощевский	6	4,95
72			Прилепы	6	3,41
73			Хлопово	6	6,41
74	Белевский	Районного подчин.	Белев	6	2,30
75		Бакинский	Слобода	6	4,00
76		Березовский	Дулино	6	1,20
77		Богдановский	Семеновское	6	1,50
78			Челюстино	6	1,40
79		Железницкий	Бугодовищи	6	5,20
80			Федящево	6	3,90
81		Кочеровский	Борково	6	4,90
82		Новодолецкий	Зайцево	6	3,90
83				6	0,80
84				6	1,40
85	Богородицкий	Районного подчин.	Бегичевский	6	4,30
86			Суходольский	6	1,60
87			Товарковский	6	0,90
88		Большесухо-дольский	Сухотино	6	1,20
89	Веневский	Пашковский	Грицовский	6	1,20
90			Юдино	6	0,50
91	Кимовский	Районного подчин.	Епифань	6	1,50
92		Краснопольский	Краснополье	7	2,20
93	Киреевский	Районного подчин.	Болохово	6	0,50
94			Киреевск	6	2,70
95			Приупский	6	2,20
96			Улановский	6	1,40
97		Кузнецовский	Кузнецово	6	6,30
98		Новоселебенский	Кузьмищево	6	1,20
99			Моховое	6	0,90
100		Подосиновский	Анненки	6	1,40
101	Новомосковский	Иван-Озерский	Богдановка	6	0,70
102		Прохоровский	Орловка	6	1,20
103			Троицкое	6	3,40
104	Одоевский	Рылевский	Нижние Дубки	6	2,70
105			Рылево	6	1,30
106			Ур. Хуторка	6	1,60
107		Сомовский	Верхнее Касимово	6	2,30
108			Сомово	6	1,40
109		Стрелецкий	Стрелецкий	5	2,60
110	Плавский	Районного подчин.	Плавск	25	11,43
111		Горбачевский	Локна	7	9,60
112			Новая Локна	8	11,08
113			Михайловское	8	9,46
114			Никольское 1	8	9,50
115			Никольское 2	8	9,85
116		Камынинский	Молочные Дворы	14	10,03
117			Средние Мармыжи	9	12,14
118			Нижние Мармыжи	15	9,16
119			Масловка	6	8,35
120			Новоселки	7	8,22
121			Камынино	11	7,67
122			Губа 2	7	4,92
123		Мещеринский	Мещерино	9	2,42

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
124		Октябрьский	Красное	9	2,00
125			Октябрьский	7	4,10
126			Косая Губа	8	2,55
127			Пеньково	8	2,31
128			Красное Заречье	8	1,74
129			Васильевка	8	2,91
130			Кожухово	7	3,61
131			Крекшино	7	2,74
132			Александровка	7	4,14
133			Александровский	6	2,72
134			Волхоновщино	7	2,96
135			Красная Нива	7	3,54
136		Пригородный	Юрьево	9	6,32
137			Синявино	9	9,46
138			Пригородный	8	9,25
139			Юрьевский	7	5,27
140		Рахмановский	Рождествено 1	8	11,00
141			Рождествено 2	7	10,74
142			Новая Слободка	8	12,63
143			Заречье	7	14,25
144			Рахманово	8	9,02
145			Орликово	8	12,48
146			Гамовка	7	9,67
147			ур. Березовый Верх	2	12,74
148			ур. Высокий Верх	6	9,65
149		Старолесковский	Ушаково	8	9,79
150			Ботвиньево	7	12,86
151			Щепотьево	7	10,74
152			Арсеньево	8	9,38
153			Стрешнево	8	10,76
154			Смычка	8	11,10
155			Юсупово	7	9,41
156			Лунино	7	9,03
157			Витцинские Выселки	8	10,65

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
158			Желябово	8	7,75
159			Озерки	8	10,23
160		Частинский	Акуловские Выселки	9	8,16
161			Красногорье	13	5,54
162			Сорочинка	7	4,10
163			Акулово	9	4,82
164			Синявинские Выселки	7	6,22
165			Красный	6	6,79
166			Средний	7	8,20
167	Тепло-	Районного подчин.	Теплое	6	3,20
168	Огаревский	Большеогаревский	Огарево	6	1,50
169		Волчье-Дубравский	Волчья Дубрава	6	0,90
170		Нарышкинский	Нарышкино	6	3,60
171		Плесовский	Плесы	6	4,00
172	Чернский	Районного подчин.	Чернь	6	1,00
173		Большескуратов-ский	Вязовка	6	0,96
174		Малоскуратовский	Малое Скуратово	6	2,50
175		Полтевский	Полтево	6	5,10
176		Поповский	Поповка-1	6	3,00
177		Синегубовский	Синегубово	6	9,40
178	Щекинский	Районного подчин.	Огаревка	6	1,60
179			Советск	6	3,50
180		Даниловский	Даниловка	6	1,90
181		Карамышевский	Карамышево	6	0,97
182		Крапивенский	Крапивна	6	0,90
183		Лазаревский	Голощапово	6	1,60
184			Ржаво	6	3,70
185		Лукинский	Лукино	11	2,68
186			Сумароково	6	3,10
187		Пироговский	Пирогово	10	7,62
188		Пушкинский	Пушкино	9	8,00
189	Донской	Районного подчин.	Комсомольский	6	1,90
190	Горсовет		Руднев	6	1,80

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ РСФСР СТРОНЦИЕМ-90 (Ки/км^2)
(Strontium-90)

БРЯНСКАЯ ОБЛАСТЬ (BRYANSK)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Обл. подчинения		Клинцы	2	0,10
2			Новозыбков	9	0,25
3	Климовский	Сушановский	Прогресс	3	1,10
4	Клинцовский	Гулевский	Туросна	2	0,21
5	Красногорский	Заборский	Борки	3	0,80
6			Буковец	1	0,58
7			Гущи	2	0,90
8			Долгое	1	0,22
9			Заборье	7	2,00
10			Ковали	1	0,92
11			Прохоренки	1	0,44
12			Тугани	6	1,00
13		Кургановский	Березовка	3	0,96
14			Николаевка	4	0,75
15		Макаричский	Макаричи	3	0,43
16		Увельский	Барсуки	3	1,50
17			Увелье	3	1,10
18		Яловский	Яловка	6	0,80
19	Новозыбковский	Районного подчин.	Злынка	5	0,70
20			Вышков	3	0,20
21		Верещакский	Верещаки	4	0,24
22		Деменский	Борки	3	0,45
23			Гута	1	0,80
24			Перевоз	2	0,84
25			Столпенко	1	1,25
26		Добродеевский	Добродеевка	2	0,12
27			Чехов	1	1,80
28		Новобобовичский	Новые Бобовичи	2	0,70
29		Новоместский	Новое Место	8	0,60
30		Святский	Святск	3	0,55
31		Старобобовичский	Старые Бобовичи	2	0,65
32		Старовышковский	Старый Вышков	4	1,00

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ УССР ЦЕЗИЕМ-137 (Ки/км^2)
(Caesium-137)

ВИННИЦКАЯ ОБЛАСТЬ (VINNITSK)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Обл. подчинения		Жмеринка	1	0,1
2	Бершадский	Пятковский	Пятковка	2	0,3
3	Гайсинский	Районного подчин.	Гайсин	1	0,2
4		Бубновский	Дмитренки	1	1,3
5		Кузьминецкий	Шуровцы	1	1,2
6			Косаново	1	1,2
7		Кунковский	Кунка	2	3,6
8		Харпачский	Степашки	2	1,0
9			Харпачка	2	1,0
10		Ярмолинецкий	Басалычевка	1	0,6
11			Ярмолинцы	2	2,3
12	Крыжопольский	Павловский	Павловка	2	0,2
13			Торкановка	2	0,2
14	Немировский	Районного подчин.	Брацлав	3	0,6
15		Байраковский	Думбасловка	2	0,2
16			Казаковка	2	0,2
17		Брацлавский	Гриненки	2	0,9
18		Волчекский	Волчок	2	0,1
19		Воробиевский	Воробиевка	2	3,4
20			Гвоздев	2	0,9
21			Новая Николаевка	2	0,4
22		Вышковецкий	Вышковцы	2	0,4
23		Грабовецкий	Грабовец	2	2,3
24			Сорокодубы	2	1,5
25		Зяньковецкий	Зяньковцы	2	0,6
26		Медвежанский	Медвежья	2	0,2
27			Супруновка	2	0,1
28		Муховецкий	Муховцы	1	0,7
29		Никифоровецкий	Гостинное	2	1,4
30			Лука	3	1,4
31			Никифоровцы	3	0,9
32		Скрицкий	Новоселовка	2	0,6
33			Скрицкое	4	0,9
34		Соколецкий	Соколец	2	0,6
35			Алексеевка	2	0,8
36		Стрельчинецкий	Стрельчинцы	4	0,9
37	Томашпольский	Районного подчин.	Томашполь	1	0,8
38			Вапрянка	2	0,7
39		Вербовский	Вербовая	2	0,4
40		Горышковский	Горышковка	2	2,5
41			Жолобы	2	2,4
42		Комаргородский	Комаргород	2	0,4
43			Кислицкое	1	0,9
44		Марковский	Антополь	1	1,3
45			Марковка	1	1,2
46	Тростянецкий	Районного подчин.	Ладыжин	4	1,1
47		Ильящевский	Красногорка	2	0,9
48	Тульчинский	Районного подчин.	Кирнасовка	5	2,5
49			Тульчин	1	1,2
50		Аннопольский	Аннополь	2	2,3
51		Бортникский	Бортники	2	0,6
52		Дранский	Одаи	2	1,4
53		Журавлевский	Журавлевка	2	1,1
54		Заозерненский	Заозерное	5	0,9
55			Васильевка	1	2,0
56		Клебанский	Клебань	3	1,7
57			Федьковка	2	1,0
58			Марково	2	1,3
59		Крищинецкий	Крищенцы	7	3,6
60		Михайловский	Михайловка	4	3,8
61			Маньковка	3	0,4
62		Печерский	Печера	2	0,6
63		Суворовский	Суворовское	2	0,6
64		Тарасовский	Тарасовка	2	0,6
65		Тимановский	Тимановка	1	1,2
66		Тульчинский	Нестерварка	1	0,7
67		Холодовский	Холодовка	2	1,8
68		Шпиковский	Шпиков	2	1,0
69		Юрковский	Станиславка	2	1,5
70			Юрковка	2	1,2
71	Тывровский	Районного подчин.	Тывров	1	0,2
72		Бушинский	Бушинка	3	4,2
73				1	3,8
74		Василевский	Василевка	1	1,0
75			Курники	1	0,1
76		Дзвонихский	Дзвониха	2	0,3
77			Колюхов	2	0,4
78			Канава	2	2,1
79		Рахно-Полевский	Рахны-Полевые	3	0,9
80		Следянский	Следы	3	2,4

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
81		Уяринецкий	Уяринцы	2	3,9
82	Чечельницкий	Белокаменский	Белый Камень	2	0,7
83		Бондуровский	Бондуровка	2	2,7
84		Вербский	Вербка	2	2,5
85			Куреневка	2	1,5
86		Каташинский	Каташин	2	0,9
87		Лугский	Луги	2	0,5
88		Ольгопольский	Ольгополь	2	0,4
89		Рогозковский	Рогозка	2	0,8
90		Стратиевский	Стратиевка	2	0,3
91		Тартакский	Тартак	2	1,0
92		Червоногребельский	Червоная Гребля	2	0,7
93	Шаргородский	Голыньчинецкий	Голынчинцы	2	1,3
94		Деребчинский	Малая Деребчинка	2	2,0
95		Джуринский	Джурин	2	2,7
96		Ждановский	Должок	1	0,9
97		Зведеновский	Зведеновка	2	1,1
98			Попелевка	2	2,1
99			Вербовка	2	1,0
100		Рахновско-Лесовый	Рахны-Лесовые	2	1,7

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ УССР ЦЕЗИЕМ-137 (Ки/км^2)
(Caesium-137)

ЖИТОМИРСКАЯ ОБЛАСТЬ (ZHITOMIRSK)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Обл. подчинения		Коростень	64	8,0
2	Коростенский	Берестовецкий	Берестовец	6	5,4
3		Беховский	Бехи	16	9,5
4			Шатрище	8	5,5
5		Выговский	Выгов	3	3,0
6		Давыдковский	Давидки	3	5,4
7		Дедковичский	Дедковичи	4	2,7
8		Кожуховский	Кожуховка	2	4,1
9			Чигири	6	10,4
10			Диброва	2	2,3
11			Клочево	3	4,9
12			Ж/д. ст. Клочки	1	5,0
13		Купищенский	Жабче	9	11,9
14			Купище	8	7,4
15		Мединовский	Мединовка	2	4,0
16		Обиходовский	Обиходы	42	9,6
17		Полесский	Чоловка	2	3,0
18			Житомирское	4	8,1
19		Сарновичский	Сарновичи	3	3,8
20		Сингаевский	Купечь	6	7,5
21			Немировка	19	11,1
22			Сингаи	5	4,5
23		Ходаковский	Ходаки	2	3,9
24		Хотиновский	Хотиновка	3	4,0
25	Лугинский	Районного подчин.	Лугины	8	3,2
26		Бовсуновский	Бовсуны	2	1,4
27			Соловьи	2	1,6
28		Будо-Литковский	Березовый Груд	6	2,9
29			Будо-Литки	3	2,3
30			Радогоща	3	3,7
31		Жеревецкий	Жеревцы	5	6,5
32			Рудня-Жеревцы	5	7,7
33			Ж/д. ст. Жерев	4	12,3
34			п. Гранитного карьера	3	12,2
35			Заполье	4	3,6
36			Заречка	6	5,0
37		Красноставский	Красностав	3	1,5

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
38			Тесновка	2	1,4
39		Летковский	Диброва	3	2,3
40			Летки	3	2,2
41			Глухова	4	1,0
42		Липниковский	Липники	3	2,1
43			Малаховка	10	8,7
44			Мощаница	11	10,6
45			Осны	3	2,1
46		Лугинский	Крупчатка	3	5,3
47			Лугинки	2	2,0
48		Остаповский	Остапы	2	2,1
49		Повчанский	Повч	6	5,0
50			Рудня-Повчанская	7	10,0
51		Путиловичский	Путиловичи	5	1,6
52			Старые Новаки	10	2,9
53		Старосельский	Староселье	3	2,7
54		Степановский	Степановка	13	7,2
55			Новая Рудня	4	4,7
56		Топильнянский	Чапаевка	6	4,0
57			Топильня	2	3,4
58		Червоноволокский	Червона Волока	11	2,8
59			Бобричи	9	5,0
60			Волошино	10	6,6
61			Красноселка	9	3,4
62			Ж/д. ст. Волошино	1	8,4
63	Малинский	Районного подчин.	Малин	4	0,7
64		Владовский	Писаревка	2	1,5
65		Вышевский	Марьятин	6	3,2
66			Трудолюбовка	1	2,9
67		Дибровский	Диброва	3	2,5
68		Ксаверовский	Ксаверов	1	1,1
69			Рудня-Калиновка	3	12,0
70			Савлуки	3	2,0
71		Недашковский	Недашки	6	1,3
72		Скуратовский	Скураты	2	1,0
73	Народичский	Районного подчин.	Народичи	26	17,1
74		Базарский	Базар	25	8,7
75			Бродник	7	1,2
76			Великие Миньки	17	8,4
77			Колосовка	3	3,3
78			Листвиновка	3	5,7
79			Рудня-Базарская	4	8,5
80			Сухаревка	13	4,0
81		Болотницкий	Болотница	3	4,2
82		Великоклещевский	Великие Клещи	36	30,3
83			Полесское	17	36,0
84		Вязовский	Вязовка	2	3,5
85		Голубиевичский	Буда-Голубиевичи	12	1,4
86			Васьковцы	7	4,9
87			Голубиевичи	26	9,4
88			Недашковка	6	0,7
89			Заводное	3	2,5
90		Гуто-	Гуто-Марьятин	3	3,4
91		Марьятинский	Рубежовка	3	2,5
92			Сингаи	3	3,1
93			Славковцы	2	3,1
94			Старый Кужель	2	6,0
95			Вила	3	0,5
96		Давыдковский	Давыдки	3	4,1
97		Закусиловский	Жерев	2	4,0
98			Закусилы	3	5,0
99			Бабиничи	3	2,6
100		Залесский	Залесье	11	4,0
101		Звиздальский	Звиздаль	24	27,6
102			Малые Миньки	29	46,6
103			Рудня-Осошня	23	58,9
104			Шишеловка	23	44,6
105		Калиновский	Калиновка	20	9,3
106			Малинка	6	2,8
107			Слобода	15	15,2
108		Любарский	Журавлинка	12	13,9
109			Лозница	18	21,4
110			Любарка	22	12,5
111			Роги	7	22,7
112			Северовка	9	14,6
113		Малоклещевский	Малые Клещи	15	25,7
114			Перемога	9	30,9
115			Хрипля	16	29,2
116		Межилесский	Межилеска	16	6,6
117			Осыка	11	8,7
118		Народичский	Старое Шарное	22	28,8
119		Новодорогинский	Новый Дорогинь	6	4,1
120			Славенщина	13	4,4
121			Яжберень	7	5,0
122			Отрубы	4	4,7
123		Радчанский	Грезля	3	1,1
124			Радча	3	1,9
125			Новая Радча	3	1,2
126			Ольховая	3	2,4
127			Ровба	3	2,1

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
128			Старая Радча	13	6,3
129			Тычков	7	3,8
130		Рассоховский	Гута-Ксаверовская	6	3,8
131			Рассоховское	18	10,9
132			Батьковщина	4	6,0
133			Рудня-Каменка	4	4,4
134			Анновка	14	15,0
135		Селецкий	Булев	8	20,0
136			Селец	39	9,1
137		Стародорогинский	Старый Дорогинь	1	5,1
138		Христиновский	Мотейки	22	6,1
139			Ноздрище	26	31,7
140			Христиновка	38	26,0
141	Овручский	Районного подчин.	Овруч	9	2,0
142		Бондаревский	Бондари	5	4,6
143			Бондаревка	3	2,2
144			Красноселка	2	3,9
145			Папирня	1	4,7
146		Великохайчанский	Великая Хайча	7	3,0
147			Кобылин	4	3,7
148			Збраньки	1	4,1
149		Великочерниговский	Великая Черниговка	3	3,7
150			Малая Черниговка	3	1,1
151		Выступовичский	Борутино	14	11,7
152			Выступовичи	12	7,2
153			Солотино	15	10,5
154		Гладковичский	Александры	9	7,2
155			Гладковичи	6	3,9
156			Гладковичская Каменка	7	4,0
157			Ж/д. ст. Грезля	3	3,5
158		Гошевский	Гошев	2	2,4
159			Смоляное	2	2,8
160		Журбовский	Будолюбовка	6	3,4
161			Грязево	3	3,0
162			Деревцы	4	3,8
163			Переезд	9	4,0
164			Ситовка	7	5,4
165			Сосновка	10	5,7
166			Степки	12	4,7
167			Подчашье	4	4,1
168			Желудевка	4	3,0
169		Кирдановский	Кирданы	3	2,5
170		Левковичский	Левковичи	4	2,9
171			Белка	1	4,4

