February 1995

Ph.D. Qualifying Examination
Reactor Theory and Experimentation

1. (20 min.) A bare spherical reactor that is 50 cm in radius consists of a uniform dilute mixture of U^{235} and water. The thermal diffusion length (L_T) of the mixture is 1.95 cm and the Fermi age to thermal energy for fission neutrons in water is 27 cm^2.

Determine:
(a) the buckling and K_∞, if the reactor is critical.
(b) the nonleakage probabilities of fast and thermal neutrons.
(c) the thermal utilization, if η for U^{235} is 2.065.
(d) the neutron flux distribution when the reactor operates at 200 MW_t. Assume each fission releases 200 MeV and the macroscopic fission cross section of the water-U^{235} mixture is 0.22 cm^{-1}.

2. (10 min.) Assume that you have just completed a pin-cell calculation using transport theory and 200 energy groups and that you know the spatially-averaged scalar flux in the moderator $\left[\bar{\phi}_g^m\right]$, clad $\left[\bar{\phi}_g^c\right]$, and fuel $\left[\bar{\phi}_g^f\right]$, for g = 1, ..., 200. You also know the 200-group macroscopic total cross sections in each region $\left(\Sigma_{t,g}^m, \Sigma_{t,g}^c, \Sigma_{t,g}^f\right)$ and you know the volume (V^m, V^c, V^f) of each region in the cell.

A subsequent calculation will need 10 - *group homogenized* cross sections representing the pin cell. In the new 10-group structure, one group (call it group G) spans groups 25 through 40 of the original 200-group structure. For group G, write the expression for the *homogenized total cross section*, $\bar{\Sigma}_{t,G}^{cell}$, of the pin cell.

3. (20 min.) A critical experiment performed using a neutron detector, a neutron source and a small research reactor results in the following data:

No. of Fuel Elements	Neutron Counts with Control Rods In	Neutron Counts with Control Rods Out
0	1000	1000
10	1142	1170
30	1600	1750
40	2000	2321
50	2670	3510
60	4000	6900
65	5310	14280

(a) (50%) What is the predicted critical fuel loading (number of fuel elements) with the control rods in and with the control rods out?
(b) (50%) What is the estimated worth of the control rods for each fuel loading? Give the result in dollars (for a U-235 reactor $\beta = 0.0065$).

4. (20 min.) (a.) Write down the equation that determines the collision density, F(E), in an infinite hydrogen moderator that contains an absorber (with large mass, $A \approx \infty$). Assume that neutrons are produced from a monoenergetic source whose strength is $S_0 \frac{n}{cm^3 - sec}$ at $E = E_0$. The diagram below may help. Also recall for hydrogen that $P(E' \rightarrow E)dE = \frac{dE}{E'}$. Do not attempt to solve for F(E).

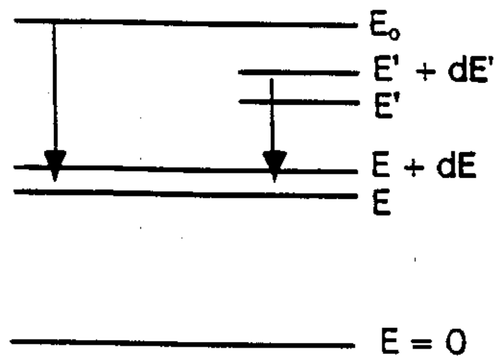

Fig. 1. Figure for Problem 4a.

(b) Compute the infinitely dilute resonance integral to the cadmium cutoff energy for the nuclide whose absorption cross-section is shown in the figure. The highest energy of any neutron of interest can be taken to be 10 MeV. The cadmium cutoff energy can be assumed to be 0.4 eV.

