22.312 ENGINEERING OF NUCLEAR REACTORS

Due November 16, 2007 by 12:00 pm

TAKE HOME QUIZ 2

Problem 1 (45%) – Effect of internal cooling on fuel temperatures

Consider the following three UO_2 pellets:

- Solid pellet
- Annular pellet with only external cooling
- Annular pellet with simultaneous internal and external cooling

The dimensions for all three pellets are in the table below. Assume that the fuel thermal conductivity is k_f=3 W/m·K (independent of temperature), the pellet surface temperature is 700°C and the linear power is q'= 40 kW/m in all three cases.

Geometry of the pellets

	ID (mm)	OD (mm)
Solid pellet	N/A	8.2
Annular pellet with only external cooling	2.0	8.44
Annular pellet with internal and external cooling	9.9	14.1

i) Calculate the maximum temperature for the solid pellet. (5%)

ii) Calculate the maximum temperature for the annular pellet with only external cooling. (5%)

iii) Calculate the maximum temperature for the annular pellet with simultaneous external and internal cooling. (20%)

iv) For the annular pellet with simultaneous internal and external cooling calculate also the heat flux at the inner and outer surfaces. (10%)

v) What are in your judgment the advantages and drawbacks of the annular fuel pellet with simultaneous internal and external cooling? (5%)

Problem 2 (55%) – Flow-levitated control rod in a PWR

Prof. Driscoll has recently proposed a novel control rod design based on flow levitation, to be used in PWRs. The control rod consists of a slug of absorbing material (boron carbide, B_4C) that can slide within a guide tube (see Figure 1). During normal operating conditions the control rod is held out of the core by the coolant flow. If the coolant flow suddenly decreases, the control rod falls back into the core. The idea is to create a scram system that would automatically (passively) shut down the reactor in case of loss of flow and loss of coolant accidents. The control rod slug diameter is D=2 cm and its length is L=3.7 m. The guide tube diameter is D_o=2.6 cm. The properties of B_4C and coolant are reported in the table below.

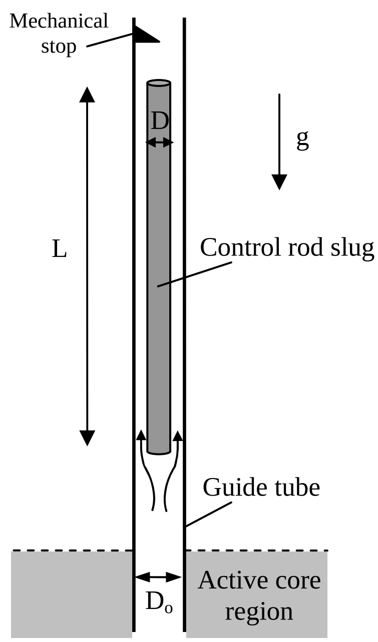

Figure 1. The flow-levitated control rod system. (There is a mechanical stop to ensure that the control rod is not dragged away by the flow.)

i) Calculate the minimum flow rate through the guide tube required for control rod levitation. Assume turbulent flow in the annulus between the guide tube and the control rod slug. Use a friction factor equal to 0.017, and form loss coefficients equal to 0.25 and 1.0 for the flow contraction and expansion at the bottom and top of the control rod slug, respectively. Ignore the presence of the stop. Assume steady-state. (30%)

ii) Now consider the operation of this control rod at reduced flow conditions, when it is fully inserted in the core. In this situation the control rod is exposed to a high neutron flux, so significant heat is generated due to (n,α) reactions on the B_4C. Because the absorption cross section of B_4C is so high, the neutrons only penetrate a few microns beneath the control rod surface. In fact, for all practical purposes we can assume that the volumetric heat generation rate within the control rod is zero, and describe the situation simply by means of a surface heat flux. Calculate the maximum temperature in the control rod, assuming that the heat flux at its surface has a cosine axial shape with an average of 80 kW/m^2. At the conditions of interest here the coolant flow rate, inlet temperature and pressure are 0.3 kg/s, 284°C and 15.5 MPa, respectively. (25%)

Properties of liquid water (assumed constant over the temperature and pressure range of interest)

Density	730 kg/m^3
Viscosity	9×10^{-5} Pa·s
Specific Heat	5500 J/kg-K
Thermal Conductivity	0.56 W/m-K

Properties of boron carbide

Density	2500 kg/m^3
Specific Heat	950 J/kg-K
Thermal Conductivity	35 W/m-K