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
172		Липско-Романовский	Колесники	12	4,8
173			Личманы	6	1,5
174			Магдин	5	3,0
175			Маленовка	3	4,1
176			Сидоры	3	2,6
177			Столпичное	8	7,2
178		Листвинский	Ракитное	5	6,1
179			Ж/д. ст. Мощаница	1	2,6
180			Листвин	4	2,5
181		Лучанковский	Лучанки	2	1,8
182		Нововеледникский	Новые Веледники	6	4,4
183			Сорокапень	3	4,5
184		Норинский	Чабан	3	2,5
185			Норинск	4	3,1
186			Мошаница	2	4,5
187			Подвеледники	2	2,0
188		Першотравненский	Каменевка	9	6,0
189			Першотравневое	5	3,9
190		Песчаницкий	Павловичи	5	1,9
191			Песчаница	3	4,1
192			Клинец	3	2,3
193			Полесское	4	5,2
194		Подрудянский	Подрудье	4	4,2
195		Покалевский	Гаевичи	4	4,0
196			Коптевщина	3	2,1
197			Покалев	3	3,1
198			Полохачев	4	3,6
199			Скребеличи	3	3,7
200		Руднянский	Бережесть	4	1,8
201			Бирковское	4	4,1
202			Людвиновка	4	4,4
203			Прилуки	1	1,7
204			Рудня	5	2,5
205		Слободской	Слобода	2	1,8
206			Средняя Рудня	4	1,3
207			Девошин	6	1,0
208			Заболоть	2	1,3
209			Кораки	2	0,5
210			Текловка	2	1,0
211			Островы	3	1,2
212			Ясенец	5	0,9
213		Хлуплянский	Нагоряны	3	3,7
214			Оленичи	3	4,1
215		Черевковский	Белка	3	4,4

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
216			Черевки	4	3,8
217		Черепинский	Черепин	3	2,9
218		Шоломковский	Заречье	5	2,5
219			Збраньки	4	4,2
220			Шоломки	7	2,6
221			Долгиничи	2	2,7
222	Олевский	Районного подчин.	Олевск	2	1,7
223			Диброва	1	4,9
224			Дружба	3	1,6
225		Белокоровичский	Белокоровичи	2	1,5
226		Дибровский	Дуброва-Олевская	2	9,9
227		Жовтневый	Жовтневое	2	0,3
228		Жубровичский	Жубровичи	2	2,3
229		Замысловичский	Замысловичи	2	1,2
230		Каменский	Каменка	2	2,1
231		Кишинский	Болярка	1	1,1
232			Кишин	2	1,8
233		Комсомольский	Комсомольское	2	2,1
234		Радовельский	Радовель	5	1,9
235			Рудня-Радовельская	4	9,1
236		Хочинский	Рудня-Хочинская	5	2,7

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ УССР ЦЕЗИЕМ-137 (Ки/км^2)
(Caesium-137)

КИЕВСКАЯ ОБЛАСТЬ (KIEV)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Обл. подчинения		Белая Церковь	3	0,1
2			Ирпень	1	1,9
3	Барышевский	Жуковский	Жуковка	1	0,1
4		Лукьяновский	Лукьяновка	2	0,3
5		Семеновский	Семеновка	1	0,1
6	Белоцерковский	Ивановский	Ивановка	7	7,0
7		Иосиповский	Иосиповка	11	9,1
8			Красное	4	2,9
9			Павловка	4	13,5
10		Коженикский	Кожeники	2	0,3
11		Михайловский	Михайловка	3	5,3
12		Пилипчанский	Пилипча	2	0,2
13		Розалеевский	Розалеевка	1	2,4
14		Тарасовский	Тарасовка	2	5,5
15		Трушковский	Трушки	1	0,1
16		Шкаровский	Шкаровка	2	0,3
17	Богуславский	Бранопольский	Браное Поле	4	2,3
18		Исайковский	Исайки	2	2,8
19		Медвинский	Медвин	7	2,4
20		Митаевский	Митаевка	4	4,9
21		Москаленковский	Москаленки	3	4,3
22		Побережковский	Побережка	3	2,7
23		Щербашинецкий	Щербашинцы	4	8,5
24	Бородянский	Районного подчин.	Бородянка	1	3,2
25	Броварский	Зазимянский	Зазимье	3	0,6
26		Летковский	Летки	2	1,4
27		Мокрецкий	Мокрец	2	0,2
28		Погребовский	Погребы	3	0,7
29		Пуховский	Пуховка	3	0,5
30			Рожевка	2	0,6
31		Руднянский	Рудня	6	1,7
32	Васильковский	Кодаковский	Кодаки	1	0,7
33		Ольшанско-Новоселицкий	Ольшанская Новоселица	7	5,1
34		Тростинско-Новоселицкий	Тростинская Новоселица	5	0,7
35	Вышгородский	Районного подчин.	Вышгород	6	1,6
36			Дымер	40	1,2

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
37		Богдановский	Авдеева Нива	2	2,8
38			Рихта	2	3,5
39		Ваховский	Ваховка	5	5,3
40		Высщедубичанский	Высшая Дубечня	27	2,0
41		Гавриловский	Гавриловка	12	1,3
42		Демидовский	Демидов	35	0,7
43		Жукинский	Жукин	4	1,2
44		Катюжанский	Гута-Катюжанская	3	2,7
45		Козаровичский	Глебовка	4	1,3
46			Козаровичи	37	2,6
47		Лебедевский	Лебедевка	38	1,6
48		Литвиновский	Литвиновка	25	1,4
49		Любимовский	Любимовка	23	2,6
50		Новопетровцевский	Новые Петровцы	15	1,1
51		Пирновский	Воропаев	14	1,1
52		Рововский	Ровы	1	1,1
53			Федоровка	2	2,0
54		Рудне-Дымерский	Владимировка	2	1,9
55			Рудня Дымерская	15	3,8
56			Червоное	1	2,5
57		Синяковский	Синяк	2	0,8
58		Старопетровский	Старые Петровцы	12	1,6
59		Сухолучанский	Сухолучье	7	0,7
60		Толокунский	Толокунь	13	1,7
61			Рудня-Толокунская	1	0,8
62		Ясногородский	Ясногородка	10	2,2
63	Иванковский	Районного подчин.	Иванков	29	1,5
64		Блидчанский	Блидча	4	1,3
65			Коленцы	9	1,5
66			Леоновка	13	1,2
67		Варовской	Варовск	5	0,4
68		Дымарский	Дымарка	17	0,5
69			Петровское	6	0,3
70		Жмиевский	Жмиевка	39	0,3
71			Олизаровка	31	0,7
72		Иванковский	Запрудка	20	2,1
73			Сукачи	4	2,3
74			Федоровка	20	1,6
75		Кухаревский	Зарудье	8	1,6
76			Кухари	39	1,0
77		Макаровский	Новые Макалевичи	23	1,4
78			Макаровка	4	0,9
79			Русаки	17	1,9
80		Мусуйковский	Мисуйки	28	1,4
81		Обуховицкий	Обуховичи	41	2,9

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
82		Оливский	Олива	40	1,1
83		Оранский	Ораное	11	4,2
84			Степановка	7	2,6
85		Песковский	Доманoвка	9	1,7
86			Карпиловка	16	4,1
87			Ковалевка	7	1,9
88			Пески	58	4,0
89			Потоки	6	1,5
90			Старые Соколы	6	2,1
91		Приборский	Пироговичи	17	2,3
92			Приборск	48	2,5
93		Розважевский	Розважев	55	0,8
94		Термаховский	Термаховка	43	0,8
95		Тетеревский	Тетеревское	3	0,8
96			Подгайное	3	1,1
97		Феневичский	Рудня-Тальская	3	2,3
98			Сосновка	30	1,2
99			Феневичи	19	1,3
100			Зимовище	7	1,7
101		Шпилевский	Воропаевка	9	2,9
102			Шпили	27	2,1
103	Кагарлыкский	Районного подчин.	Кагарлык	1	1,8
104		Балыко-Щучинский	Балыко-Щучинка	6	1,2
105		Певецкий	Яблоновка	1	1,2
106	Киево-Свято-шинский	Петропавловско-Борщаговский	Чайки	6	1,6
107		Хотовский	Хотов	2	1,0
108	Мироновский	Грушевский	Грушев	2	1,7
109			Дудари	5	5,9
110			Ходоров	2	1,4
111		Емчихский	Емчиха	2	0,6
112		Кипячковский	Кипячка	2	0,3
113		Козинский	Козин	2	0,9
114		Македонский	Македоны	2	0,8
115		Малобукринский	Малый Букрин	4	0,7
116			Ромашки	2	0,8
117		Масловский	Масловка	2	0,2
118		Пиевский	Пии	1	0,2
119		Потокский	Поток	5	0,4
120			Очеретяное	2	0,4
121		Тулинский	Тулинцы	2	0,4
122		Шандровский	Шандра	4	0,2
123	Обуховский	Районного подчин.	Обухов	40	0,3
124			Украинка	3	0,3
125			Козин	2	0,6

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
126		Великодмитрович-ский	Великие Дмитровичи	26	0,4
127		Веремяцкий	Веремье	2	0,1
128		Витачовский	Витачов	29	0,8
129		Григоровский	Григоровка	20	0,4
130			Гусачевка	2	0,1
131		Долинский	Долина	28	3,8
132		Жуковцевский	Жуковцы	24	0,6
133		Копачовский	Копачов	24	0,4
134		Красненский-Второй	Красное Второе	14	1,4
135		Красненский-Первый	Красное Первое	11	1,0
136		Краснослободский	Красная Слободка	28	0,4
137		Малоольшанский	Малая Ольшанка	30	0,4
138		Перегоновский	Перегоновка	2	0,2
139		Семеновский	Семеновка	29	0,5
140		Старобезрадичевский	Новые Безрадичи	7	0,8
141			Старые Безрадичи	12	1,0
142		Трипольский	Триполье	33	0,8
143	Полесский	Районного подчин.	Вильча	31	7,0
144			Полесское	84	24,7
145		Буда-Варовичский	Буда-Варовичи	27	7,9
146		Вильчанский	Становище	13	7,0
147			Старая Вильча	5	9,3
148			Ж/д. ст. Вильча	4	9,1
149		Волчковский	Волчков	14	1,5
150			Пуховое	27	16,7
151		Денисовичский	Денисовичи	28	14,2
152		Дибровский	Диброва	32	6,7
153		Жовтневый	Жовтневое	35	11,5
154		Залишанский	Вересня	3	0,3
155			Залишаны	3	0,7
156		Красятичский	Красятичи	3	0,2
157			Михлевщина	6	0,3
158			Дубовая	3	0,3
159		Луговикский	Луговики	2	1,2
160			Фабриковка	5	4,8
161			Червоная Зирка	3	0,5
162		Максимовичский	Королевка	8	8,9
163			Максимовичи	5	0,7
164		Мартыновичский	Мартыновичи	40	8,8
165		Марьяновский	Зеленая Поляна	5	1,7
166			Марьяновка	11	3,8
167		Млачевский	Млачевка	8	2,3

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
168		Новомирский	Новый Мир	28	6,2
169			Ж/д. ст. Павловичи	5	11,9
170		Полесский	Грезля	29	17,6
171			Рудня-Грезлянская	24	20,6
172		Раговский	Котовское	10	1,7
173			Шевченково	40	40,0
174			Ясен	41	91,3
175			Раговка	4	1,9
176		Радинский	Буда-Радынская	3	0,3
177			Нивецкое	8	1,5
178			Омельяновка	4	1,2
179			Радинка	8	0,5
180			Черемошна	8	0,9
181			Федоровка	2	1,3
182		Стещинский	Калиновка	4	0,5
183			Стещина	3	0,5
184			Марковка (нежил.)	4	3,8
185			Орджоникидзе	3	1,2
186		Тарасовский	Тарасы	32	9,5
187		Шкневский	Войсковое	6	2,4
188			Новая Марковка	19	33,0
189			Старая Марковка	4	1,3
190			Шкнева	8	3,2
191	Ракитянский	Ольшаницкий	Ольшаница	3	2,3
192	Сквирский	Дулицкий	Дулицкое	2	0,3
193		Пищиковский	Пищики	1	0,2
194			Матгоши	2	0,3
195		Шамираевский	Шамираевка	2	0,2
196	Таращанский	Кирдановский	Кирданы	9	6,5
197		Ковшеватский	Ковшеватая	3	4,7
198		Лукьяновский	Кисловка	6	8,5
199			Лукьяновка	4	3,4
200		Лучанский	Лука	5	3,9
201		Степковский	Бовкун	3	4,5
202			Степок	4	4,7
203	Тетиевский	Районного подчин.	Тетиев	2	0,3
204		Звенячский	Звенячье	1	0,1
205		Дубровский	Дубровка	1	0,1
206		Кашперовский	Кашперовка	3	0,2
207		Тележнецкий	Тележницы	1	0,3
208		Черепинский	Черепин	2	0,3
209	Чернобыльский	Горностайпольский	Горностайполь	30	3,7
210			Губин	6	4,0
211			Лапутьки	3	3,6
212		Дитятковский	Дитятки	21	4,8

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
213			Зорин	6	4,4
214			Фрузиновка	7	3,0
215		Зеленомысский	Зеленый Мыс	61	2,4
216			Медвин	3	1,9
217		Опачичский	Липники	3	5,3
218		Тереховский	Блистюн	1	4,0
219	Ирпенский		Буча	1	5,1
220	горсовет		Ворзель	1	2,1
221	Республ. подч.		Киев	68	0,6
222	Районы г.Киева	Днепровский	Гидропарк	2	0,7

ДАННЫЕ О ЗАГРЯЗНЕНИИ ТЕРРИТОРИИ УССР ЦЕЗИЕМ-137 (Ки/км^2)
(Caesium-137)

РОВЕНСКАЯ ОБЛАСТЬ (ROVENSK)

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
1	Обл. подчинения		Сарны	4	0,9
2	Владимирецкий	Районного подчин.	Владимирец	3	1,6
3			Кузнецовск	2	1,6
4			Рафаловка	2	0,7
5			Ровенская АЭС	18	0,7
6		Антоновский	Антоновка	2	1,7
7		Балаховичский	Маюничи	2	1,1
8		Беленский	Белое	2	1,5
9			Луко	1	0,8
10			Новоселки	3	1,3
11		Бельско-Вольский	Бельская Воля	10	0,6
12			Рудка	5	0,9
13		Великожолудский	Великий Жолудск	2	1,1
14			Малый Жолудск	2	1,1
15		Великотелковичский	Великие Телковичи	2	0,6
16			Бышляк	2	0,7
17		Великоцепцевичский	Нетреба	2	1,0
18			Великие Цепцевичи	2	1,1
19		Воронковский	Воронки	2	0,7
20			Радыжево	2	1,9
21		Городецкий	Городец	2	1,5
22			Велихов	2	0,2
23			Сварыни	2	1,1
24		Долговольский	Берестовка	2	2,0
25			Долговоля	2	2,0
26			Островцы	2	1,1
27		Жовкиновский	Жовкини	2	1,8
28		Заболотьевский	Заболотье	6	0,4
29		Каноничский	Дубовка	2	1,1
30			Новаки	2	0,6
31		Кидровский	Кидры	2	0,8
32		Красносельский	Красноселье	4	2,0
33			Зеленое	2	1,8
34			Липно	2	1,4
35		Лозковский	Лозки	2	1,0
36		Мульчицкий	Мульчицы	5	1,4
37			Журавлиное	2	1,0
38		Озерецкий	Озерцы	2	0,3
39		Озерский	Озеро	2	2,8
40		Полицкий	Полицы	2	3,3
41			Веретено	2	1,6
42			Иванчи	2	1,4
43			Сошники	2	0,6
44		Половлевский	Половли	2	1,3
45			Зеленица	2	2,0
46			Щеков	2	0,6
47		Рафаловский	Балаховичи	2	0,6
48			Остров	2	0,6
49			Полонное	2	0,6
50			Суховоля	2	1,2
51		Ромейковский	Ромейки	2	0,9
52		Собещицкий	Собещицы	2	1,3

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
53		Сопачовский	Дуброва	2	1,3
54			Сопачев	2	2,0
55		Старорафаловский	Старая Рафаловка	2	0,9
56			Бабка	2	1,4
57			Чудля	2	0,6
58		Хиночский	Хиночи	3	1,4
59			Степангород	2	0,8
60	Дубровицкий	Районного подчин.	Дубровица	7	2,8
61		Бережковский	Бережки	3	3,4
62			Узлесье	2	2,3
63		Бережницкий	Бережница	5	1,4
64			Белаши	3	2,0
65			Подлесное	3	1,8
66		Берестовский	Берестье	3	2,6
67			Працюки	3	1,7
68			Орвяница	3	1,8
69		Великоозерянский	Великие Озера	5	1,4
70			Великая Черемель	3	2,0
71			Шахи	3	2,1
72		Вербовский	Вербовка	5	2,7
73		Высоцкий	Высоцк	6	2,9
74		Жаденский	Жадень	4	1,2
75		Залужский	Залужье	3	2,5
76		Колковский	Колки	3	2,7
77			Заслучье	3	2,0
78		Лесовский	Лесовое	5	2,2
79			Озерск	2	0,8
80		Людынский	Людынь	7	3,4
81			Партизанское	8	5,9
82			Рудня	4	3,7
83			Золотое	3	1,8
84		Лютинский	Велюнь	5	6,9
85			Лютинск	6	3,5
86		Милячский	Загребля	4	7,0
87			Луговое	3	2,3
88			Миляч	2	1,6
89			Бяла-над-Горынем	7	6,6
90		Мочулищенский	Крупово	2	1,9
91			Червоное	3	2,4
92			Мочулище	3	2,0
93		Нивецкий	Грицки	3	1,5
94			Нивецк	3	1,1
95		Осовский	Осова	3	1,4
96		Перебродовский	Будымля	5	2,2
97			Переброды	5	1,2

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
98		Сварицевичский	Зелень	3	1,0
99			Сварицевичи	3	1,1
100		Селецкий	Селец	3	2,8
101			Ясинец	3	2,4
102		Соломиевский	Кураш	3	1,2
103			Соломиевка	3	1,7
104		Трипутнянский	Залешаны	3	1,1
105			Литвица	5	1,7
106			Трипутня	4	3,6
107			Вольное	6	1,3
108			Грани	3	1,4
109		Туменский	Бродец	4	3,1
110			Городище	3	1,6
111			Тумень	3	2,7
112		Удрицкий	Смордск	3	2,8
113			Удрицк	4	6,1
114			Хочин	4	1,4
115	Зареченский	Районного подчин.	Заречное	3	3,1
116		Боровский	Боровое	3	0,9
117			Млинок	3	0,7
118		Вичевский	Бутово	3	0,5
119			Бродница	3	0,4
120			Вичевка	3	0,4
121		Дибровский	Волчицы	3	1,5
122			Дибровск	5	2,4
123		Зареченский	Парская	3	3,0
124			Чернин	3	3,0
125		Кутинский	Заозерье	3	1,3
126			Кутин	3	1,7
127		Кухотско-Вольский	Островск	3	1,3
128			Ждань	3	0,6
129		Кухченский	Кухче	3	1,5
130			Новоселье	3	2,0
131			Задолжье	3	1,0
132		Локницкий	Локница	2	1,2
133		Морочновский	Морочное	3	1,7
134			Мутвица	3	3,1
135		Неньковичский	Коморы	8	2,1
136			Неньковичи	4	1,2
137		Нобельский	Дедовка	3	1,3
138			Млин	2	2,0
139			Нобель	3	1,5
140			Радовель	6	1,7
141			Котыра	3	2,0
142		Новоречицкий	Новоречица	5	1,1

№	Район (Region)	Сельсовет (Village)	Нас. пункт (Location)	Проб. (Sample)	Средн. (Average)
143			Голубное	3	1,5
144		Омытский	Горыничи	3	1,6
145			Ниговищи	4	2,2
146			Омыт	3	1,3
147		Перекальский	Тиховиж	3	1,2
148			Перекалье	3	0,7
149		Речицкий	Приветовка	3	2,4
150			Речица	2	2,2
151			Ласицк	3	1,2

Annex II
Questions Put to Experts

Questions and Statements Presented to the Experts during the Fact Finding Preparatory Mission

Polesskoe, UkrSSR, 26 March 1990

1. Is it safe to live here?
2. Will we ever see the results of this mission?
3. A question to Dr. A. Kuramoto:
   Was the Chernobyl accident worse than Hiroshima?
4. What about the 35 rem (350 mSv) limit? Is this a humane level?
5. Why are we meeting in a small room when there is a larger one available in the town?
6. It has been four years since the accident, and nothing has been done.
7. Will you use your own equipment for the medical examinations? Will you examine all children?
8. As our children will leave during the summer for holiday, when do you expect to be in our town so that we can arrange to be here also?
9. What is the dose to the children in rad in an area that has 350 Ci/km^2 (12.95 MBq/m^2)?
10. Will you be able to influence our Government? Last year a commission of Soviet experts (Mr. Dopev) said that they would be back in two months but they did not return.
11. In 1987 samples were taken in our gardens and we have not received the results of these samples. Are the results being kept secret? Please publish your results. [A copy of the Goiânia report, in Russian, was sent to the settlement mayor the next day.]
12. Is 35 rem (350 mSv) a dose that one will not die from? What do you think the dose should be? Is there an international basis for the 35 rem (350 mSv) concept?
13. Could radiation cause throat cancer?
14. Do you think it is necessary to keep the children here for four years? They are suffering from nosebleeds, loss of consciousness, loss of sight.
15. A proposal was made for a medical doctor to meet with the doctors at the hospitals.