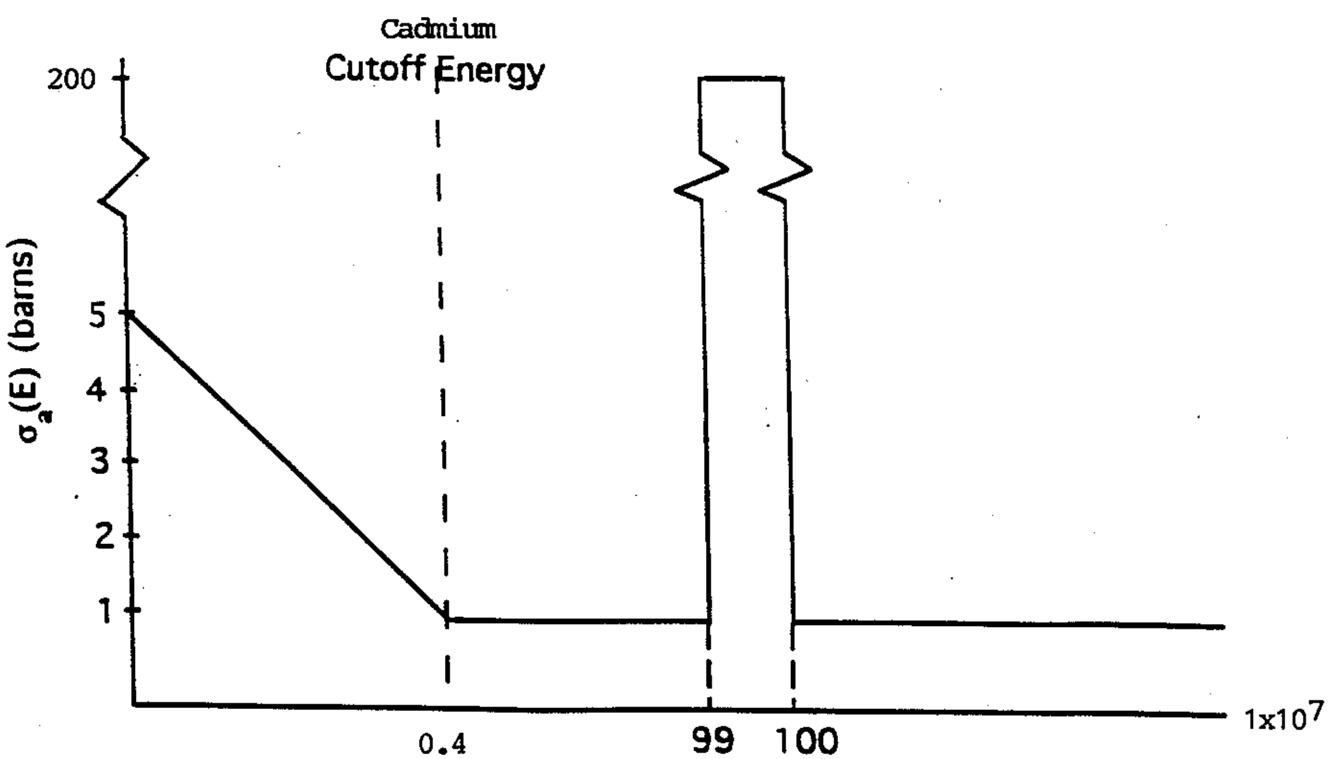

Fig. 2. Figure for Problem 4b.

5. (20 min.)

(a.) (80%) Starting from the standard form of the point kinetics equation with one delayed neutron group and assuming that a small positive reactivity insertion is made, make the infinite delay time approximation and derive an analytic solution for the transient power and one-group precursor concentration. What is the value of the prompt jump?

(b.) (20%) Assuming you know the six-group kinetics parameters, how would you evaluate an effective one delayed neutron group decay constant, λ? Explain.

6. (10 min.) You are asked to provide a certain excess reactivity control margin for an LWR using movable control rods of unspecified design.

(a.) (50%) Briefly describe how and why you would design the reactor if your only goal was to have a minimum mass of control material in the system.

(b.) (50%) What practical considerations (if any) would mitigate against your design of part (a.)?

7. (20 min.) Derive an expression for the time following reactor shutdown at which the maximum xenon-135 concentration occurs. Assume that the reactor was in equilibrium prior to shutdown. The equations for the time dependent iodine-135 and xenon-135 concentrations during reactor operation are given below.

$$\frac{dI}{dt} = \gamma_I \Sigma_f \varphi - \lambda_I I$$

$$\frac{dX}{dt} = \gamma_X \Sigma_f \varphi + \lambda_I I - \lambda_x X - \sigma_a^x \varphi X$$