22.312 **ENGINEERING OF NUCLEAR REACTORS**

Due November 17, 2004 by 12:00 pm

TAKE HOME QUIZ #2

Problem 1 (60%) – Thermal analysis of a lead-cooled reactor fuel assembly

An innovative fast reactor concept uses molten lead as the coolant with the small hexagonal fuel-assembly design shown in Figure 1. The geometry and operating conditions of the fuel assembly are described in Table 1. Each fuel pin consists of a cylindrical slug made of U-Zr with a stainless steel cladding. Since U-Zr swells significantly under irradiation, a relatively large gap must be provided for between the fuel slug and the cladding (Figure 1). The gap is filled with a "thermal bond" to prevent excessive temperatures in the fuel, when the reactor is at power. The thermal bond material is molten sodium. Useful properties for all materials in the fuel assembly are reported in Table 2 at the end of the problem statement.

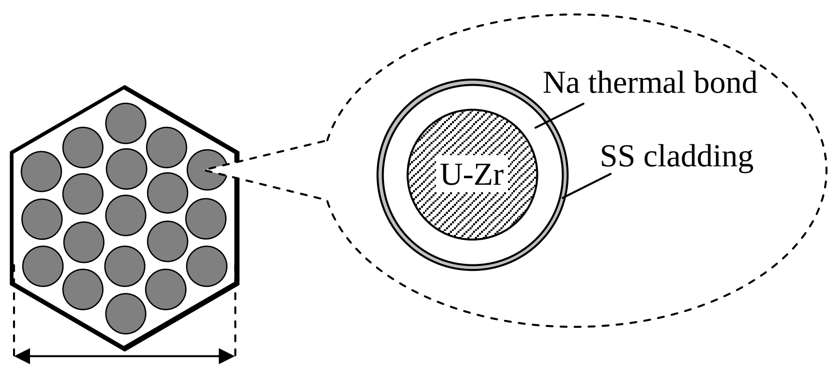


Figure 1. Cross sectional view of the fuel assembly.

Table 1. Operating conditions and geometry of the fuel assembly.

Parameter	**Value**
Fuel assembly power (thermal)	456 kW
Inlet / outlet temperature	400°C / 550°C
Local / axial peaking factor	1.0 / 1.0
Fuel assembly inner width	51.1 mm (see Figure 1)
Number of fuel pins	19
Fuel pin pitch	11.0 mm
Fuel pin outer diameter	9.0 mm
Cladding thickness	0.6 mm
Fuel slug diameter	6.8 mm
Active fuel length	1.2 m

i) Select a suitable heat transfer correlation from your text book. (Assume fully-developed velocity and temperature profiles) (10%)

ii) Evaluate the length of the entry region for the fuel assembly, and comment on the accuracy of the fully-developed velocity and temperature profiles assumption used in answering the previous question. Will the actual heat transfer coefficient be over- or under-estimated if a correlation for fully-developed flow is used? Explain. (10%)

iii) Assuming a uniform axial power profile, sketch the coolant bulk temperature and the cladding outer temperature as a function of the axial coordinate. (Assume constant coolant properties) (10%)

iv) Calculate the peak outer cladding temperature and the fuel centerline temperature. (In calculating the temperature drop across the gap, consider only heat conduction). (10%)

v) Suppose the plant operator increases the reactor power by 10% without changing the coolant mass flow rate and the inlet temperature. How do the peak cladding temperature and fuel centerline temperature change at these new operating conditions? (10%)

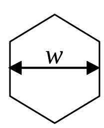
vi) Wire wrapping is often used for fuel pin spacing in liquid-metal-cooled fast reactors. If this approach were used for the fuel assembly in Figure 1, would the coolant velocity, bulk temperature, heat transfer coefficient and pressure drop increase, decrease or remain the same? Why? (Assume that power, mass flow rate, inlet temperature and fuel pin geometry remain the same) (10%)

Table 2. Properties (all properties constant with temperature)

Material	ρ (kg/m^3)	k (W/m·K)	μ (Pa·s)	c_p (J/kg·K)
Molten Pb	10,400	16	1.9×10^{-3}	155
Stainless steel	8,000	14	/	470
Molten Na	780	60	1.7×10^{-4}	1,300
U-Zr	16,000	20	/	120

Hexagon area: $A = \frac{\sqrt{3}}{2} w^2$

Hexagon perimeter: $p = 2\sqrt{3}w$



Problem 2 (40%) – Maximum Linear Power from a Duplex Fuel Pellet

To uprate the power of its Light Water Reactor fleet, an electric utility is considering the use of duplex fuel pellets. A duplex fuel pellet consists of two radial zones, one loaded with UO_2 and one with PuO_2 (Figure 2). The pellet outer temperature is fixed at 400°C.

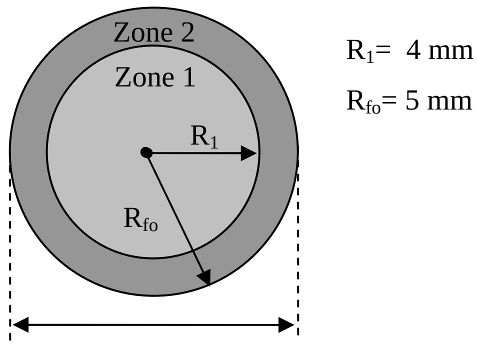


Figure 2. Cross-sectional view of a duplex fuel pellet.

i) Assuming that centerline fuel melting is the design limit for this pellet, which oxide would you put in Zone 1 (i.e., the inner zone)? (5%)

ii) Using only the properties in Table 3 and assuming that the volumetric heat generation rate in PuO_2 is 50% higher than in UO_2, calculate the maximum linear power at which the pellet can be operated without melting the fuel? (30%) (Neglect the thermal conductivity dependence on temperature)

iii) How does the maximum linear power in "iii" compare with the maximum linear power for an all-UO_2 pellet? (5%)

Table 3. Properties of oxide fuels.

Parameter	**UO_2**	**PuO_2**
Density (g/cm^3)	10.5	10.9
Thermal conductivity (W/m°C)	3.0	2.5
Melting Point (°C)	2,800	2,300
Specific heat (J/kg°C)	410	380