Ovruch, UkrSSR, 27 March 1990

Concerns of the local authorities:

1. Examining the district for heavy metal contamination, not just caesium, strontium and plutonium contamination.
2. Look into hot spots, up to 1500 μrem/h (0.015 mSv/h).
3. Supply of dosimeters, at least 85 000.
4. Truthful information on acceptable gamma background.
5. What conditions are acceptable and what not?
6. Psychological climate.
7. Explaining to the public about what is acceptable, what is normal, and what is not acceptable.
8. Why is caesium acceptable at a level of 15 Ci (555 GBq) and not 5 Ci (185 GBq) or 10 Ci (370 GBq)? The same for strontium.
9. Clear, well defined concept for safe living.
10. Help in providing a clear concept of how service could be rendered to the people.
11. Examine foodstuffs from all points of view.
12. Shortage of dosimetry instruments for internal and external measurements.
13. Influence of radiation on the immune system.
14. Clear picture of effects of radionuclides, nitrates and pesticides.
15. Assessment of future health of people living there.
16. Diagnosis by medical specialists.
17. Obtaining clean foodstuffs.
18. Possible genetic effects of contamination.
19. Effects of radiation on pregnancy.
20. Needs for the gamut of medical equipment.
21. Running water.

Questions submitted by the townspeople:

1. A question to Dr. M. Rosen:

   You will have formed some idea of the situation from the discussion here. Could you tell us whether the situation is analogous to the one which prevailed in Brazil? And how were the problems related to the safety of the population dealt with there?

2. A question to Dr. A. Kuramoto:

   How would you assess the possible consequences of the accident in our region, bearing in mind Japan's experience of radiation and its effects on the population? What should we anticipate in the near and the more remote future?

3. Is mothers' milk being investigated at all, and could it potentially cause harm to an infant? Do you think that there is any possibility of giving birth to healthy children in our region?
4. Have the IAEA and other international organizations been drawn into the discussion as to whether the Chernobyl nuclear power plant should be closed down altogether and, in particular, the reactor in Unit 4?
5. We keep talking about eliminating the consequences of the accident, but is it really possible to eliminate them? Is it perhaps not closer to truth to think that this is a pure waste of time and resources and that it would be better to evacuate everybody?
6. What is the real threat to children born before the explosion at Chernobyl who continue to live in this region? What are the first signs of illness? What prophylactic measures can we, the parents, apply to our children in the conditions prevailing here? And, finally, would it make sense for those who live here regularly to go away?

Bragin, BSSR, 27 March 1990

Questions and statements submitted by the townspeople:

1. Did the Government give you data before coming here? How well informed are you on the data and the overall situation?
2. What kind of prospects do the scientists think our children have who have been living in Bragin since the first day of the accident?
3. [Addressed to E. Smales] You are a mother of two children. So am I. I am healthy, my husband is healthy, but my daughters, born 1986 and 1987, both have enlarged thyroids.
4. How can you explain that children, i.e. in Minsk, are having low haemoglobin counts, leukocytes, vision decreased by 50%, immune deficiency problems, liver complaints?
5. What are your intentions? Where do you intend to send the health experts?
6. At what dose levels do you start seeing effects?
7. What are international norms for foodstuffs?
8. What are the dangers of plutonium?
9. How long can we go on eating food with the permitted levels of contamination?
10. What do you think of the 35 rem (350 mSv) level and do you consider it safe?
11. Will there be a unified opinion of the scientists and medical doctors regarding safety of living in zones of strict control?
12. Who can determine the total radionuclide dose people receive here in a day? (I mean from the air, food and water, at present.)
13. Why is it safe to live here 300 m from the 30 km boundary and not safe to live within the 30 km boundary?
14. How and on what basis is the accumulation of radionuclides in people living in the high risk zone determined at present, taking into account the working conditions: i.e. in people such as drivers, tractor drivers, construction workers, office workers?
15. You said you could not examine 250 000 people, which is true. But you asked for our help. Four years have now elapsed since the accident, and it has just been during the last two years that there have been stationary medical facilities. The doctors who came here during the first two years after the accident never mentioned radiation in relation to illnesses which means that the data are distorted. Will you take these data into account? Maybe, it would be best to take unbiased data from before the accident.
16. Your investigation will hamper the possibility of evacuating the area.
    Evacuation groups: (a) those wanting to leave, (b) those staying, and (c) those undecided.
17. We received a note that we should not ask any questions that could not be answered, why are we wasting our time?
18. Regarding the immune system: before 1986 no one studied the immune system; after 1986 the tests were done at random; between 1987 and 1989 not all children were checked. Conclusion: there are no data on which a comparison could be based.

Regarding thyroid: before the accident, iodine prophylaxis was not carried out. How are you going to determine what anomalies are here as a natural result of the area and which are the result of contamination?

19. Komarin is 30 km from the Chernobyl nuclear power plant. Can one live in this area when the radiation levels are as follows:

    (1) Plutonium — ten times higher than at Bragin;
    (2) Heavy metals;
    (3) Hot particles?

    The prevailing winds blow in the direction of Komarin (from the Chernobyl power plant). The radiation is accumulating as years go by. The children's health has suffered, and complaints concerning the thyroid gland and other organs have increased.

20. In Bragin we have a monument to Chernobyl — a house where no one lives on the first floor; on the second and third floors there are living children, adults and old people.

    Tell me, please, can one live in this house from a psychological point of view, even though the radiation levels are not the same throughout the house?

21. What does a psychologist think of the fact that our children are being sent on holiday thousands of kilometers away, without their parents, for as long as a month and, moreover, to a dangerous area in terms of the intercultural situation — in particular, to Georgia? And this has now been going on for four years.

22. Could you please check our drinking water? The radiation level in it is very bad, and they are hiding this from us.

23. Do you need facts? Here they are: an examination of the children in kindergarten No. 1 in Bragin showed the following:

    — in 1985, of the 150 children examined, 14 showed abnormalities of the thyroid gland;
    — in 1989, 65 of the 150 children showed abnormalities.

24. Could you please investigate what impact radiation has had on the psychic and mental development of children conceived and born under these current conditions, and also whether the greater frequency of convulsive attacks in children is caused by radiation?

25. Is the international public aware of the fact that on 26 April there will be a charitable TV marathon to help those people who suffered from the Chernobyl catastrophe?

26. To the representatives of the Ministry of Atomic Power and Industry:

    What category of irradiated persons are the inhabitants of Bragin after the Chernobyl nuclear power plant accident — A, B or C?

27. What do you think of the fact that all this research is starting four years after the event? To my mind a lot of time has been lost, particularly in view of the fact that the radiation doses in the first few days were several hundreds of times higher than now, and they were never recorded.

28. To Dr. F.A. Mettler:

    Can one really provide objective information on children's health if practically no research was done on this before 1986 and between 1986 and 1989 not all children were being examined even though there were reports of 100% health care for children?

29. What distance should there be between an evacuated zone and inhabited areas? In particular, around Bragin?

30. Is it possible to live within a radius of 21 km from the Chernobyl nuclear power plant? [A question from the inhabitants of Komarin, Bragin region.]

31. How do you explain the fact that children examined in Minsk have impaired immunity? — low haemoglobin, leucocytes, 50% reduction in vision. Practically all those examined have pathological conditions of the liver.

Veprin, BSSR, 28 March 1990

Questions and statements submitted by the townspeople:

1. Do you know what the contamination density is here in Veprin? Can one live in an area where the land is contaminated by radionuclides such as ^{137}Cs? Official statements were issued to the effect that families with children under 14 years and pregnant women would be evacuated before 1 April 1990 but we are still here. Are we being fairly dealt with?

2. Can people live at present in the contaminated area according to the categories of contaminated regions? Could you please explain the situation settlement by settlement and give the level of contamination in:

   (i) Veprin;
   (ii) Grokov;
   (iii) Ust'e; and
   (iv) the forests in the vicinity of these villages.

3. Can the effect of radiation on the human metabolism be reduced by mechanical or physical means?

4. (a) What is the maximum permissible level for produce in the USA, England, Austria, Japan? Please give a specific figure in Ci/kg (Bq/kg) of produce (meat, milk, vegetables).

   (b) What causes frequent sensations of dizziness, nosebleeds, etc.?

   (c) Is it not possible that, by the time you have prepared your conclusions as to where it is safe to live, there will be no one left in this area? When can we expect to see your conclusions?

5. The following question should be included in your research programme. Can the timber from our forests be used to build houses and children's institutions, etc.?

6. The UN commission researching into the consequences of Hiroshima has ascertained that the peak for incidence of anaemia occurred five to six years after the explosion of the atomic bomb, the peak for cancer tumours 30 to 40 years later, and genetic abnormalities are being observed to this day. What are your views in this regard with respect to Chernobyl?

7. To Dr. M. Rosen:

   People have been deceiving us for five years. Will you tell us the truth? Do you believe the scientists of the BSSR? Will world scientists strive to call to account those people who have misled us in this situation?

8. Can radionuclides migrate along the surface of the ground and, if they can, how does this happen and at what speed? [A question from the Regional Executive Committee, Kosityukovichi.]

9. Can one have children in an area where the contamination level is 15 Ci (555 GBq) and above?

10 To Dr. A.J. González:

   Professor L.A. Il'in tries insistently to persuade us that it is safe to live in an area where the contamination level is 35 rem (350 mSv). What are the accepted standards and rem (sievert) levels in western Europe, the USA, Japan and other highly developed countries? The press here says that they are not higher than 7 rem (70 mSv)? Is this true?

11. On behalf of the inhabitants of the Bykhov region in the Mogilev district, I would like to ask whether, in view of the effect of small doses of radiation on the human metabolism, it is possible to continue to live in our region where the contamination level ranges from 1 to 12 Ci/km^2 (37 kBq/m^2 to 444 kBq/m^2). [A question from T. Solonovich, Chairman of the Bykhov Regional Executive Committee.]

12. A letter to Dr. M. Rosen,

    With a view to inspiring greater confidence in your specialists, we feel it would be useful to open a laboratory in our region and to equip it with instruments from the USA, Japan and other countries, which would examine agricultural and stock breeding produce for radionuclide content: radioactive caesium, strontium-90, plutonium and others. This would then allow us to monitor in a more informed manner the migration of radionuclides and their presence in food products. [Signed, Grigorij Leonovich Bobkov, First Deputy to the Chairman of the Regional Agroindustrial Committee.]

13. In the Cherikov region, the following poem (in Russian) was submitted:

    The wound of Chernobyl gapes wide
    and strikes us painfully in the temples,
    the whirlwind of death hovers over us
    and summons us into the dark abyss.

    We retreat from one another
    and hasten obediently into the next world.
    Where is God? Clearly, he does not exist,
    otherwise it would not be drizzling smoke!

    The desolate forests have grown cold,
    the roads smoke gloomily,
    like cursed creatures we have been forgotten,
    we are all to be bound in fetters.

    We are all condemned men! This we already know.
    We have become guinea pigs.
    Man did not look to his own losses,
    but only to the successes of foreign states.

    See, the helicopters are flying,
    from the UN, the IAEA, and others,
    the stricken inhabitant greets them
    and regales them with his sorrow like a lunatic ...

    But this is only poetry,
    there is no pity for us in this world,
    which has hurtled to a point
    where we are to disappear in the darkness.

    Oh, you rulers of human fate,
    today you are our guests,
    and tomorrow? ...
    Veprin will forget you,
    left sitting on a pile of dead bones.

Korma, BSSR, 28 March 1990

Questions and statements submitted by the townspeople:

1. How long will the 'temporary maximum permissible concentrations' of radioactive materials in foodstuffs remain in force? My own feeling is that whatever is temporary is untrustworthy.

2. Why are you so interested in public health matters as handled in the district hospital? What are our scientific research institutes doing? Why was the haematological centre in Gomel not opened to the [visiting] Japanese in 1987? [A question from the journal 'Ogonek', March 1990.]
3. We would like to hear the answers in brief but understandable form.
4. Who finances the committee's work?
5. Why is this meeting being held today, precisely?
6. We, the inhabitants of the settlement of Gorodok, ask you to investigate the radiation situation in our settlement and tell us the truth about it.
7. Are all elements taken into account in the aggregate dose or only caesium?
8. What do you think about the '35 rem (350 mSv) over 75 years' concept as a safe limit?
9. Is it possible to live in a zone with >5 Ci/km^2 (185 kBq/m^2) if one has a thyroid illness of the third degree?
10. What do you think about L.A. Il'in's '35 rem (350 mSv) over 75 years' concept? And what do you think of the approach taken by scientists of the BSSR? [A question from the Delegation of the Gomel Regional Doctors' Association.]
11. (1) Are diseases of the lymph vessels, and in particular of the lymph nodes, associated with radiation?
    (2) What illnesses can be caused by hot particles?
12. During the period of radiation effects, there has been a significant deterioration of vision and memory among the population.
13. What radiation levels are found at the present time in Hiroshima and Nagasaki in portions of the natural environment that were largely unscathed (always assuming, of course, that there are such places)?
14. If the radiation doses are not high, how do we explain the fact that there has been a marked physical weakening of children — and even of adults?
15. What is to be done with land that has been contaminated beyond 40 Ci/km^2 (1.48 MBq/m^2)?
16. Is it possible to draw parallels between the accidents at Goiânia (Brazil) and Chernobyl? Judging from your experience with, and conclusions about, the accident in Brazil, would it have been possible in 1986 to foresee, say, at least 50% of the consequences that followed from our accident? Did the Governments of the USSR or the BSSR approach you in 1986?
17. Are you wearing personal dosimeters? What readings are they giving at the moment?
18. Does there exist in western Europe or the USA some criterion for assessing the damage caused to health by radiation? If so, what total rem (sievert) figure is involved? Have there been cases where monetary compensation was paid?
19. (1) What is the use of removing children from the strict surveillance zone to other parts of the BSSR for 24 days if there are no facilities for medical examinations and treatment in the places to which they are taken?
    (2) What sort of convalescent leave do the doctors think would be justified for workers in our zone?
    (3) Could you suggest some sort of temporary prescription for an appropriate dietary regime and life style, pending issue of the final report? We need something to go on, especially as there are next to no instruments, checkups, etc.
    (4) Do you have any data or information which would indicate unambiguously whether it is advisable to remain in our zone?
20. We are worried about the health of our children. If at all possible, could you arrange for them to be examined further and offer recommendations as to how they can safely remain in our zone?
21. Here in Korma we have contamination amounting to 18 Ci/km^2 (666 kBq/m^2). Can you, with this information alone, determine unambiguously whether it is safe to live here or not?
22. Would it be possible for the residents of our zone to make a complete change of climate — i.e. to find a permanent residence further south or further north?
23. (1) Where are ^{90}Sr and plutonium determinations carried out?
    (2) Are there maximum permissible levels for ^{90}Sr and plutonium? Where can they be found?
    (3) What are the effects of plutonium on the human body?
24. What medical apparatus do you have available for conducting examinations on the population?
25. (1) Is the radionuclide ^{40}K present in nature? Is it true that in determining the radionuclide content of foodstuffs ^{40}K is missed out?
    (2) So far foodstuffs have been tested only for caesium, but surely other elements are present?
26. What body burden is received by human beings from the natural background?
27. All animals are concerned about their offspring. We are disturbed about the consequences of the accident for future generations, the offspring of our children and grandchildren.

28. Is it part of the committee's programme of work to investigate every settlement in the region, or only those settlements which have to be evacuated?

29. When was it (what precise date) that you received the official invitation from our Government to make this visit?

30. "If all our people had diets consisting exclusively of products grown in the Chernobyl region, they would still receive only 7 mrem (0.07 mSv) per year — in other words, only 10% of the maximum permissible annual dose. This is *absolutely* not dangerous!". This was a statement made by Professor L.A. Buldakov. To what extent is it true in your opinion?

31. What are the internationally accepted maximum permissible concentrations in milk (^{137}Cs and ^{90}Sr, in Ci/kg (Bq/kg)) and in meat?

32. We are interested primarily in our own future and that of our children. That being so, we expect you to tell us the truth and describe the situation to us as it really is. How much time are you going to spend working in our region?

33. What dose limits have been established abroad in various countries for the general population in NPP accident conditions (both external exposure and ingestion with food products)?

34. The investigation of radiation conditions in our region will require a certain amount of time, and at present radiation levels are fairly high. What prophylactic measures would the specialists recommend to us for the immediate future?

35. How were the late consequences of the Hiroshima and Nagasaki bombardments reflected in public health?

36. There is a widespread opinion that alcoholic beverages promote the elimination of caesium and strontium from the body. What do you think of this idea?

37. What information is available on the effects of radiation on sexual potency in human beings?

38. Do you consider it a reasonable state of affairs when the scientists quarrel for four years about various concepts but reach no real decisions? Is this not, rather, a crime against millions of people who have unwillingly been turned into experimental rabbits?

39. Why is it that people who work in schools and kindergartens have to undergo X ray examinations more frequently than people who work in other areas? Are teachers really such special people?

40. Very recently, they have not been declaring diagnoses openly in the infirmaries (the diagnosis is put into code). One presumes that this must be in order to conceal the diagnosis from the patient.

41. Owing to a lack of detailed knowledge about the radiation situation in the zone with 5–15 Ci/km^2 (185–555 kBq/m^2) and more, the departure of residents of the Buda-Koshelevo region is taking on the proportions of an avalanche. The important thing now is to give comprehensive information to the people in a hurry — information in particular concerning their own places of residence. Any delay in this important work will probably mean that, when the information does come, it will be of no further use to anybody.

    What is being done, and what is going to be undertaken, in this important area?

