22.312 **ENGINEERING OF NUCLEAR REACTORS**

Monday, December 14th, 2009, 9:00am-12:00 pm

OPEN BOOK	FINAL EXAM	3 HOURS

Problem 1 (15%) – Sizing the shell of a spherical containment

The Westinghouse reactor IRIS features a spherical containment made of steel and of diameter 25 m.

i) Estimate the minimum shell thickness required to limit the shell displacement to 1 cm at the design pressure and temperature (1.4 MPa and 190°C). (10%)

ii) Assuming the shell thickness is actually 8 cm, calculate the margin to the ASME limit at the design pressure and temperature. (5%)

Properties of steel at 190°C:

S_m =110 MPa
S_y = 170 MPa
ρ = 7900 kg/m^3
E = 184 GPa
ν = 0.33

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Problem 2 (25%) – Reduction of containment pressure after LOCA

Consider the IRIS containment from Problem 1. Assume a LOCA has occurred. Immediately after it the resulting pressure, temperature and steam quality in the containment are 1.4 MPa, 190°C and 0.11, respectively. There is a safety system that removes a constant 20 MW of heat from the containment. Write a complete set of equations that would allow you to calculate the time it takes for the containment pressure to be reduced to 0.5 MPa. In calculating the decay heat, assume the reactor had operated for an infinite time prior to the LOCA.

The total containment volume: V_{tot}=6,000 m^3
Mass of air in containment: M_a= 6,400 kg
Total mass of water in containment: M_w= 320,000 kg
Air specific heat at constant volume: $c_{v,a}$=719 J/kg-K
Air gas constant: R_a=286 J/kg-K
Nominal reactor power: $\dot{Q}_0$ =1,000 MW_t

Problem 3 (45%) – Superheated Boiling Water Reactor

The schematic of an advanced Boiling Water Reactor (BWR) concept being studied at MIT is shown in the figure below. Water is boiled in the reactor core (A→B), and the steam-liquid mixture enters a steam separator; the liquid from the steam separator is returned to and mixed with the feedwater (C→D), while the steam from the steam separator is superheated in a second pass through the reactor core (E→F), and then sent to the turbine. The first and second pass in the reactor core occur in physically separated channels. Steam superheating is done to increase the thermal efficiency of the plant.

- The system operating pressure is 6 MPa
- The feedwater temperature is 230°C
- The superheated steam temperature is 510°C

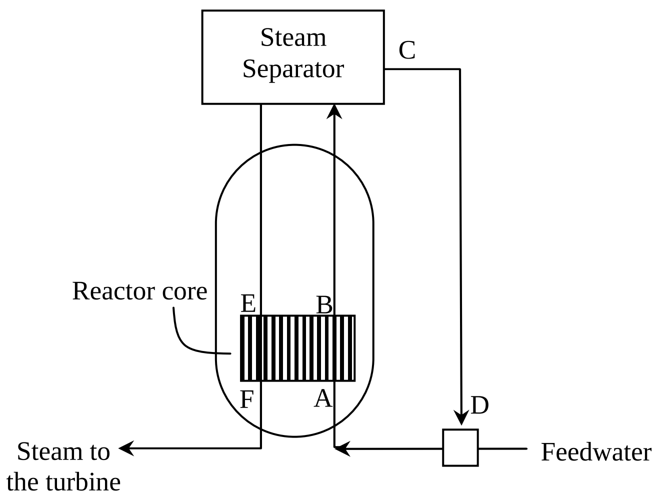

Table 1. Properties of water at 6 MPa.

Parameter	**Value**
T_{sat}	275°C
ρ_f	760 kg/m^3
ρ_g	30 kg/m^3
h_f	1211 kJ/kg
h_g	2785 kJ/kg
$C_{p,f}$	5.2 kJ/(kg°C)
$C_{p,g}$	4.8 kJ/(kg°C)
μ_f	1×10^{-4} Pa·s
μ_g	2×10^{-5} Pa·s
k_f	0.6 W/(m°C)
k_g	0.06 W/(m°C)
σ	0.02 N/m

i) Put points A, B, C, D, E and F on a T-s diagram. (5%)

ii) Determine the feedwater mass flow rate required to operate the reactor at a thermal power of 1,000 MW. Assume constant specific heat for subcooled water and superheated steam. (10%)

iii) Assuming that the slip ratio is $S=2$, calculate ΔP_{acc} in the A→B core channels. The total mass flow rate in these channels is 2270 kg/s, the inlet (Point A) temperature is 268°C and the outlet (Point B) steam quality is 15%. The channels are 3 m long, have an equivalent diameter of 2 cm and a total flow area of 1.26 m^2. Assume the heat flux in the core is axially uniform. (15%)

iv) Calculate the Critical Power Ratio in the A→B channels, using the CISE-4 correlation reported below. Use the same operating conditions of question 'iii' above. The boiling length can be assumed to be equal to the distance from the channel inlet. The heat flux is axially uniform. (15%)

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CISE-4 correlation (simplified)

$x_{cr} = a\frac{L_b}{L_b + b}$ with $a = (1 - P/P_{cr})/(G/1000)^{1/3}$ and $b = 0.199(P_{cr}/P - 1)^{0.4} G D_e^{1.4}$,

G in kg/m^{2}s and D_e in m.

Problem 4 (15%) – Thermodynamic analysis of a power cycle

Researchers at a university have proposed a new power cycle that takes heat (1,000 MW) from a nuclear reactor at 450°C, converts part of it into electricity (400 MW net), and discharges heat at low temperature in a cooler. The cooler uses 15,000 kg/s of seawater, which enters the cooler at 15°C and 1 atm, and exits at 25°C and 1 atm.

Does this system violate the 1st and/or 2nd law of thermodynamics?

Assumptions

Treat seawater as an incompressible fluid with density 1,000 kg/m^3 and specific heat 4,000 J/kg°C. Recall that the entropy change for an incompressible fluid can be calculated as $s - s_o = c\ln(T/T_o)$

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