ENGY.4340 Nuclear Reactor Theory

Fall 2016

HW #9: Reactivity Worth Considerations

Problem #1 (15 points)

The core of a fast reactor is a finite cylinder with diameter D = 100 cm and height H = 100 cm. The composition of the core by volume is as follows: 18% fuel, 25% stainless steel cladding and structure, and 57% liquid sodium. The fuel consists of a mixture of U238 and Pu239 having a density of 19.1 g/cm^3, with the plutonium making up 15 w/o of the fuel mixture.

a. Calculate the multiplication factor, k, for a bare system with the core size and composition noted here.
b. If a reflector is added with an effective reflector savings of 20 cm, estimate the multiplication factor for the fully reflected configuration.
c. If the control system requires a total of 12% $\Delta k/k$ of reactivity control within twenty (20) B_4C control rods, estimate the mass of B_4C needed per rod.

Hint: This problem deals with the design of a control system for a fast reactor. In particular, you need to determine the bare and reflected core multiplication factors, the excess reactivity associated with the reflected core, and the amount of B_4C required in each control rod to give the desired total worth (to override the initial excess reactivity and to safely shutdown the reactor). Use 1-group theory for a homogeneous system as an approximate methodology for this problem. Also, for ease in the calculations, assume that stainless steel is primarily iron (Fe) and that a reasonable appropriately averaged cross section for natural boron for this fast system is about 0.27 b. You should get the remainder of the needed microscopic cross section data from Lamarsh Table 6.1 (within the Appendix to the Lecture Notes on "Cross Section Data for Preliminary Calculations"). Note also that the density of iron is about 7.9 g/cm^3 and that of liquid sodium is about 0.93 g/cm^3.

Problem #2 (10 points)

The integral blade worth curves within the UMLRR are currently measured using a technique referred to as the Inverse Kinetics Method. Data for the annual calibration done in February 2014 are available in an interactive format within the Matlab-based **bw_display** GUI. Note that the fully withdrawn position for all the blades is roughly 26 inches out, but the exact value for each blade is set internally if you specify a value greater than the maximum blade traverse, z_{max}.

In this problem you are asked to address several items of interest that require knowledge of the blade worth curves (here we will assume that they do not chance significantly with burnup -- which is actually a pretty good approximation). Thus, using the **bw_display** GUI with data from Feb. 2014, answer the following questions:

a. At the beginning of life (BOL), the UMLRR was critical with Blades 1-4 banked at 14.9 inches out with the regulating blade (RegBlade) at 10 inches out. With this information, estimate the **excess reactivity in the BOL startup core**.

b. The **shutdown margin** for the UMLRR is the amount of negative reactivity that can be inserted into the core with the blade with the most worth stuck in its fully withdrawn position. Estimate the **shutdown margin for the BOL core**.

c. In February 2014, the critical height of Blades 1-4 with the RegBlade at 10 inches out was about 16.7 inches withdrawn. Estimate the **excess reactivity and shutdown margin for the M-2-5 core configuration at that time**. Also, estimate the amount of reactivity loss up to Feb. 2014 due to depletion and fission product buildup since the fuel was loaded at the BOL.

d. The average coolant $\Delta T = T_{out} - T_{in}$ across the UMLRR core is about 36 ^oF when the reactor is operating in natural convection mode at about 100 kW (so the average coolant temperature increase in the core is roughly 36/2 = 18 ^oF). The combined (fuel + coolant) temperature coefficient for the UMLRR is about -0.0033 %Δk/k per ^oF. Again, in Feb. 2014, if the reactor is just critical at low power (say 10 W) with the regulating blade at 10 inches withdrawn, estimate the critical position of the RegBlade for critical steady state operation at 100 kW in natural convection mode. Assume that all other blades are fixed and ignore any Xe poisoning effects (xenon only becomes important with extended operation in this state).

Note: Be sure to think about these questions carefully, and to explain any assumptions made and the overall logic used to arrive at your results. Be thorough here, since a simple numerical answer with no explanation will not be worth much!!!

Problem #3 (10 points)

Study the Lecture Notes "Xenon Poisoning in Thermal Reactors". Now, with this background and the **xenon_gui.m** code, as needed, address the following questions:

a. The maximum equilibrium Xe worth in a large high-power thermal system is shown in the reference material to be about -2.73 % Δk/k. For a small critical system, however, the maximum worth can be significantly different. In particular, estimate the maximum equilibrium Xe worth for the UMLRR using the data from the Lecture Notes. Assume that the reactor can be run at a high power level such that $\phi_\infty >> \phi_X$ (see the Lecture Notes for the definition of these terms).

b. Figure 1 in the Lecture Notes shows that the actual equilibrium worth in the UMLRR to be about -2.5 % Δk/k for operation at 1 MW. However, the UMLRR, at some point, may consider an upgrade to 2 MW or more. Within this context, estimate the equilibrium Xe worth if the UMLRR is operated for a long time at 2 MW. What about 5 MW? At what power level do you start to approach the maximum worth computed in Part a?

c. Also apparent in Fig. 1 in the Lecture Notes is that it takes nearly 3 days of full power operation to approach equilibrium conditions. However, the UMLRR does not operate 24 hours per day. Assuming full power operation 5 days per week with 8 hours on and 16 hours off per day, what is the practical maximum Xe worth that will occur for operations at 2 MW? Also address how will this affect operation of the reactor relative to current operation at 1 MW (note that the current excess reactivity in the system is between 2.5 – 3.0 %Δk/k and the critical blade height is between 16.7 and 17.1 inches withdrawn with no xenon present). The goal here is to rationalize how going to 2 MW would affect operations relative to the expected xenon reactivity dynamics within the system…

Problem #4 (10 points)

Consider the following fission product chain involving Ru105 and Rh105. In particular, Ru105 has an equilibrium yield of about 0.0098 atoms/fission and it decays to Rh105 with a half-life of 4.44 hr. Rh105 can decay to Pd105 with a half-life of 35.4 hr and it also has a large thermal absorption cross section of approximately 14,100 barns.

$$\begin{array}{l} \text{Ru105} \xrightarrow[4.44\ \text{hr}]{\beta^-} \text{Rh105} \left\{ \begin{array}{l} \xrightarrow[35.4\ \text{hr}]{\beta^-} \text{Pd105} \\ \xrightarrow[1.41\times10^4\ \text{b}]{n,\gamma} \text{Rh106} \end{array} \right. \\ \uparrow 0.0098 \\ \text{fission} \end{array}$$

With this information, perform the following analyses:

a. Develop an expression for the equilibrium Rh105 density and worth, and evaluate ρ_∞ for the case of a very high power thermal system with negligible leakage. Assume a U235 fueled system.

b. Assuming that the reactor is shutdown quickly after it has been operating at constant power for a long time, develop an expression for the Rh105 density and reactivity worth versus time after shutdown. Carefully sketch the expected profile for $\rho(t)$ for this situation.