42. We would like your report to be made available in our region. With your permission, we shall endeavour to familiarize as many people as possible with the conclusions you have reached.

43. What chance do we have — the inhabitants of strict control regions — to raise normal, viable children, when in fact after four years they have already fallen ill with various diseases, including thyroid problems, iron deficiency, anaemia and all sorts of respiratory problems as well as hypotony?

44. Professor D. Pomov states that, in regions of radionuclide fallout, favourable conditions have automatically been created in which people can receive medicinal doses of caesium more or less equivalent to the radon baths. What do you think of this statement?

45. What, in fact, are the limits on caesium contamination for safe habitation of an area? In the Cherchersk region we have zones with 5–15 Ci/km^2 (185–555 kBq/m^2) and others with 15–40 Ci/km^2 (555–1480 kBq/m^2) and even higher. What we need to know is where can one live safely here?

46. Is it good, in our circumstances, to drink red wine in moderate amounts?

Gomel, BSSR, 29 March 1990

Meeting with Gomel district authorities and members of the Supreme Soviet of the BSSR.

Requests:

1. Study problems of safe living concept.
2. Would like advice and recommendations regarding agriculture. Living on the land without working it is nonsensical.
3. Medical and social aspects related to living in the affected areas.

4. Would like to receive more detailed recommendations on how to continue living in contaminated areas.
5. Analyse the present approaches and methodologies used to calculate exposures during medical examinations.
6. Carry out parallel research regarding the environment and people's health.
7. Conclusion on how right or wrong we were.
8. Would like co-operation on a long term basis. Would like to see stationary laboratories and mobile clinical laboratories, exchange of information and training of doctors.
9. Establish long term co-operation and contracts to study the present situation.
10. Radioecology, radiobiology, radiation medicine, ecology experts.
11. Contacts with FAO, WHO, CEC, IAEA.
12. Exchange of information on accidents at other nuclear power plants.
13. Detailed data about most severe contaminations in the world.
14. Practical help.

Novozybkov, RSFSR, 29 March 1990

Questions and statements submitted by the townspeople:

1. Are you aware of the existing 35 rem (350 mSv) concept which is said to be safe for us? We have difficulties in determining whether a radiological centre should be established in a contaminated area or a clear area.
2. What would be your recommendations on physical training for children? Should they exercise indoors only or could they do special exercises?
3. We hear a lot about occupational and medical exposures. But when these people go home they are no longer exposed. We cannot leave here. Can we live like this?
4. I have only one concern. I am old, but I have grandchildren and I am worried about them. We had a research institute, and they kept telling us that removal of the topsoil was enough and that afterwards the people could grow foods and eat the food and it would be healthy. They said it was as healthy as going to the South (Black Sea). Yesterday another article was published by a newspaper entitled 'Catastrophe' and it was signed by 92 medical doctors stating that it was safe to live here. Furthermore, they said that doctors of the BSSR were no good, not creditable. The concept of those 'no good' doctors who thought it was not safe to live here was shared by French doctors.
5. How do Hiroshima and Nagasaki compare with Chernobyl?
6. Could you please give me your recommendations on the following:

   On 29 April 1986 there was fallout of radionuclides onto a house which was under construction. Measurements taken from the floor today showed that there was a radiation level of 60–90 microröntgens (15.5–23.2 nC/kg) an hour, whereas the standard is 10–20 (in Moscow 7–14). The local authorities are proposing that it should simply be concreted over, but before this is done it should be decontaminated, i.e. washed, and a shielding should be put down (iron, foil, powder, etc.). What types of shielding would you recommend before we proceed with concreting the area? [A question from I. Zarechnyj.]
7. You are talking about all of the natural radiation we are exposed to. However, in addition we are also being exposed to plutonium, strontium and caesium from Chernobyl. This is what we would like to hear about and what effect it is having: at the work place 0.015 mCi (555 kBq), in the home 0.015 mCi (555 kBq), atmospheric background 0.097 mCi (3.59 MBq), not to mention exposure via the food products. How much has to accumulate in the metabolism before one gets ill?
8. Is it possible that incidences of tiredness, headaches, and pains in the joints experienced by people in our contamination zone are connected with the radiation situation?
9. Medical question: My legs hurt badly. When I go upstairs, my legs feel very weak and will not work anymore. Over the last month I have lost three teeth and have been off work twice. [A question from Roza Oglovlisha.]
10. (a) Everyone sitting in this room has received a radiation dose. Is somebody in this position a radiation source and is he or she emitting radiation?
    (b) Can one work on agricultural land where the caesium contamination level is 30–40 mCi/km^2 (1.11–1.48 kBq/m^2)?
11. Can one use locally produced food and light industry products? We eat food from our own allotments at the farm. What is the minimum period children need to be removed from the zone for them to eliminate radioactive substances? What effect do radioactive substances have on subsequent generations?

12. Can people from our town take summer vacations in the southern areas of the country? The Crimea? The South?

13. Are there still discharges coming out of Chernobyl? If so, what effect is this having there?

14. If we were to move to a clean area, would the radiation we have accumulated in our metabolism over four years be eliminated entirely, and over what period? Are there any products or medicines which remove radiation?

15. Does the radiation dose one has received reduce if one moves to a clean zone? If so, over what period of time for children and adults?

16. Do medicines exist which eliminate radionuclides from the human metabolism? If they do, why are they not being used in our zone?

17. During four years of living in zone R3, my son's lymph nodes have become enlarged, and his thyroid gland (second stage) also. We are taking the hormone tablets for the thyroid. My second son has constant headaches and nosebleeds. What consequences might this have? Can we really live here any longer? Before this the children were healthy. [A question from N.I. Ivanova.]

18. In 1986 a lot of mineral fertilizer containing calcium and nitrogen was used on the fields. What effect has this had, or might have, on people's health?

19. My daughter, who is 38 years old, has started to suffer from a shortage of breath (when she goes to bed), sensations of weakness and is easily tired. When she was examined by an ultrasound scanner she was found to have nodular goitre, and a lot of nodules in the thyroid gland on both sides. In the Moscow Radiological Institute she was told that the only way to cure this was to remove both sides of the thyroid gland completely. They recommended that she take Geriozin until May; this has horrible side effects — terrible palpitations of the heart and enormous pressure increase (from the normal level before taking the medicine). We have heard that in America there is a medicine which drains nodular goitre. If you know about this would you please tell us whether this is true, what this medicine is called, and where and how it can be got hold of? She has two children (one is 14 and the other four years old), and they also have these nodules though fewer than she has. Everyone in our family has the second or third stage nodular goitre. Before Chernobyl we had not even heard about goitre! I am prepared to come for an individual consultation. [Signed, Elizaveta Nikolaevna Tarasova, Novozybkov.]

20. Is the high incidence of women with gynaecological problems here in Novozybkov due to the effect of radiation? Forty-two people have had extra-uterine pregnancies over the course of a month, and women are having miscarriages.

21. I worked in an X ray unit for about 15 years, up to 1982. In 1983, I gave birth to a daughter. My daughter has an enlarged thyroid gland, and I have had the same since 1986. In 1987, in Minsk, the Scientific Research Institute suggested that I should undergo an operation. What damage could this exposure to X rays that I have undergone do to me, and what danger could my child be exposed to by living in the high risk zone? Should we move out as quickly as possible? Both my daughter and myself have many illnesses. What should we do? Please advise me.

22. Can we use local produce when the whole area is contaminated with radiation and, in an agricultural region, can we cultivate our allotments at the farm?

23. If, as you are telling us, everything is alright here, why is it that the people in our governing authorities are leaving on the quiet?

24. According to tests carried out in a kindergarten by the Moscow Scientific Research Institute, blood and urine analyses are unnecessary in children up to 14 years of age. How do you react to this? Were additional benefits introduced for people living in the contaminated area, and what benefits were these?

25. Please tell us about similar accidents in nuclear power plants. In particular, what measures were taken by governments in the contaminated regions to eliminate the consequences of the accident? Were additional benefits introduced for people living in the contaminated area, and what benefits are these?

26. (1) What do you think of the view of Dr. D.K. Popov from the Leningrad Scientific Research Institute for Radiation Health Studies (run by Professor P.V. Ramzaev) who has been living in Novozybkov for a long time and maintains that the radiation in this area represents no danger to people?
    (2) How is radiation eliminated from the metabolism if a person is removed from a contaminated to a clean zone?
    (3) If there is some area in the USSR which is at present uncontaminated (for example, the Vitebsk district), is it possible that at some time in the future radiation contamination will turn up there as a result of the accident at the Chernobyl nuclear power plant? [Signed, Aleksandr Zhitnitskij.]

Zlynka, RSFSR, 30 March 1990

Questions and statements presented at the meeting of townspeople:

1. Presentation by Mr. Kromsaev, Leningrad Research Centre for Radiation Hygiene, Committee for Radiological Protection, Assistant Health Minister of the RSFSR, responsible for the Bryansk region.

2. There are social problems as well: (1) no paved roads, (2) houses without running water, (3) no wood and coal for heating, (4) meat and milk comes from other areas but the vegetables we grow ourselves. What is the future for our children? We believe your report may differ from the report of our dear colleague from Leningrad.

3. Ever since I heard about Hiroshima and Nagasaki I have had nightmares. Four years ago that nightmare came true. I worry about my children. One scientist reports that there is no problem, and the next is counting the days we have to live.

4. Who exactly has been checked for radiation, and when? I would be glad if you could name just one resident of Zlynka and say who did the checking.

5. We have no confidence in the information presented by Professor P.V. Ramzaev. We would ask the commission to check the data and give us an answer [from the Young Mothers' Group in Zlynka].

6. Is it possible to live in an area where the radioactive contamination density amounts to 40 Ci/km^2 (1.48 MBq/m^2) and all other conditions of life are the same as where you live — i.e. normal — or not.

7. If contamination in the kitchen garden amounts to values of this order, is it not reasonable to harbour doubts about planting vegetables? I carried out nine checks in 1987, but I did not get any satisfactory answer to my question.

Participants in the International Chernobyl Project

Contents

Participants in the International Chernobyl Project

International Advisory Committee

First meeting: Kiev, UkrSSR 23–24 April 1990; Minsk, BSSR 26–27 April 1990

Second meeting: Vienna 18–22 March 1991

Members

Anspaugh, L.R.
Environmental Sciences Division,
Lawrence Livermore National Laboratory,
Livermore, California, USA

Bar'yakhtar, V.G.
Vice-President,
Academy of Sciences of the UkrSSR,
Kiev, UkrSSR

Bennett, B.G.
United Nations Scientific Committee on the Effects of Atomic Radiation, Vienna;
United Nations Environment Programme,
Nairobi

Coppee, G.H., MD *(second meeting only)*
International Labour Organisation,
Geneva

Coulon, R.
Institut de protection et de sûreté nucléaire,
Commissariat à l'énergie atomique,
Fontenay-aux-Roses, France

Fry, F.
National Radiological Protection Board,
Chilton, United Kingdom

Gheorghiev, G.K. *(first meeting only)*
Policy and Nutrition Division,
Food and Agriculture Organization of the United Nations,
Rome

Gubanov, V.A. *(second meeting only)*
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow, USSR

Jovanovich, J.
Department of Physics, University of Manitoba,
Winnipeg, Manitoba, Canada

Kelly, N.G.
Directorate General for Science, Research and Development,
Commission of the European Communities,
Brussels

Kuramoto, A., MD
Research Institute for Nuclear Medicine and Biology,
Hiroshima University Hospital,
Hiroshima, Japan

Lee, T.R.
Department of Psychology, University of St. Andrews,
St. Andrews, United Kingdom

Mettler, F.A., Jr., MD
Department of Radiology, School of Medicine,
University of New Mexico,
Albuquerque, New Mexico, USA

Rosen, M. *(Vice-Chairman)*
Assistant Deputy Director General,
Director of the Division of Nuclear Safety,
International Atomic Energy Agency,
Vienna

Salo, A.
(Formerly) Surveillance Department,
Centre for Radiation and Nuclear Safety,
Helsinki, Finland

Shigematsu, I. *(Chairman)*
Radiation Effects Research Foundation,
Hiroshima, Japan

Smales, E., MD *(first meeting only)*
(World Health Organization representative)
Department of Health and Social Security,
London, United Kingdom

Steinhäusler, F.
Institute of General Biology, Biochemistry and Biophysics,
University of Salzburg,
Salzburg, Austria

Stepanenko, A.V.
Vice-President, Academy of Sciences of the BSSR,
Minsk, BSSR

Voloshchuk, V.V. *(second meeting only)*
RSFSR State Committee on the Rectification of the Consequences of the Chernobyl Accident,
Moscow, RSFSR

Waight, P. *(second meeting only)*
World Health Organization,
Geneva

Participants in the International Chernobyl Project

Task Leaders

Task 1 (Part C)

Carnino, A. *(from September 1990)*
Direction générale, Electricité de France,
Paris, France

Kenneke, A. *(until August 1990)*
Office of Governmental and Public Affairs,
Nuclear Regulatory Commission,
Washington, DC, USA

Task 2 (Part D)

Steinhäusler, F.
Institute of General Biology, Biochemistry and Biophysics,
University of Salzburg,
Salzburg, Austria

Valkovic, V. *(Co-ordinator for laboratory analyses and intercomparison exercises)*
IAEA Laboratory,
Seibersdorf

Task 3 (Part E)

Anspaugh, L.R.
Environmental Sciences Division,
Lawrence Livermore National Laboratory,
Livermore, CA, USA

Bennett, B.G. *(Co-leader)*
United Nations Scientific Committee on the Effects of Atomic Radiation, Vienna;
United Nations Environment Programme,
Nairobi

Bouville, A. *(Co-leader)*
Environmental Measurements Laboratory,
National Cancer Institute,
United States Department of Energy,
New York, NY, USA

Task 4 (Part F)

Lee, T.R. *(Co-leader for psychological studies)*
Department of Psychology,
University of St. Andrews,
St. Andrews, United Kingdom

Mettler, F.A., Jr., MD
Department of Radiology,
University of New Mexico,
Albuquerque, NM, USA

Parr, R. *(Co-leader for nutritional studies)*
International Atomic Energy Agency,
Vienna

Task 5 (Part G)

Hedemann Jensen, P.
Safety Department,
Risø National Laboratory,
Roskilde, Denmark

Kelly, N.G. *(Co-leader for decision conferences)*
Directorate General for Science, Research and Development,
Commission of the European Communities,
Brussels

Secretariat

Anderer, J.
Asculai, E. *(Scientific Secretary)*
Congdon, M.
Crick, M.J.
Dreicer, M. *(Project Manager)*
González, A.J.
Griffith, R.
Mrabit, K.
Ouvrard, R.
Skornik, K.

Consultants

Cooper, E.
IAEA Laboratory,
Seibersdorf

Danesi, P.
IAEA Laboratory,
Seibersdorf

Duncan, K.
(Formerly) National Radiological Protection Board,
Westfield, United Kingdom

Kenneke, A. *(until August 1990)*
Office of Governmental and Public Affairs,
Nuclear Regulatory Commission,
Washington, DC, USA

Lochard, J.
Centre d'étude sur l'évaluation de la protection dans le domaine nucléaire,
Commissariat à l'énergie atomique,
Fontenay-aux-Roses, France

Núñez, J.
Centre for Radiation Protection and Hygiene,
Executive Secretariat for Nuclear Affairs,
Havana, Cuba

Osborne, R.
Chalk River Nuclear Laboratories,
Atomic Energy of Canada Ltd,
Chalk River, Ontario, Canada

Parr, R.
International Atomic Energy Agency,
Vienna

Valkovic, V.
IAEA Laboratory,
Seibersdorf

Wachholz, B.W.
National Cancer Institute,
Bethesda, MD, USA

Advisers to Soviet Members of the Committee
(Second meeting)

To V.G. Bar'yakhtar

Bobyleva, O.A.
Department of Radiation Hygiene of the Ministry of Health of the UkrSSR,
Kiev, UkrSSR

Grodzinskij, D.M.
Institute of Botanics of the Academy of Sciences of the UkrSSR,
Kiev, UkrSSR

Likhtarev, I.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

To V.A. Gubanov

Belyaev, S.T.
I.V. Kurchatov Institute of Atomic Energy of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Buldakov, L.A.
Institute of Biophysics of the Ministry of Health of the USSR;
National Commission on Radiation Protection,
Moscow

Gordeev, K.I.
Institute of Biophysics of the Ministry of Health of the USSR;
National Commission on Radiation Protection,
Moscow

Il'in, L.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Khudyakov, A.N.
Department of International Organizations of the Ministry of Foreign Affairs of the USSR,
Moscow

Kurchenko, G.P.
Council of Ministers of the USSR;
USSR State Commission for Foodstuffs and Supplies,
Moscow

Lutsev, S.D.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Moskvitchev, A.M.
Deputy Minister of Health of the USSR,
Moscow

Penyagin, A.N.
Subcommittee on Nuclear Safety;
Deputy, Supreme Soviet of the USSR,
Moscow

Sokolov, V.A.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Tsaturov, Yu.S.
USSR State Committee for Hydrometeorology,
Moscow

To A.V. Stepanenko

Efremenkov, V.M.
BSSR State Committee on the Consequences of the Chernobyl Accident,
Minsk, BSSR

Rolevich, I.V.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Stezhko, V.A.
Ministry of Health of the BSSR,
Minsk, BSSR

To V.V. Voloshchuk

Belyaev, E.N.
Ministry of Health of the RSFSR,
Moscow

Gasilina, N.K.
USSR State Committee for Hydrometeorology,
Moscow

Ramzaev, P.V.
Leningrad Scientific Research Institute for Radiation Hygiene of the Ministry of Health of the RSFSR,
Leningrad, RSFSR

Soviet Observers
(First meeting)

Ageets, V.Y.
BSSR Scientific Research Institute of Soil Science and Agrochemistry,
Minsk, BSSR

Aleksakhin, R.M.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Amvrostev, A.P.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Antipova, S.J.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk, BSSR

Antonenko, A.E.
BSSR Institute of Experimental Veterinary Science of the Lenin All-Union Academy of Agricultural Science,
Minsk, BSSR

Antyperovich, F.S.
Trade and Industry Office,
Minsk, BSSR

Astakhova, L.N.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk, BSSR

Bebeshko, V.G.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Beletskij, Y.A.
Department for Applied Systems Analysis in Ecology,
Moscow

Belotkakht, U.V.
Department of Water Radiology of the Ministry of Water Resources of the UkrSSR,
Kiev, UkrSSR

Bobyleva, O.A.
Department of Radiation Hygiene of the Ministry of Health of the UkrSSR,
Kiev, UkrSSR

Bogdanov, A.P.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Bondar', I.K.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Bonko, E.I.
Department of Child Welfare of the Ministry of Health of the UkrSSR,
Kiev, UkrSSR

Bortkevich, L.Y.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Borzilov, V.A.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, USSR

Busurin, Yu.N.
Office of International Relations of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Darydchuk, V.
Academy of Sciences of the UkrSSR,
Kiev, UkrSSR

Denisevich, N.K.
Scientific Research Institute for the Assessment of Fitness for Work of the Ministry of Social Security of the BSSR,
Minsk, BSSR

Detinkin, O.N.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Dubina, Y.V.
Nuclear Power Institute of the Academy of Sciences of the BSSR,
Minsk, BSSR

Eliseeva, K.G.
Institute of Genetics and Cytology of the Academy of Sciences of the USSR,
Moscow

Epstein, E.V.
Institute of Endocrinology and Metabolism of the Ministry of Health of the UkrSSR,
Kiev, UkrSSR

Participants in the International Chernobyl Project

Filonov, V.P.
Deputy Minister of Health of the BSSR,
Minsk, BSSR

Firsakova, S.K.
BSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Gomel, BSSR

Gajchenko, V.A.
Institute of Ecology and Evolutionary Animal Morphology of the Academy of Sciences of the USSR,
Moscow

Galonenko, V.I.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Gasilina, N.K.
USSR State Committee for Hydrometeorology,
Moscow

Germashenko, V.B.
Radiological Inspection Service,
UkrSSR State Agroindustrial Committee,
Kiev, UkrSSR

Glushkov, V.
Institute of Cybernetics of the Academy of Sciences of the UkrSSR,
Kiev, UkrSSR

Golikova, N.B.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Goncharova, N.V.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Grakovets, A.A.
Scientific Research Institute for the Assessment of Fitness for Work,
Ministry of Social Security of the BSSR,
Minsk, BSSR

Grinev, M.P.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Grodzinskij, D.M.
Institute of Botanics of the Academy of Sciences of the UkrSSR,
Kiev, UkrSSR

Guchanov, D.E.
Centre for Agrochemical Radiology,
Bryansk, RSFSR

Gurkov, V.V.
State Committee for Foodstuffs and Supplies of the BSSR,
Minsk, BSSR

Gus'kova, A.K.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Gvozdev, A.A.
Nuclear Power Institute of the Academy of Sciences of the BSSR,
Minsk, BSSR

Karyagin, V.I.
Western Branch of the Lenin All-Union Academy of Agricultural Sciences,
Minsk, BSSR

Kazakov, I.V.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Kenigsberg, Ya.E.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk, BSSR

Khudokormov, A.N.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk, BSSR

Knit'ko, V.A.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Konoplya, E.F.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Kostyuk, A.K.
Supreme Soviet of the UkrSSR,
Kiev, UkrSSR

Kudelskij, A.V.
Institute of Geochemistry and Geophysics of the Academy of Sciences of the BSSR,
Minsk, BSSR

Kuznetsov, V.A.
Institute of Geochemistry and Geophysics of the Academy of Sciences of the BSSR,
Minsk, BSSR

Los, I.P.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Participants in the International Chernobyl Project

Lynfsko, A.
Nuclear Physics Department,
V.I. Lenin State University,
Minsk, BSSR

Lysorenko, V.
Academy of Sciences of the UkrSSR,
Kiev, UkrSSR

Malko, M.V.
Institute of Nuclear Power Engineering of the Academy of Sciences of the BSSR,
Minsk, BSSR

Mar'shev, V.F.
Central Scientific Research Institute of Agricultural Electrification,
Moscow

Matveenko, I.I.
Republic Centre for Radiation Control,
USSR State Committee for Hydrometeorology,
Minsk, BSSR

Mishenko, V.F.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk, BSSR

Mizonov, V.P.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Moshchik, K.V.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk, BSSR

Mossae, I.B.
Institute of Genetics and Cytology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Nefedov, G.F.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Nina, MD
Ministry of Social Security of the BSSR,
Minsk, BSSR

Olejnik, V.A.
Institute of Endocrinology of the Academy of Sciences of the UkrSSR,
Kiev, UkrSSR

Perevoznikov, O.N.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Petrayaev, E.P.
Department of Radiation Chemistry,
V.I. Lenin State University,
Minsk, BSSR

Petrenko, S.V.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk, BSSR

Petrov, L.A.
USSR State Committee for Environmental Protection,
Moscow

Petruk, D.A.
Ministry of Health of the USSR,
Moscow

Popova, L.M.
Academy of Sciences of the UkrSSR,
Kiev, UkrSSR

Prister, B.S.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev, UkrSSR

Pyatakh, O.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Repin, V.S.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Rolevich, I.V.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Romanenko, A.E.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Ryzhov, M.N.
Office of International Relations of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Savkin, M.N.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Sergiz, Y.
Institute of Oncology of the Academy of Sciences of the UkrSSR,
Kiev, UkrSSR

Participants in the International Chernobyl Project

Shandala, N.K.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Shimanovich, E.A.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Shlakov, O.N.
Institute of Geography and Geology of the Academy of Sciences of the BSSR,
Minsk, BSSR

Smelovskij, V.E.
Peat Institute of the Academy of Sciences of the BSSR,
Minsk, BSSR

Sokolik, G.A.
Department of Radiation Chemistry,
V.I. Lenin State University,
Minsk, BSSR

Spasskij, B.B.
Ministry of Health of the USSR,
Moscow

Stezhko, V.A.
Ministry of Health of the BSSR,
Minsk, BSSR

Svelowski, W.E.
Peat Institute of the Academy of Sciences of the BSSR,
Minsk, BSSR

Svyatelin, V.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Tabachnyj, L.Ya.
UkrSSR Centre for Radiology and Hydrometeorological Observations of the UkrSSR Hydrometeorology Committee,
Kiev, UkrSSR

Tron'ko, N.D.
Institute of Endocrinology and Metabolism of the Ministry of Health of the UkrSSR,
Kiev, UkrSSR

Tsvetkova, O.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Vesnovskij, S.P.
All-Union Scientific Research Institute of Experimental Physics of the Ministry of Atomic Power and Industry of the USSR,
Gor'kij, RSFSR

Yakushev, B.I.
Institute of Experimental Botany of the Academy of Sciences of the BSSR,
Minsk, BSSR

Zabolotnyj, A.I.
Institute of Experimental Botany of the Academy of Sciences of the BSSR,
Minsk, BSSR

Zborovskij, E.I.
Scientific Research Institute for the Assessment of Fitness for Work of the Ministry of Social Security of the BSSR,
Minsk, BSSR

Participants in the International Chernobyl Project

Preliminary Project Meeting

Ministry of Atomic Power and Industry
Moscow, USSR, 8 February 1990

BSSR

Budnichenko
Western Branch of the Lenin All-Union Academy of Agricultural Sciences,
Minsk

Filonov, V.
Ministry of Health of the BSSR,
Minsk

Gruk
BSSR State Committee for Hydrometeorology,
Minsk

Matyukhin, V.
Institute of Radiation Medicine of the Academy of Sciences of the BSSR,
Minsk

Stepanenko, A.
Academy of Sciences of the BSSR,
Minsk

UkrSSR

Chumak, V.K.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Serkiz, L.I.
Institute of Oncology of the Academy of Sciences of the UkrSSR,
Kiev

USSR

Aleksakhin, R.M.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Belyaev, E.N.
Ministry of Health of the RSFSR,
Moscow

Buldakov, A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Burtsev, S.
USSR State Committee on Environmental Protection,
Moscow

Busurin, Yu.N.
Office of International Relations of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Gasilina, N.K.
USSR State Committee on Hydrometeorology,
Moscow

Il'in, L.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Kulichenkov, A.I.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Maksimenko, Y.
USSR State Committee on the Environment,
Moscow

Nikitin, M.V.
Office of International Relations of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Povalyaev, A.P.
USSR State Commission on Foodstuffs and Supplies,
Moscow

Red'kin, V.
Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Ryzhov, M.N.
Office of International Relations of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Spasskij, B.B.
Ministry of Health of the USSR,
Moscow

International Atomic Energy Agency

González, A.J.

Participants in the International Chernobyl Project

Fact Finding Preparatory Mission

Bragin, Gomel, Kiev, Korma, Moscow, Novozybkov, Ovruch, Polesskoe, Veprin and Zlynka, 25–30 March 1990

Project Team Members

Asculai, E.
International Atomic Energy Agency,
Vienna

Dreicer, M.
International Atomic Energy Agency,
Vienna

González, A.J.
International Atomic Energy Agency,
Vienna

Kelly, N.G.
Commission of the European Communities,
Brussels

Kuramoto, A.
Hiroshima University,
Hiroshima, Japan

Lee, T.R.
University of St. Andrews,
St. Andrews, United Kingdom

Mettler, F.A., Jr., MD
University of New Mexico,
Albuquerque, New Mexico, USA

Randell, A.W.
FAO/WHO Codex Alimentarius Commission,
Food and Agriculture Organization of the United Nations,
Rome

Rosen, M.
International Atomic Energy Agency,
Vienna

Smales, E., MD
(World Health Organization representative)
Department of Health and Social Security,
London, United Kingdom

Steinhäusler, F.
University of Salzburg,
Salzburg, Austria

Valkovic, V.
IAEA Laboratory,
Seibersdorf, Austria

Observers

Rynka, A.A.
Deputy, Supreme Soviet of the USSR,
Moscow

Shcherbak, Y.N.
Deputy, Supreme Soviet of the USSR,
Moscow

Officials Accompanying the Mission

Avdyushin, S.I.
USSR State Committee for Hydrometeorology,
Moscow

Bussurin, Yu.N.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Ermakov, S.V.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Gasilina, N.K.
USSR State Committee on Hydrometeorology,
Moscow

Komarov, E.N.
Leningrad Scientific Research Institute of
Radiation Medicine of the Academy of
Medical Sciences of the USSR,
Leningrad

Kulichenkov, A.I.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Mamsourova, A.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Petrov, L.A.
USSR State Committee for the Environment,
Moscow

Ryzhov, M.N.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Savkin, M.N.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Spasskij, B.B.
Ministry of Health of the USSR,
Moscow

Zubovskij, G.A.
Ministry of Health of the RSFSR,
Moscow

Officials Attending Mission Meetings

Bar'yakhtar, V.G.
Academy of Sciences of the UkrSSR,
Kiev, UkrSSR

Busurin, Yu.N.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Cheban, A.K.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Chumak, V.K.
Institute of Nuclear Research of the Academy of Sciences of the UkrSSR,
Kiev, UkrSSR

Cozzinov, A.
Southern Branch of the Lenin All-Union Academy of Agricultural Sciences,
Kiev, UkrSSR

Ferents, V.P.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Gasilina, N.K.
USSR State Committee for Hydrometeorology,
Moscow, USSR

Gul'ko, G.M.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Kovgan, L.N.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Krasin, A.G.
State Committee of the Council of Ministers of the UkrSSR on the Protection of the Public from the Consequences of the Chernobyl Accident,
Kiev, UkrSSR

Kulichenkov, A.I.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Likhtarev, I.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Los, I.P.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Loshchilov, N.A.
UkrSSR Branch of the All-Union Institute of Agricultural Radiology,
Kiev, UkrSSR

Mamsourova, Ye.A.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Massik, K.I.
Deputy Prime Minister;
State Commission of the Council of Ministers of the UkrSSR on Extraordinary Situations,
Kiev, UkrSSR

Mkrtychev, A.H.
State Commission of the Council of Ministers of the UkrSSR State on Extraordinary Situations,
Kiev, UkrSSR

Naigu, A.I., MD
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Potikha, V.M.
State Commission of the Council of Ministers of the UkrSSR on Extraordinary Situations,
Kiev, UkrSSR

Poturidis, G.G.
State Committee of the Council of Ministers of the UkrSSR on the Protection of the Public from the Consequences of the Chernobyl Accident,
Kiev, UkrSSR

Pyatakh, O.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Repin, V.S.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Romanenko, A.Ye.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Rynka, A.A.
Deputy of the Supreme Soviet of the USSR,
Moscow

Ryzhov, M.N.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Shandala, N.K.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Shcherbak, Y.N.
Deputy, Supreme Soviet of the USSR,
Moscow

Spizhenko, Yu.P.
Minister of Health of the UkrSSR,
Kiev, UkrSSR

Stepanenko, N.S.
Kiev City Council,
Kiev, UkrSSR

Tsvetkova, O.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev, UkrSSR

Expert Participants

Argentina

Abudara, G.
Fundación para la Investigación y Desarrollo del Diagnóstico Médico para Imágenes,
Buenos Aires

Palacios, E.
Comisión Nacional de Energía Atomica,
Buenos Aires

Australia

Khafagi, F.A.
Royal Brisbane Hospital,
Brisbane, Queensland

Austria

Buchtela, K.
Atominstitut der Österreichischen Universitäten,
Vienna

Duftschmid, K.
Österreichisches Forschungszentrum Seibersdorf GmbH,
Seibersdorf

Gerzabek, M.
Österreichisches Forschungszentrum Seibersdorf GmbH,
Seibersdorf

Henrich, E.
Bundesanstalt für Lebensmitteluntersuchung und Forschung,
Vienna

Holzer, H.
Bundesanstalt für Lebensmitteluntersuchungen,
Graz

Jahn, O.
Klinik für Arbeitsmedizin,
Vienna

Lettner, H.
University of Salzburg,
Salzburg

Lovranich, E.
Österreichisches Forschungszentrum Seibersdorf GmbH,
Seibersdorf

Maringer, F.J.
Bundesversuchs- und Forschungsanstalt Arsenal,
Vienna

Möslinger, M.
Canberra Packard Instruments,
Vienna

Mukherjee, U.
Histologisches-Embryologisches Institut der Universität Wien,
Vienna

Rank, D.
Bundesversuchs- und Forschungsanstalt Arsenal,
Vienna

Schindler, R.
Bundesanstalt für Lebensmitteluntersuchungen,
Graz

Steger, F.
Österreichisches Forschungszentrum Seibersdorf GmbH,
Seibersdorf

Steinhäusler, F.
University of Salzburg,
Salzburg

Streit, S.
Österreichisches Forschungszentrum Seibersdorf GmbH,
Seibersdorf

Urban, E.C.
Universitäts Kinderklinik, Karl-Franzens Universität,
Graz

Vojir, F.
Bundesanstalt für Lebensmitteluntersuchung und Forschung,
Vienna

Zahlbruckner, R.
Bundesanstalt für Lebensmitteluntersuchung und Forschung,
Vienna

Belgium

Ferrant, A.
Cliniques Universitaires Saint Luc,
Brussels

Kirchmann, R.J.C.
International Union of Radiologists,
University of Liège,
Oupeye

Brazil

Godoy, J.M.
Commissão Nacional de Energia Nuclear,
Rio de Janeiro

BSSR

Antonenko, A.E.
BSSR Experimental Veterinary Scientific Research Institute of the Lenin All-Union Academy of Agricultural Sciences,
Minsk

Astakhova, L.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Averin, V.S.
BSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Gomel

Babas, V.V.
Regional Agroindustrial Committee,
Gomel

Bakhirev, V.A.
Association of Professional Ecologists,
Minsk

Balashchenko, Z.I.
State Committee for Foodstuffs and Supplies of the BSSR,
Minsk

Bogomaz, L.G.
Gomel State University,
Gomel

Bondar, I.K.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk

Bordak, N.A.
Gomel Veterinary Laboratory,
Gomel

Bulanyj, V.A.
Meat and Dairy Industry Association,
Gomel

Bur'yak, V.N.
State Committee of the Council of Ministers of the BSSR on the Consequences of the Chernobyl Accident,
Minsk

Chunikhin, L.A.
BSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Gomel

Danchenko, V.I.
Regional Executive Committee,
Bragin

Demidenko, V.A.
Gomel Meat Factory,
Gomel

Participants in the International Chernobyl Project

Drozdov, A.I.
State Committee for Foodstuffs and Supplies of the BSSR,
Minsk

Drozdovich, V.V.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Firsakova, S.K.
BSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Gomel

Gaponenko, V.I.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk

Gilyukovich, A.A.
State Committee for Foodstuffs and Supplies of the BSSR,
Minsk

Gonchar, G.A.
Regional Executive Committee,
Gomel

Grebenshchikova, N.V.
BSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Gomel

Grinev, N.F.
Regional Executive Committee,
Mogilev

Gurkov, V.V.
State Committee for Foodstuffs and Supplies of the BSSR,
Minsk

Il'yazov, R.G.
BSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Gomel

Karpenko, A.F.
BSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Gomel

Kazakov, V.S.
Minister of Health of the BSSR,
Minsk

Kenigsberg, Ya.E.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Kennik, I.A.
Council of Ministers of the BSSR,
Minsk

Khomich, V.K.
Regional Agrochemical Service,
Gomel

Khudokormov, A.N.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Kichkajlo, A.T.
State Committee for Foodstuffs and Supplies of the BSSR,
Minsk

Klimenok, A.I.
Gomel Branch of the BSSR State Committee for Hydrometeorology,
Gomel

Klyuchenovich, V.I.
Gomel Regional Centre for Epidemiology and Health,
Gomel

Knit'ko, V.A.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk

Kolesnikov, V.S.
Institute of Sanitation and Hygiene of the Ministry of Health of the BSSR,
Minsk

Konoplya, E.F.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk

Kotlyarenko, O.I.
Regional Medical Centre,
Mogilev

Kotov, V.V.
Regional Executive Committee,
Gomel

Kuprienko, A.D.
Gomel Meat Factory,
Gomel

Lazyuk, G.I.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Malko, M.V.
Nuclear Power Institute of the Academy of Sciences of the BSSR,
Minsk

Matveenko, I.I.
Republic Centre for Radiation Monitoring,
Minsk

Participants in the International Chernobyl Project

Matyukhin, V.A.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Mezenko, N.A.
Regional Agroindustrial Committee,
Gomel

Minenko, V.F.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Minkovskij, A.A.
Gomel State University,
Gomel

Moshchik, K.V.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Nesterenko, V.B.
Nuclear Power Institute of the Academy of Sciences of the BSSR,
Minsk

Neúmerzhitskij, V.A.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Okeanov, A.E.
Oncology Institute of the Ministry of Health of the BSSR,
Minsk

Petrenko, S.V.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Petryaev, E.P.
BSSR State University,
Minsk

Pokumejko, Yu.M.
BSSR State Committee for Hydrometeorology,
Minsk

Rolevich, I.V.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk

Romanovskij, A.A.
Regional Executive Committee,
Gomel

Rudneva, S.N.
Council of Ministers of the BSSR,
Minsk

Semkin, A.S.
Regional Executive Committee,
Mogilev

Sergienko, V.S.
Council of Ministers of the BSSR,
Minsk

Shitikov, B.D.
Ministry of Health of the BSSR,
Minsk

Skryabin, A.M.
Gomel Branch of the Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Gomel

Smirnov, M.
Gomel Branch of the Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Gomel

Smolyar, I.N.
Supreme Soviet of the BSSR,
Minsk

Solovtsov, N.I.
State Committee for Foodstuffs and Supplies of the BSSR,
Minsk

Sorokin, V.N.
Nuclear Power Institute of the Academy of Sciences of the BSSR,
Minsk

Stepanenko, A.V.
Academy of Sciences of the BSSR,
Minsk

Sukhorukov, E.F.
State Committee for Foodstuffs and Supplies of the BSSR,
Minsk

Svyatelik, V.P.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Sych, V.N.
Regional Executive Committee,
Gomel

Tarasevich, G.F.
Western Branch of the Lenin All-Union Academy of Agricultural Sciences,
Minsk

Timoshchenko, N.M.
Council of Ministers of the BSSR,
Minsk

Tyutyunnikov, A.B.
Regional Health and Epidemiological Station,
Bragin

Ul'yanovskij, A.V.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Vojtenkov, N.G.
Regional Executive Committee,
Gomel

Vojtik, A.N.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Vorontsova, T.V.
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk

Yarchak, A.M.
Regional Executive Committee,
Gomel

Zel'chan, A.P.
Meat and Dairy Industry Association,
Gomel

Zinovich, V.N.
Regional Health and Epidemiological Station,
Gomel

Canada

Barry, P.
Atomic Energy of Canada Ltd,
Chalk River, Ontario

Burns, K.
Atomic Energy of Canada Ltd,
Chalk River, Ontario

Jovanovich, J.
University of Manitoba,
Winnipeg, Manitoba

Osborne, R.
Atomic Energy of Canada Ltd,
Chalk River, Ontario

Utting, R.E.
Atomic Energy Control Board,
Ottawa, Ontario

China

Li, D.
China Institute for Radiation Protection,
Taiyuan, Shanxi

Sun, S.
China Institute for Radiation Protection,
Taiyuan, Shanxi

Denmark

Hedemann Jensen, P.
Risø National Laboratory,
Roskilde

Finland

Kumpulainen, J.
Agricultural Research Centre of Finland,
Jokioinen

Salo, A.
(Formerly) Centre for Radiation and Nuclear Safety,
Helsinki

Suomela, M.
Centre for Radiation and Nuclear Safety,
Helsinki

France

Coulon, R.
Commissariat à l'énergie atomique,
Fontenay-aux-Roses

Desprès, A.
Commissariat à l'énergie atomique,
Fontenay-aux-Roses

Gongora, R.
Institut Curie,
Paris

Lochard, J.
Commissariat à l'énergie atomique,
Fontenay-aux-Roses

Nénot, J-C.
Commissariat à l'énergie atomique,
Fontenay-aux-Roses

Pellerin, P.
Service centrale de protection contre les rayonnements ionisants,
Le Vésinet

Schneider, T.
Commissariat à l'énergie atomique,
Fontenay-aux-Roses

Tribondeau, J-F.
Coultronics,
Margency

Germany

Arndt, D., MD
Staatliches Amt für Atomsicherheit und Strahlenschutz,
Berlin

Heinzelmann, M.
Forschungszentrum Jülich GmbH,
Jülich

Martin, B.
Max-Planck-Institut für Kernphysik,
Heidelberg

Müller, H.
Institut für Strahlenschutz, Strahlen- und Umweltforschung GmbH,
Neuherberg/Munich

Musiol, D.
Staatliches Amt für Atomsicherheit und Strahlenschutz,
Berlin

Pittelkow, E.
Bundesamt für Strahlenschutz,
Neuherberg/Munich

Proehl, G.H.
Institut für Strahlenschutz, Strahlen- und Umweltforschung,
Neuherberg/Munich

Schelenz, R.
Bundesforschungsanstalt für Ernährung,
Karlsruhe

Schirmer, F.
Forschungszentrum Jülich GmbH,
Jülich

Schwarz, I.R.
Bundesamt für Strahlenschutz,
Neuherberg/Munich

Schweiger, M.
Institut für Strahlenhygiene des Bundesgesundheitsamtes,
Neuherberg/Munich

Siebert, H.U.
Staatliches Amt für Atomsicherheit und Strahlenschutz,
Berlin

Sitter, H.
Kernforschungszentrum Karlsruhe,
Karlsruhe

Winkelmann, I.
Institut für Strahlenhygiene des Bundesgesundheitsamtes,
Neuherberg/Munich

Wirth, E.
Bundesamt für Strahlenschutz,
Neuherberg/Munich

Hungary

Kerekes, A.
Frédéric Joliot-Curie National Research Institute for Radiobiology and Radiohygiene,
Budapest

Köteles, G.J.
Frédéric Joliot-Curie National Research Institute for Radiobiology and Radiohygiene,
Budapest

Sztanyik, L.B., MD
Frédéric Joliot-Curie National Research Institute for Radiobiology and Radiohygiene,
Budapest

Zombori, P.
Central Research Institute for Physics,
Hungarian Academy of Sciences,
Budapest

Israel

Levin, I.
Nuclear Research Center — Negev,
Beersheba

Italy

Boeri, G.C.
Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare e delle Energie Alternative (DISP),
Rome

Frittelli, L.
Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare e delle Energie Alternative (DISP),
Rome

Ingrao, G.
Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare e delle Energie Alternative CRE Casaccia,
Rome

Moschini, G.
Istituto Nazionale de Fisica Nucleare,
Leguaro, Padore

Santaroni, G.P.
Istituto Nazionale della Nutrizione,
Rome

Japan

Akiyama, M.
Radiation Effects Research Foundation,
Hiroshima

Aoki, Y., MD
National Institute of Radiological Sciences,
Chiba

Awa, A.
Radiation Effects Research Foundation,
Hiroshima

Choshi, K.
Hiroshima University,
Hiroshima

Cologne, J.
Radiation Effects Research Foundation,
Hiroshima

Dohy, H.
Hiroshima Red Cross and Atomic Bomb Survivors Hospital,
Hiroshima

Imamura, N.
Hiroshima University Hospital,
Hiroshima

Imanaka, F.
Hiroshima University Hospital,
Hiroshima

Kasumi, S.
Radiation Effects Research Foundation,
Hiroshima

Kuramoto, A., MD
Hiroshima University Hospital,
Hiroshima

Mabuchi, K., MD
Radiation Effects Research Foundation,
Hiroshima

Sasaki, H.
Radiation Effects Research Foundation,
Hiroshima

Shigematsu, I.
Radiation Effects Research Foundation,
Hiroshima

Shimaoka, K., MD
Radiation Effects Research Foundation,
Nagasaki

Yokoyama, N., MD
Radiation Effects Research Foundation,
Nagasaki

Netherlands

Bode, I.P.
Delft University of Technology,
Delft

de Bruin, M.
Delft University of Technology,
Delft

de Goeij, I.J.J.M.
Delft University of Technology,
Delft

Giel, R.
University Hospital,
Groningen

Natarajan, A.
Silvius Laboratories, University of Leiden,
Leiden

van den Berg, G.J.
Delft University of Technology,
Delft

van den Jagt, P.J.
Free University,
Amsterdam

Vis, R.D.
Free University,
Amsterdam

Wagenaar, G.
Netherlands Organization for Applied Scientific Research,
Apledorm

Wolterbeek, H.T.
Delft University of Technology,
Delft

Norway

Brynildsen, L.
Ministry of Agriculture,
Oslo

Hove, K.
Agricultural University of Norway,
Ås-Nlh

Norendal, T.
Ministry of Foreign Affairs,
Oslo

Strand, P.
National Institute of Radiation Hygiene,
Osteras

Poland

Liniecki, J., MD
Medical Academy of Łódz,
Łódz

Pietruszewski, A.
Central Laboratory for Radiological Protection,
Warsaw

Spain

Rodríguez, A.G.O.
Centro de Investigaciones Energéticas,
Medioambientales y Tecnológicas,
Madrid

Sweden

Abdulla, M.
University Hospital,
Lund

Edvardson, K.E.
National Institute of Radiation Protection,
Stockholm

Holm, L-E.
Karolinska Hospital,
Stockholm

Melin, J.
National Institute of Radiation Protection,
Stockholm

Schütz, A.
University Hospital,
Lund

Sokolovskij, E.
Nuclear Training and Safety Centre, Studsvik,
Nyköping

Switzerland

Wyttenbach, A.
Paul Scherrer Institute,
Villigen

UkrSSR

Ageev, V.A.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Andrushchenko, A.I.
Regional Executive Committee,
Kiev

Astasheva, N.P.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Babenko, V.V.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Balyuk, G.N.
Kiev State University,
Kiev

Bar'yakhtar, V.G.
Academy of Sciences of the UkrSSR,
Kiev

Bebeshko, V.G.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Berdov, G.V.
Ministry of Internal Affairs of the UkrSSR,
Kiev

Berkovskij, V.B.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Bernadina, L.I.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Beshchenko, Yu.A.
State Planning Committee of the UkrSSR,
Kiev

Bobyleva, O.A.
Ministry of Health of the UkrSSR,
Kiev

Bogdanov, I.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Bondar', P.F.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Bondarchuk, M.S.
Civil Defence Headquarters of the UkrSSR,
Kiev

Bondarenko, G.N.
Institute of Geochemistry and the Physics of Minerals of the Academy of Sciences of the UkrSSR,
Kiev

Bruslova, M.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Buchak, S.V.
Civil Defence Headquarters of the UkrSSR,
Kiev

Participants in the International Chernobyl Project

Bugaev, V.N.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Bukovskaya, V.S.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Buntova, E.G.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Cheban, A.K.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Chepurnoj, N.D.
Cybernetics Institute of the Academy of Sciences of the UkrSSR,
Kiev

Chmyrev, M.A.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Chumak, V.K.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Dashkevich, V.E.
Institute for the Protection of Mothers and Children of the Ministry of Health of the UkrSSR,
Kiev

Degtyareva, O.S.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Denisenko, A.G.
State Agroindustrial Committee of the UkrSSR,
Kiev

D'yachuk, V.A.
UkrSSR Hydrometeorological Research Institute,
Kiev

Dzeverin, I.A.
Literature Institute of the Academy of Sciences of the UkrSSR,
Kiev

Epstein, E.V.
Institute of Endocrinology and Metabolism of the Ministry of Health of the UkrSSR,
Kiev

Fedorenko, A.
Civil Defence Headquarters of the Kiev Region,
Kiev

Garger, E.K.
Kiev Radioecology Department of the Typhoon Scientific Production Group,
Kiev

Gavrilyuk, V.I.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Germashenkov, G.
State Agroindustrial Committee of the UkrSSR,
Kiev

Gorskij, A.S.
Regional Executive Committee,
Polesskoe

Gotovchits, G.A.
State Committee of the Council of Ministers of the UkrSSR on the Protection of the Public from the Consequences of the Chernobyl Accident,
Kiev

Grodzinskij, D.M.
Institute of Botanics of the Academy of Sciences of the UkrSSR,
Kiev

Gudzenko, V.V.
Institute of Geological Science of the Academy of Sciences of the UkrSSR,
Kiev

Gul'ko, G.M.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Il'in, M.I.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Ivanov, Yu.A.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Kapustyan, N.K.
Civil Defence Headquarters of the Kiev Region,
Kiev

Karasev, V.S.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Participants in the International Chernobyl Project

Kashparov, V.A.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Kashuba, M.I.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Khomutinin, Yu.V.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Kocherga, V.N.
Municipal Executive Committee,
Kiev

Kolomejchuk, S.S.
Regional Hospital of the UkrSSR,
Ovruch

Kononenko, L.V.
Institute of Geochemistry and the Physics of Minerals of the Academy of Sciences of the UkrSSR,
Kiev

Kopylova, O.V.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Korovin, A.T.
Regional Civil Defence Headquarters of the UkrSSR,
Ovruch

Kostenko, E.
State Committee of the Council of Ministers of the UkrSSR on the Protection of the Public from the Consequences of the Chernobyl Accident,
Kiev

Kostyuk, D.M.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Kovgan, N.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Krasin, A.G.
State Committee of the Council of Ministers of the UkrSSR on the Protection of the Public from the Consequences of the Chernobyl Accident,
Kiev

Krivtsov, I.L.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Ledoshchuk, B.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Likhtarev, I.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Los, I.P.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Loshchilov, N.A.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Luk'yanova, E.M.
Institute for the Protection of Mothers and Children of the Ministry of Health of the UkrSSR,
Kiev

Lyashchenko, S.A.
State Agroindustrial Committee of the UkrSSR,
Kiev

Makovetskij, Yu.V.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Maksimov, V.S.
UkrSSR Hydrometeorological Research Institute,
Kiev

Marchenko, A.B.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Marushchak, A.V.
Regional Executive Committee,
Kiev

Massik, K.I.
Council of Ministers of the UkrSSR,
Kiev

Mel'nik, V.V.
Ministry of Health of the UkrSSR,
Kiev

Mkrtychev, A.H.
State Commission of the Council of Ministers of the UkrSSR on Extraordinary Situations,
Kiev

Nech, A.V.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Participants in the International Chernobyl Project

Obodovskij, I.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Okhrimchuk, I.S.
Regional Executive Committee,
Ovruch

Ozornov, A.G.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Parshakov, A.E.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Pedchenko, V.A.
Ministry of Health of the UkrSSR,
Kiev

Perepelyatnikov, G.P.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Perepelyatnikova, L.V.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Perevoznikov, O.N.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Pinchuk, V.G.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Ponomarev, A.P.
Institute of Art History, Folklore and Ethnography of the Academy of Sciences of the UkrSSR,
Kiev

Popova, L.M.
Academy of Sciences of the UkrSSR,
Kiev

Potikha, V.M.
State Commission of the Council of Ministers of the UkrSSR on Extraordinary Situations,
Kiev

Poturidis, G.G.
State Committee of the Council of Ministers of the UkrSSR on the Protection of the Public from the Consequences of the Chernobyl Accident,
Kiev

Prister, B.S.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Prisyazhnyuk, A.E.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Pugachevskij, V.P.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Pyatakh, O.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Repin, V.S.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Romanenko, A.E.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Romanov, L.I.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Rudenskaya, G.A.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Safonov, M.I.
Ministry of Finance of the UkrSSR,
Kiev

Semenyutin, A.M.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Serdyuk, A.M.
Ministry of Health of the UkrSSR,
Kiev

Sergienko, N.M.
Kiev Institute for Advanced Training of Doctors of the Ministry of Health of the UkrSSR,
Kiev

Shandala, N.K.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Shatilo, V.I.
Regional Executive Committee,
Zhitomir

Shestakov, V.I.
Ministry of Health of the UkrSSR,
Kiev

Shestopalov, V.M.
Institute of Geological Science of the Academy of Sciences of the UkrSSR,
Kiev

Shnyukov, E.F.
Institute of Geological Science of the Academy of Sciences of the UkrSSR,
Kiev

Shushakov, I.A.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Sidorenko, N.Ya.
State Agroindustrial Committee of the UkrSSR,
Kiev

Skalej, A.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Smolyar, V.I.
Institute of Nutritional Health of the Academy of Sciences of the UkrSSR,
Kiev

Sobolev, A.S.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Sobotovich, E.V.
Institute of Geochemistry and the Physics of Minerals of the Academy of Sciences of the UkrSSR,
Kiev

Spizhenko, Yu.P.
Ministry of Health of the UkrSSR,
Kiev

Stepanenko, N.S.
Regional Executive Committee,
Kiev

Stepanova, E.I.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Suprun, L.P.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Surkova, N.V.
Women's Association of the UkrSSR,
Slavutich

Tabachnyj, L.Ya.
UkrSSR State Committee for Hydrometeorology,
Kiev

Taranenko, M.G.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Tertyshnyj, E.
UkrSSR Hydrometeorological Research Institute,
Kiev

Tret'yakova, G.N.
Regional Executive Committee,
Kiev

Tron'ko, N.D.
Institute of Endocrinology and Metabolism of the Ministry of Health of the UkrSSR,
Kiev

Tseganenko, O.I.
Institute of Nutritional Health of the Academy of Sciences of the UkrSSR,
Kiev

Tsesin, V.Yu.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Tsvetkova, O.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Tsyfir, V.F.
UkrSSR Agricultural Chemistry Association,
Kiev

Udovichenko, V.P.
Municipal Executive Committee,
Slavutich

Vajsband, D.F.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Vasil'chenko, V.S.
Minister of Labour of the UkrSSR,
Kiev

Venediktova, N.A.
UkrSSR Hydrometeorological Research Institute,
Kiev

Yakovenko, N.S.
Regional Health and Epidemiological Station of the UkrSSR,
Ovruch

Yakovlev, A.A.
Institute for the Protection of Mothers and Children of the Ministry of Health of the UkrSSR,
Kiev

Yudin, E.B.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Zagraj, A.I.
Municipal External Dosimetry Laboratory of the UkrSSR,
Slavutich

Zhuravel, N.I.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Zhurkina, T.V.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Zygar, G.N.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

USSR

Abagyan, A.A.
All-Union Scientific Research Institute for Nuclear Power Plant Operation of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Adamov, E.O.
Scientific Research and Design Institute for Power Technology of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Aleksakhin, O.M.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Anishchenko, V.N.
Municipal Agricultural Complex,
Novozybkov, RSFSR

Arkhipov, N.P.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Arzhanova, E.V.
Novozybkov Branch of the Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Novozybkov, RSFSR

Astasheva, N.P.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev, UkrSSR

Atroshenko, L.I.
Children's Section of the Regional Hospital,
Novozybkov, RSFSR

Avetisov, G.M.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Babenko, A.F.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Bad'in, V.I.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Bajborodova, L.A.
Municipal Health and Epidemiological Station,
Novozybkov, RSFSR

Balonov, M.I.
Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Leningrad, RSFSR

Barannik, A.N.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Baranov, A.E.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Barkhudarov, R.M.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Baturin, A.K.
Nutrition Institute of the Academy of Medical Sciences of the USSR,
Moscow

Baturov, B.B.
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Participants in the International Chernobyl Project

Belova, N.V.
Institute of Ecology and Evolutionary Animal Morphology of the Academy of Sciences of the USSR,
Chernobyl, UkrSSR

Belyaev, E.N.
Ministry of Health of the RSFSR,
Moscow

Belyaev, S.T.
I.V. Kurchatov Institute of Atomic Energy of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Bessalaya, L.A.
Working Group of the Ministry of Atomic Power and Industry of the USSR on Implementation of the International Chernobyl Project,
Moscow

Bobovnikova, T.I.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Bochkov, L.P.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Boldarev, M.M.
RSFSR Non-Fertile Soil Construction Association,
Moscow

Borisov, G.I.
I.V. Kurchatov Institute of Atomic Energy of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Borodastov, G.V.
Working Group of the Ministry of Atomic Power and Industry of the USSR on Implementation of the International Chernobyl Project,
Moscow

Borovoj, A.A.
I.V. Kurchatov Institute of Atomic Energy of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Borzilov, V.A.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Bruk, G.Ya.
Novozybkov Branch of the Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Novozybkov, RSFSR

Buldakov, L.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Bulgakov, I.A.
Council of Ministers of the RSFSR,
Moscow

Bulychev, O.A.
USSR State Commission for Foodstuffs and Supplies,
Moscow

Busurin, Yu.N.
Office of International Relations of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Bychkov, A.S.
USSR Civil Defence Staff,
Moscow

Cheburaev, V.I.
Ministry of Health of the USSR,
Moscow

Chelyukanov, V.V.
State Committee for Hydrometeorology of the USSR,
Moscow

Cherkashov, Yu.M.
Scientific Research and Design Institute for Power Technology of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Chernitsov, V.B.
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Chtetsov, V.P.
Moscow State University,
Moscow

Chugunov, V.A.
Chernobyl Nuclear Power Plant,
Chernobyl, UkrSSR

Chumichov, V.B.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Demichev, A.P.
Regional Executive Committee,
Kaluga, RSFSR

Demin, V.F.
I.V. Kurchatov Institute of Atomic Energy of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Participants in the International Chernobyl Project

Dibobes, I.K.
Institute of Applied Geophysics,
Moscow

Dobromyslov, V.V.
I.V. Kurchatov Institute of Atomic Energy of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Dolgova, N.A.
Office of International Relations of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Dushutin, K.K.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Ermilov, A.R.
All-Union Scientific Research Institute of Physical and Radiation Measurements,
Moscow

Fesenko, S.V.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Feshchenko, V.V.
Regional Executive Committee,
Bryansk, RSFSR

Fil'chagov, L.P.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Filyushkin, I.V.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Firsanov, V.B.
Scientific Research Institute for Marine Transport Health Studies,
Leningrad, RSFSR

Gajchenko, V.A.
Institute of Ecology and Evolutionary Animal Morphology of the Academy of Sciences of the USSR,
Chernobyl, UkrSSR

Galaev, E.I.
Scientific Research Institute for Marine Transport Health Studies,
Leningrad, RSFSR

Gasilina, N.K.
USSR State Committee for Hydrometeorology,
Moscow

Gavrilin, Yu.I.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Gaziev, Ya.I.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Geras'kov, O.P.
Municipal Hospital,
Novozybkov, RSFSR

Glinka, E.V.
USSR State Commission for Foodstuffs and Supplies,
Moscow

Gorbatkov, F.D.
Regional Executive Committee,
Bryansk, RSFSR

Gorbunova, N.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Gordeev, K.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Gordienko, A.I.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Gruzdev, G.P.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Gryaznova, A.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Gubanov, V.A.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Guchanov, D.E.
Centre for Agrochemical Radiology,
Bryansk, RSFSR

Gul'ev, B.F.
Institute of Ecology and Evolutionary Animal Morphology of the Academy of Sciences of the USSR,
Chernobyl, UkrSSR

Gusev, I.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Gus'kova, A.K.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Participants in the International Chernobyl Project

Il'in, L.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Ivanov, B.P.
(Formerly) USSR Civil Defence Headquarters,
Moscow

Ivanov, S.I.
Ministry of Health of the USSR,
Moscow

Ivanov, V.K.
Institute of Medical Radiology of the Academy of Medical Sciences of the USSR,
Obninsk, RSFSR

Izmalkov, V.I.
USSR Civil Defence Headquarters,
Moscow

Israel, Yu.A.
State Committee for Hydrometeorology of the USSR,
Moscow

Kajdanovskij, G.N.
Novozybkov Branch of the Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Novozybkov, RSFSR

Kambulov, I.N.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Kaplun, I.S.
Municipal Health and Epidemiological Station,
Novozybkov, RSFSR

Karasyuk, A.A.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Kashcheeva, I.V.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Kazakov, Yu.F.
USSR State Committee for Hydrometeorology,
Moscow

Kham'yanov, L.P.
All-Union Scientific Research Institute for Nuclear Power Plant Operation of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Khodkin, S.S.
State Committee for Hydrometeorology of the USSR,
Moscow

Khomichenko, S.A.
Nutrition Institute of the Academy of Medical Sciences of the USSR,
Moscow

Khrushch, V.T.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Kirillov, Yu.S.
Office of the Head of Chemical Warfare of the Ministry of Defence of the USSR,
Moscow

Kiryushin, V.I.
USSR State Commission for Foodstuffs and Supplies,
Moscow

Knizhnikov, V.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Kochukov, V.L.
Regional Office for Foodstuffs and Supplies,
Bryansk, RSFSR

Kondrusev, A.I.
Ministry of Health of the USSR,
Moscow

Konstantinov, Yu.O.
Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Leningrad, RSFSR

Kopchinskij, G.A.
Bureau of the USSR Council of Ministers for Fuel and Energy,
Moscow

Korepanov, G.V.
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Kornelyuk, V.A.
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Kornikhin, Yu.O.
Scientific Research Institute for Marine Transport Health Studies,
Leningrad, RSFSR

Kovtun, A.N.
Scientific Research Institute for Marine Transport Health Studies,
Leningrad, RSFSR

Participants in the International Chernobyl Project

Kozlovskaya, L.,
Scientific Research Institute for Marine Transport Health Studies,
Leningrad, RSFSR

Koz'min, G.V.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Krasnoshchekov, N.V.
USSR State Commission for Foodstuffs and Supplies,
Moscow

Krasnyuk, V.I.
Central Advanced Training Institute of the Ministry of Health of the USSR,
Moscow

Kremenskov, L.S.
USSR Civil Defence Headquarters,
Moscow

Kruglikov, P.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Krysanov, E.Yu.
Institute of Ecology and Evolutionary Animal Morphology of the Academy of Sciences of the USSR,
Chernobyl, UkrSSR

Kuchinov, V.P.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Kudinova, R.V.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Kudryashov, A.S.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Kuleshov, I.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Kulichenkov, A.I.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Kulikov, A.O.
Institute of Ecology and Evolutionary Animal Morphology of the Academy of Sciences of the USSR,
Chernobyl, UkrSSR

Kurashin, V.I.
Regional Executive Committee,
Bryansk, RSFSR

Kurchenko, F.P.
USSR State Commission for Foodstuffs and Supplies,
Moscow

Kurinov, A.D.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Kut'kov, V.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Lamonov, V.V.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Letova, A.N.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Lineva, I.
Gor'kij State University,
Gor'kij, RSFSR

Linge, I.I.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Lisyanskij, B.G.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Logachev, V.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Lomakin, M.D.
Institute of Ecology and Evolutionary Animal Morphology of the Academy of Sciences of the USSR,
Chernobyl, UkrSSR

Lutsev, S.D.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Lyaginskaya, A.M.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Makeenko, S.G.
State Planning Committee of the RSFSR,
Moscow

Makhon'ko, P.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Participants in the International Chernobyl Project

Mar'in, V.V.
Bureau of the USSR Council of Ministers for Fuel and Energy,
Moscow

Martyshkin, V.V.
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Minenko, A.I.
Regional Executive Committee,
Novozybkov, RSFSR

Mironov, V.D.
IAEA Office in Gomel;
Working Group of the USSR Ministry of Atomic Power and Industry on Implementation of the International Chernobyl Project,
Moscow

Mitlyaeva, N.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Molokanov, A.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Molotkov, E.M.
Regional Executive Committee,
Bryansk, RSFSR

Moshkin, O.Yu.
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Myasnikov, V.G.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Nadezhina, N.M.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Nasledukhov, E.A.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Nefedov, G.F.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Nigiyan, V.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Nikipelov, B.V.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Ostapyuk, I.V.
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Panfilov, I.I.
RSFSR State Planning Committee,
Moscow

Panov, V.G.
Ministry of Health of the RSFSR,
Moscow

Panteleeva, A.P.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Parkhomenko, V.L.
Novozybkov Branch of the Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Novozybkov, RSFSR

Parshin, V.S.
Institute of Medical Radiology of the USSR,
Obninsk, RSFSR

Pavlovskij, O.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Pavlovskij, V.P.
USSR Civil Defence Headquarters,
Moscow

Perminova, G.S.
Ministry of Health of the RSFSR,
Moscow

Petrov, K.V.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Petrov, L.A.
USSR State Committee for the Environment,
Moscow

Petrunenko, A.I.
Regional Executive Committee,
Bryansk, RSFSR

Pikalov, V.K.
Office of the Head of Chemical Warfare of the Ministry of Defence of the USSR,
Moscow

Participants in the International Chernobyl Project

Plekhanov, A.N.
All-Union Scientific Research Institute for Fertilizers and Agricultural Land Management of the Lenin All-Union Academy of Agricultural Sciences,
Novozybkov, RSFSR

Podstrigich, T.A.
Regional Executive Committee,
Bryansk, RSFSR

Pokutnyj, P.P.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Polonskij, V.T.
Ministry of Agricultural Produce of the RSFSR,
Moscow

Ponomarev, A.V.
Novozybkov Branch of the Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Novozybkov, RSFSR

Popov, D.K.
Novozybkov Branch of the Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Novozybkov, RSFSR

Porfir'ev, B.N.
All-Union Scientific Research Institute of Systems Analysis of the Academy of Sciences of the USSR,
Moscow

Posadskij, V.I.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Povalyaev, A.P.
USSR State Commission on Foodstuffs and Supplies,
Moscow

Pozdyshev, E.N.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Prokof'ev, E.M.
Scientific Research Institute for Marine Transport Health Studies,
Leningrad, RSFSR

Proskuryakov, A.G.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Rabchuk, I.A.
Working Group of the Ministry of Atomic Power and Industry of the USSR on Implementation of the International Chernobyl Project,
Moscow

Ramzaev, P.V.
Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Leningrad, RSFSR

Ratnikov, A.N.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Razumeeva, G.V.
Municipal Executive Committee,
Novozybkov, RSFSR

Red'kin, V.V.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Rejkhtman, G.I.
Chernobyl Nuclear Power Plant,
Chernobyl, UkrSSR

Reznichenko, B.Yu.
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Risovanij, Yu.V.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Rogachev, N.P.
Regional Executive Committee,
Zlynka, RSFSR

Ryabov, I.N.
Institute of Ecology and Evolutionary Animal Morphology of the Academy of Sciences of the USSR,
Chernobyl, UkrSSR

Rynka, A.A.
Supreme Soviet of the USSR,
Moscow

Ryzhov, M.N.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Samojlenko, V.M.
Regional Executive Committee,
Bryansk, RSFSR

Sarychev, V.A.
State Commission of the Council of Ministers of the RSFSR on Emergency Situations,
Moscow

Savkin, M.N.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Sedov, M.A.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Semenov, P.E.
USSR State Planning Committee,
Moscow

Senin, E.V.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Sergienko, T.S.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Shcheplyagina, L.A.
Ministry of Health of the USSR,
Moscow

Shershakov, V.M.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Shiker, E.P.
Regional Health and Epidemiological Station,
Novozybkov, RSFSR

Shishkanov, A.P.
USSR Civil Defence Headquarters,
Moscow

Shmatok, N.P.
Regional Executive Committee,
Zlynka, RSFSR

Shmelev, V.M.
I.V. Kurchatov Institute of Atomic Energy of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Silant'ev, A.N.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Siroshtan, V.G.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Sivolap, T.E.
Novozybkov Branch of the Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Novozybkov, RSFSR

Skoropad, Yu.D.
Institute of Medical Radiology of the Academy of Medical Sciences of the USSR,
Obninsk, RSFSR

Smirnova, O.G.
Institute of Ecology and Evolutionary Animal Morphology of the Academy of Sciences of the USSR,
Chernobyl, UkrSSR

Snykov, V.P.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Sokolov, V.A.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Sokolovskij, V.G.
USSR State Committee for the Environment,
Moscow

Sorokin, N.M.
Chernobyl Nuclear Power Plant,
Chernobyl, UkrSSR

Spasskij, B.B.
Ministry of Health of the USSR,
Moscow

Spirin, E.V.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Starodumov, V.M.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Stolbov, S.N.
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Stukin, E.K.
USSR State Committee for Hydrometeorology,
Moscow

Sumin, I.P.
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Svetlichnij, S.M.
Scientific Research Institute for Marine Transport Health Studies,
Leningrad, RSFSR

Tereshchenkov, A.S.
Regional Executive Committee,
Bryansk, RSFSR

Teslenko, V.P.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Participants in the International Chernobyl Project

Testov, B.V.
Institute of Ecology and Evolutionary Animal Morphology of the Academy of Sciences of the USSR,
Chernobyl, UkrSSR

Tikhomirov, D.D.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Timenov, V.V.
Moscow State University,
Moscow

Tokarev, N.P.
Municipal Executive Committee,
Novozybkov, RSFSR

Toritsyn, O.S.
Scientific Research Institute for Nuclear Power Plant Operation of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Trusova, N.E.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Tsaturov, Yu.S.
USSR State Committee for Hydrometeorology,
Moscow

Tukov, A.R.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Umanets, M.P.
Chernobyl Nuclear Power Plant,
Chernobyl, UkrSSR

Ushcherbov, G.S.
USSR State Planning Committee,
Moscow

Vakulovskij, S.M.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Vasil'ev, A.V.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Vasilevitskij, V.A.
Municipal Health and Epidemiological Station,
Novozybkov, RSFSR

Vasutin, S.I.
Regional Executive Committee,
Tula, RSFSR

Vesnovskaya, I.S.
Gor'kij State University,
Gor'kij, RSFSR

Vinyukov, K.I.
USSR Civil Defence Headquarters,
Moscow

Volokiotin, A.A.
Typhoon Scientific Production Group of the USSR State Committee for Hydrometeorology,
Obninsk, RSFSR

Voloshchuk, S.S.
RSFSR State Committee on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Voronezhtsev, Yu.I.
Supreme Soviet of the USSR,
Moscow

Voznyak, V.Ya.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Yakubovich, N.D.
Regional Executive Committee,
Bryansk, RSFSR

Zhigareva, T.L.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Zhukov, V.M.
Scientific Research and Design Institute for Power Technology of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Zubovskij, G.A.
Scientific Research Institute of X Ray Radiology of the Ministry of Health of the RSFSR,
Moscow

Zvonova, I.A.
Novozybkov Branch of the Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Novozybkov, RSFSR

Zyablitskaya, E.Ya.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

United Kingdom

Beresford, N.
Institute of Terrestrial Ecology,
Grange-over-Sands

Berry, R.J.
British Nuclear Fuels plc,
Risley

Bobrow, M.
Prince Philip Research Laboratories,
London

Duncan, K.
(Formerly) National Radiological Protection Board,
Westfield

French, G.S.
University of Leeds,
Leeds

Fry, F.
National Radiological Protection Board,
Chilton

Grime, G.W.
University of Oxford,
Oxford

Howard, B.
Institute of Terrestrial Ecology,
Grange-over-Sands

Lee, T.R.
University of St. Andrews,
St. Andrews

Lloyd, D.
National Radiological Protection Board,
Chilton

Mitchell, N.T.
Ministry of Agriculture and Fisheries Laboratory,
Lowestoft

Morrey, M.
National Radiological Protection Board,
Chilton

Reeves, G.
University of Oxford,
Oxford

Schaefer, M.
British Nuclear Forum,
London

O'Riordan, M.C.
National Radiological Protection Board,
Chilton

Ward, N.
University of Surrey,
Guildford

Watt, F.
University of Oxford,
Oxford

Wilkins, B.T.
National Radiological Protection Board,
Chilton

Winteringham, P.
Darbod,
Harlech

United States of America

Anspaugh, L.R.
Lawrence Livermore National Laboratory,
Livermore, California

Bouville, A.
Department of Energy,
New York, N.Y.

Chase, C.F.
Washington, D.C.

Collins, C.A.
University of New Mexico,
Albuquerque, New Mexico

Davis, H.A.
Department of Energy,
New York, N.Y.

Ginzburg, H.M.
United States Public Health Service,
Rockville, Maryland

Goldman, M.
University of California,
Davis, California

Hurley, J.R.
Division of Nuclear Medicine,
New York, N.Y.

Hutter, A.R.
Department of Energy,
New York, N.Y.

Kenneke, A.
Nuclear Regulatory Commission,
Washington, D.C.

Klusek, C.S.
Department of Energy,
New York, N.Y.

Littlefield, L.G.
Oak Ridge Associated Universities,
Oak Ridge, Tennessee

Loesch, R.M.
Health Physics Society,
Washington, D.C.

Mettler, F.A., Jr., MD
University of New Mexico,
Albuquerque, New Mexico

Miller, K.
Department of Energy,
New York, N.Y.

Monetti, M.A.
Department of Energy,
New York, N.Y.

Nelson, J.W.
Florida State University,
Tallahassee, Florida

Perkins, R.W.
Battelle Pacific Northwest Laboratories,
Richland, Washington

Reichle, D.
Oak Ridge National Laboratory,
Oak Ridge, Tennessee

Ricks, R.
Oak Ridge Associated Universities,
Oak Ridge, Tennessee

Royal, C.
Town and Country,
St. Louis, Missouri

Royal, H.D., MD
Washington University Medical Center,
St. Louis, Missouri

Saenger, E.
University of Cincinnati,
Cincinnati, Ohio

Stark, M.
University of New Mexico,
Albuquerque, New Mexico

Stark, S.N., MD
University of New Mexico,
Albuquerque, New Mexico

Swinth, K.L.
Battelle Pacific Northwest Laboratories,
Richland, Washington

Thiessen, J.W., MD
(Present address) Radiation Effects Research Foundation,
Nagasaki

Wachholz, B.W.
National Cancer Institute,
Bethesda, Maryland

Ward, G.M.
Colorado State University,
Fort Collins, Colorado

Winchester, J.W.
Florida State University,
Tallahassee, Florida

Yugoslavia

Korun, M.
E. Kardelj University,
Ljubljana

Limi, N.
Ruder Bošković Institute,
Zagreb

Stegnar, P.
E. Kardelj University,
Ljubljana

Commission of the European Communities (CEC)

Dorogoi, A.
Brentford

Kelly, N.G.
Directorate General for Science Research and Development,
Brussels

Luykx, F.
Directorate General for Environment, Civil Protection and Nuclear Safety,
Luxembourg

Sabbioni, E.
Research Centre,
Ispra (Varese)

Food and Agriculture Organization of the United Nations (FAO)

Gheorghiev, G.K.
Food Policy and Nutrition Division,
Rome

McNamara-Hutchinson, J.
Rome

Randell, A.W.
Food Policy and Nutrition Division,
Rome

International Atomic Energy Agency (IAEA)

Anderer, J.
Asculai, E.
Barabanova, A.
Bridi, D.
Burns, K. *(as of July 1990 under Canada)*
Bush, W.
Carnino, A.
Congdon, M.
Cooper, E.
Crick, M.J.
Dekner, R.
Dreicer, M.
Fröhlich, K.
Gaensbacher, J.
Ghods-Esphahani, A.
Girzikowsky, R.
González, A.J.
Griffith, R.
Haider, K.
Hartmann, R.
Haselberger, N.
Heiss, J.
Hochmann, R.
Jansta, V.
Kenneke, A. *(as of September 1990 under USA)*
La Rosa, J.
Makarewicz, M.
Mouchkin, V.
Mrabit, K.
Mukherjee, R.
Ogris, R.
Ouvrard, R.
Parr, R.
Pavlick, P.
Rosen, M.
Shawky, S.
Skornik, K.
Stichler, W.
Strachnov, V.
Vajda, N.
Valkovic, V.
Wehrstein-Werner, E.
Zeiller, E.

International Labour Organisation (ILO)

Coppee, G.H., MD
Occupational Health,
Geneva

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)

Bennett, B.G.
Vienna

World Health Organization (WHO)

Beral, V.
Radcliffe Infirmary,
Oxford

Eden, T.
Royal Hospital for Sick Children,
Edinburgh

Petridou, E., MD
European Society for Social Paediatrics,
Athens

Sheppard, M.C.
University of Birmingham,
Birmingham

Smales, E.
Department of Health and Social Security,
London

World Meteorological Organization (WMO)

Landa, E.R.
Department of the Interior,
Reston, Virginia, USA

Support

Analytical Support

IAEA Laboratory, Seibersdorf

Ghods-Esphahani, A.
^{90}Sr

Jansta, V.
Gamma spectrometry

La Rosa, J.
Pu isotopes

Makarewicz, M.
Gamma spectrometry

Ogris, R.
Neutron activation analysis

Shawky, S.
^{90}Sr

Vajda, N.
Pu isotopes

Wehrstein-Werner, E.
Atomic absorption spectrometry

Zeiller, E.
Inductively coupled plasma emission spectrometry

Austria

Atominstitut der Österreichischen Universitäten, Vienna

Buchtela, K.
Gamma spectrometry

Bundesanstalt für Lebensmitteluntersuchung und Forschung, Vienna

Vojir, F.
Atomic absorption spectrometry

Zahlbruckner, R.
Atomic absorption spectrometry

Bundesanstalt für Lebensmitteluntersuchungen, Graz

Holzer, H.
Atomic absorption spectrometry

Schindler, R.
Atomic absorption spectrometry

Bundesversuchs- und Forschungsanstalt Arsenal, Vienna

Rank, D.
Gamma spectrometry

Maringer, F.J.
Gamma spectrometry

Institute of General Biology, Biochemistry and Biophysics, University of Salzburg, Salzburg

Lettner, H.
Gamma spectrometry

Österreichisches Forschungszentrum Seibersdorf GmbH, Seibersdorf

Duftschmid, K.
Gamma spectrometry

Lovranich, E.
Gamma spectrometry

Streit, S.
Pu isotopes

Finland

Agricultural Research Centre of Finland, Jokioinen

Kumpulainen, J.

Germany

Forschungszentrum Jülich GmbH, Jülich

Heinzelmann, M.
Gamma spectrometry

Schirmer, F.
^{90}Sr

Institut für Strahlenhygiene des Bundesgesundheitsamtes, Abteilung Radioaktive Stoffe und Umwelt, Neuherberg/Munich

Winkelmann, J.
Gamma spectrometry, in situ gamma spectrometry

Kernforschungszentrum Karlsruhe, Bundesforschungsanstalt für Ernährung, Karlsruhe

Schelenz, R.
Gamma spectrometry

Medizinische Universität, Klinik für innere Medizin, Lübeck

Gutekunst, R.

Hungary

Health Physics Department, Central Research Institute for Physics, Budapest

Zombori, P.
Gamma spectrometry

Italy

Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia nucleare e delle Energie Alternative CRE Casaccia, Area Ambiente AMB-BIO, Rome

Ingrao, G.

National Institute of Nutrition, Rome

Santaroni, G.P.

Netherlands

Delft University of Technology, Interfaculty Reactor Institute, Delft

Ammerlaan, M.J.J.
Atomic absorption spectrometry, instrumental neutron activation analysis

van den Berg, G.J.
Atomic absorption spectrometry, instrumental neutron activation analysis

Volkers, K.J.
Atomic absorption spectrometry, instrumental neutron activation analysis

Wolterbeek, H.T.
Atomic absorption spectrometry, instrumental neutron activation analysis

Woroniecka, U.D.
Atomic absorption spectrometry, instrumental neutron activation analysis

Sweden

Department of Occupational Medicine, University Hospital, Lund

Abdulla, M.

Schütz, A.

United Kingdom

Surrey Chemical Trace Analysis Research, Department of Chemistry, University of Surrey, Guildford

Ward, N.

United States of America

Battelle Pacific Northwest Laboratories, Richland, Washington

Perkins, R.W.
Gamma spectrometry

Environmental Measurements Laboratory, Environmental Studies Division, New York, N.Y.

Klusek, C.S.
Gamma spectrometry

Florida State University, Tallahassee, Florida

Nelson, J.W.
X ray fluorescence

Yugoslavia

Department of Nuclear Chemistry, Jozef Stefan Institute, E. Kardelj University, Ljubljana

Dermelj, M.
Hg, Se, I

Komosa, A.
Gamma spectrometry, Pu

Korun, M.
Gamma spectrometry

Prosenc, A.
Hg, Se, I

Stegnar, P.
Gamma spectrometry, ^{90}Sr, Pu, Hg, Se, I

Stibilj, V.
Hg, Se, I

Support to the Medical Teams

The following field trip workers assisted the Project medical field teams:

Bebeshko, V.G.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR, Kiev, UkrSSR

Bryslova, K.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR, Kiev, UkrSSR

Cheban, A.K.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR, Kiev, UkrSSR

Chesin, V.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR, Kiev, UkrSSR

Parshin, V.S.
Medical Radiology Institute, Obninsk

Taranenko, M.G.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR, Kiev, UkrSSR

Zhyrkina, T.V.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR, Kiev, UkrSSR

Assistance was also provided by:

Griaznova, E.
Hospital 6, Moscow

Krasnyuk, V.I.
Hospital 6, Moscow

Ramirez, Y.
University of New Mexico, Albuquerque, New Mexico, USA

Romanenko, A.E.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR, Kiev, UkrSSR

Tsvetkova, O.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR, Kiev, UkrSSR

Thanks are due to the following persons for advice and help in their respective fields of expertise:

Epidemiology

Beebe, G.
Clinical Epidemiology Branch, National Cancer Institute, Bethesda, Maryland, USA

Beral, V., and group
Gibson Laboratory, Radcliffe Infirmary, Oxford, United Kingdom

Kuramoto, A., and others
Radiation Effects Research Foundation, Hiroshima, Japan

Samet, J.
School of Medicine, University of New Mexico, Albuquerque, New Mexico, USA

Equipment

Armitage, E.
Academy of Health Sciences, United States Army, San Antonio, Texas, USA

Haematology

Oske, F.
Department of Medicine, Johns Hopkins University, Baltimore, Maryland, USA

Dallman, P.
Department of Medicine, University of California at San Francisco, San Francisco, California, USA

Lead

Matte, T.
Lead Program, Center for Disease Control, Atlanta, Georgia, USA

Thyroid

Becker, D.
Department of Nuclear Medicine, New York Hospital, Cornell University Medical Center, New York, N.Y., USA

Gorman, C.
Department of Medicine, Mayo Clinic, Rochester, Minnesota, USA

Administrative Support

Aeroflot

Bratsun, E.V.
Moscow

Swift, R.
New York

Zavalishina, M.I.
Moscow

International Atomic Energy Agency (IAEA)

Adler, A.
Bacher, H.
Brandl, I.
Cejka, G.
Cibulka, R.
De Monte, M.
Delgado, E.
Delves, D.M.
Demal, G.
Diesner-Küpfer, A.
Dietl, W.
Dreger, G.
Dworzak, H.
Emge, I.
Fischer, R.
Fischl, R.
Frank, E.
Frank, M.
Gerken, W.
Hanel, G.
Hendricks, J.
Hobot, M.
Holzberger, I.
Huemer, C.
Karbassioun, M.
Kelleher, R.F.
Klimscha, F.
Kornis, S.
Kreutzer, W.
Lewis, M.
Løvschall, I. *(Assistant project manager, 1991)*
Luttenfeldner, R.
Murray, P.
Patak, P.
Peniston-Bird, R.
Platzer, R.
Popova, M.
Primes, A.
Prochaska, F.
Pucci, L.
Ramesh, G.V.
Ratheiser, S.
Rath-Türk, C.
Rombach, C.
Scharf, I.
Seitz, S.
Takacsy, M.
Utner, R.
Vide, L.
Wan Hamid, W.Z.
Weil, J.
Williams, M. *(Assistant project manager, 1990)*
Witter, N.
Yamashita, V.
Zappe, M.
Zink, U.
Zmuck, E.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)

Habersack, S.
Holzer, W.

Logistical Support in the USSR

Aderikha, V.N.
Translator,
Trade and Industry Office,
Gomel, BSSR

Anikanova, A.
Translator/editor,
Central Bureau of Interpreters,
Moscow

Artemenko, F.P.
Translator,
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Babarina, L.I.
Translator/editor,
Office of International Relations of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Belousova, E.N.
Translator,
Intourist,
Moscow

Beránek, J.
IAEA Office in Gomel,
Gomel, BSSR

Bessalaya, L.A.
Translator/editor,
Working Group of the Ministry of Atomic Power and Industry of the USSR on the Implementation of the International Chernobyl Project,
Moscow

Participants in the International Chernobyl Project

Bruj, E.I.
Translator,
Trade and Industry Office,
Gomel, BSSR

Buravkova, N.V.
IAEA Office in Gomel;
Regional Executive Committee,
Gomel, BSSR

Burtsev, L.F.
Translator,
Trade and Industry Office,
Gomel, BSSR

Chepelov, V.I.
IAEA Office in Gomel;
Regional Executive Committee,
Gomel, BSSR

Chertok, T.V.
IAEA Office in Gomel,
Gomel, BSSR

Demidova, E.A.
Translator,
Bryansk Technological Institute,
Bryansk, RSFSR

Evdokimenko, E.I.
Translator/editor,
Working Group of the Ministry of Atomic Power and Industry of the USSR on the Implementation of the International Chernobyl Project,
Moscow

Evleva, N.M.
Translator,
Institute of Radiation Medicine of the Ministry of Health of the BSSR,
Minsk, BSSR

Griaznova, E.A.
Translator/editor,
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Kalinkin, Yu.D.
Translator,
IAEA Office in Gomel,
Gomel, BSSR

Kondachkova, L.N.
Translator/editor,
Ministry of Atomic Power and Industry of the USSR,
Moscow

Kudinova, R.V.
Translator/editor,
Ministry of Atomic Power and Industry of the USSR,
Moscow

Lebedev, A.E.
Translator/editor,
Ministry of Atomic Power and Industry of the USSR,
Moscow

Lyapin, A.E.
Interpreter,
M. Torez Institute of Foreign Languages,
Moscow

Mamsourova, E.A.
Interpreter,
Ministry of Atomic Power and Industry of the USSR,
Moscow

Mikhajlova, O.A.
Working Group of the Ministry of Atomic Power and Industry of the USSR on the Implementation of the International Chernobyl Project,
Moscow

Mironov, V.D.
IAEA Office in Gomel,
Gomel, BSSR

Nasledukhov, E.A.
Translator/editor,
Ministry of Atomic Power and Industry of the USSR,
Moscow

Nesterov, M.P.
Translator/editor,
Central Bureau of Interpreters,
Moscow

Nevskaya, I.A.
Translator,
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Novikova, G.V.
Working Group of the Ministry of Atomic Power and Industry of the USSR on the Implementation of the International Chernobyl Project,
Moscow

Orekhova, N.N.
Interpreter,
Central Bureau of Interpreters,
Moscow

Ostapyuk, I.V.
Translator/editor,
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Pashchenko, A.V.
Interpreter,
Foreign Languages Institute,
Minsk, BSSR

Participants in the International Chernobyl Project

Perminov, S.P.
Translator/editor,
Ministry of Atomic Power and Industry of the USSR,
Moscow

Polyakova, O.A.
Interpreter,
Ministry of Atomic Power and Industry of the USSR,
Moscow

Protsenko, E.I.
Interpreter,
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Reutskaya, S.V.
IAEA Office in Gomel,
Gomel, BSSR

Ryndina, I.Yu.
Interpreter,
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Shamkov, K.G.
Interpreter,
M. Torez Institute of Foreign Languages,
Moscow

Shesteryakov, A.M.
Interpreter,
M. Torez Institute of Foreign Languages,
Moscow

Shulikova, V.R.
Interpreter,
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Stashkevich, M.P.
Translator/editor,
Working Group of the Ministry of Atomic Power and Industry of the USSR on the Implementation of the International Chernobyl Project,
Moscow

Stel'makov, E.N.
Interpreter,
Foreign Languages Institute,
Minsk, BSSR

Sten'shin, E.A.
Interpreter,
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Sukhovej, A.B.
Interpreter,
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Yashin, V.M.
Translator/editor,
Central Bureau of Interpreters,
Moscow

Zabarina, L.E.
Translator,
Pripyat Scientific Production Group,
Chernobyl, UkrSSR

Zimina, E.V.
Interpreter,
Central Advanced Training Institute of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Participants in the Decision Conferences

Kiev, UkrSSR, 8–9 October 1990

Aleksakhin, R.M.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Astasheva, N.P.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Balyuk, G.N.
Kiev State University,
Kiev

Bar'yakhtar, V.G.
Academy of Sciences of the UkrSSR,
Kiev

Bobyleva, O.A.
Ministry of Health of the UkrSSR,
Kiev

Chumak, V.K.
Nuclear Research Institute of the Academy of Sciences of the UkrSSR,
Kiev

Gotovchits, G.A.
State Committee of the Council of Ministers of the UkrSSR for the Protection of the Public from the Consequences of the Chernobyl Accident,
Kiev

Grodzinskij, V.M.
Institute of Botanics of the Academy of Sciences of the UkrSSR,
Kiev

Kapustyan, N.K.
Civil Defence Headquarters of the UkrSSR,
Kiev

Likhtarev, I.A.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Los, I.P.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Mantsevitch, Y.N.
UkrSSR State Institute of City Design,
Kiev

Mazyk, K.I.
Council of Ministers of the UkrSSR,
Kiev

Pinchuk, V.G.
All-Union Scientific Centre for Radiological Medicine of the Academy of Medical Sciences of the USSR,
Kiev

Popova, L.M.
Academy of Sciences of the UkrSSR,
Kiev

Poturidis, G.G.
State Committee of the Council of Ministers of the UkrSSR on the Protection of the Public from the Consequences of the Chernobyl Accident,
Kiev

Potykha, V.M.
Council of Ministers of the UkrSSR,
Kiev

Prister, B.S.
UkrSSR Branch of the All-Union Scientific Research Institute of Agricultural Radiology,
Kiev

Rabchuk, I.A.
Working Group of the Ministry of Atomic Power and Industry of the USSR on the Implementation of the International Chernobyl Project,
Kiev

Rynka, A.A.
Supreme Soviet of the USSR,
Moscow

Sidorov, S.I.
Ministry of Health of the USSR;
Academy of Sciences of the UkrSSR,
Kiev

Sokolov, V.A.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Spizhenko, Yu.P.
Minister of Health of the UkrSSR,
Kiev

Stukin, E.K.
USSR State Committee for Hydrometeorology,
Moscow

Tabachnyj, L.Ya.
UkrSSR State Committee for Hydrometeorology,
Kiev

Tron'ko, N.D.
Institute of Endocrinology and Metabolism of the Ministry of Health of the UkrSSR,
Kiev

Minsk, BSSR, 11-12 October 1990

Buryak, V.N.
State Committee of the Council of Ministers of the BSSR on the Consequences of the Chernobyl Accident,
Minsk

Kazakov, V.S.
Minister of Health of the BSSR,
Minsk

Kenik, I.A.
Council of Ministers of the BSSR,
Minsk

Pokumejko, Yu.M.
BSSR State Committee for Hydrometeorology,
Minsk

Semkin, A.S.
Mogilev Regional Executive Committee,
Mogilev

Smolyar, I.N.
State Committee of the Council of Ministers of the BSSR on the Consequences of the Chernobyl Accident,
Minsk

Stepanenko, A.V.
Academy of Sciences of the BSSR,
Minsk

Sukhorukov, E.F.
State Committee for Foodstuffs and Supplies of the BSSR,
Minsk

Sych, V.N.
Gomel Regional Executive Committee,
Gomel

Experts

Gurkov, V.V.
State Committee for Foodstuffs and Supplies of the BSSR,
Minsk

Klyuchenovich, V.I.
Gomel Regional Centre for Epidemiology and Health of the Ministry of Health of the BSSR,
Gomel

Konoplya, E.F.
Institute of Radiobiology of the Academy of Sciences of the BSSR,
Minsk

Kotlyarenko, O.I.
Mogilev Regional Medical Centre,
Mogilev

Matvenko, I.I.
Republican Centre for Radiation Monitoring,
Minsk

Shitikov, B.D.
Ministry of Health of the BSSR,
Minsk

Observers

Aleksakhin, R.M.
All-Union Scientific Research Institute of Agricultural Radiology,
Obninsk, RSFSR

Sokolov, V.A.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Moscow, RSFSR 15-16 October 1990

Belyaev, E.N.
Deputy Minister of Health of the RSFSR,
Moscow

Boldarev, M.M.
RSFSR Non-Fertile Soil Construction Association,
Moscow

Demichev, A.P.
Kaluga Regional Executive Committee,
Kaluga, RSFSR

Feshchenko, V.V.
Bryansk Regional Executive Committee,
Bryansk, RSFSR

Makeenko, S.G.
RSFSR State Planning Committee,
Moscow

Panfilov, I.I.
RSFSR State Planning Committee,
Moscow

Perminova, G.S.
Radiation Medicine Department of the Ministry of Health of the RSFSR,
Moscow

Polonskij, V.T.
Ministry of Agricultural Products of the RSFSR,
Moscow

Ramzaev, P.V.
Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Leningrad, RSFSR

Sarychev, V.A.
State Commission of the Council of Ministers of the RSFSR on Emergency Situations,
Moscow

Tereshchenkov, A.S.
Regional Executive Committee,
Bryansk, RSFSR

Tsaturov, Yu.S.
USSR State Committee for Hydrometeorology,
Moscow

Vasutin, S.I.
Regional Executive Committee,
Tula, RSFSR

Voloschchuk, S.S.
RSFSR State Committee on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Zubovskij, G.A.
Scientific Research Institute of X Ray Radiology of the Ministry of Health of the RSFSR,
Moscow

Representatives of the Working Group of the Ministry of Atomic Power and Industry of the USSR on the Implementation of the International Chernobyl Project, Moscow

Belousova, E.N.
Bessalaya, L.A.
Borodastov, G.V.
Busurin, Yu.N.
Evdokimenko, E.I.
Korneeva, M.A.
Orekhova, N.N.

Moscow, USSR 18–19 October 1990

Belyaev, S.T.
I.V. Kurchatov Institute of Atomic Energy of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Cheburaev, V.I.
Ministry of Health of the USSR,
Moscow

Gubanov, V.A.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Il'in, L.A.
Institute of Biophysics of the Ministry of Health of the USSR,
Moscow

Israel, Yu.A.
State Committee for Hydrometeorology of the USSR,
Moscow

Mar'in, V.V.
Bureau of the USSR Council of Ministers for Fuel and Energy,
Moscow

Nikipelov, B.V.
Ministry of Atomic Power and Industry of the USSR,
Moscow

Semenov, P.E.
USSR State Planning Committee,
Moscow

Sokolovskij, V.G.
USSR State Committee for the Environment,
Moscow

Consultants

Dibobes, I.K.
Institute of Applied Geophysics,
Moscow

Dyomin, V.F.
I.V. Kurchatov Institute of Atomic Energy of the Ministry of Atomic Power and Industry of the USSR,
Moscow

Ivanov, S.I.
Ministry of Health of the USSR,
Moscow

Kirillov, Yu.S.
Office of the Head of Chemical Warfare of the Ministry of Defence of the USSR,
Moscow

Kiryushin, V.I.
USSR State Commission for Foodstuffs and Supplies,
Moscow

Kopchinskij, G.A.
Bureau of the USSR Council of Ministers for Fuel and Energy,
Moscow

Povalaev, A.P.
USSR State Commission for Foodstuffs and Supplies,
Moscow

Ramzaev, P.V.
Leningrad Scientific Research Institute for Radiation Health Studies of the Ministry of Health of the RSFSR,
Leningrad, RSFSR

Sokolov, V.A.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Tsaturov, Yu.S.
USSR State Committee for Hydrometeorology,
Moscow

Ushcherbov, G.S.
USSR State Planning Committee,
Moscow

Voznyak, V.Ya.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Observers

Glinka, E.V.
USSR State Commission for Foodstuffs and Supplies,
Moscow

Lutsev, S.D.
State Committee of the Council of Ministers of the USSR on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Porfir'ev, B.N.
All-Union Scientific Research Institute for Systems Analysis of the Academy of Sciences of the USSR,
Moscow

Voloshchuk, S.S.
RSFSR State Committee on the Rectification of the Consequences of the Chernobyl Accident,
Moscow

Voronezhtsev, Yu.I.
Supreme Soviet of the USSR,
Moscow

International Chernobyl Project Team for the Decision Conferences

Facilitators

French, G.S.
University of Leeds,
Leeds, United Kingdom

Morrey, M.
National Radiological Protection Board,
Chilton, United Kingdom

Observers

Hedemann Jensen, P.
Risø National Laboratory,
Roskilde, Denmark

Kelly, N.G.
Commission of the European Communities,
Brussels

Schaefer, M. *(Moscow only)*
British Nuclear Forum,
London, United Kingdom

Schneider, T.
Commissariat à l'énergie atomique,
Fontenay-aux-Roses, France

Interpreters

Dorogoj, A.
Free-lance

Witter, N.
International Atomic Energy Agency,
Vienna

Secretary

Løvschall, I.
International Atomic Energy Agency,
Vienna

91-03536