October 1995

Ph.D. Qualifying Examination
Reactor Theory and Experimentation

1. (20 min.) The "slowing-down" equation describes how neutrons slow down in an infinite homogeneous medium. Given a monoenergetic source at energy E_0, it is:

$$\Sigma_t(E)\phi(E) = S_0 \frac{\Sigma_s(E_0 \to E)}{\Sigma_t(E_0)} + \int_0^{E_0} \Sigma_s(E' \to E)\phi(E')dE', \quad E<E_0.$$

This equation assumes that there is no fixed source at energy E, although it allows sources at other energies.

a) (25 %) If the medium is pure hydrogen and the energy range of interest is $10\text{eV} \leq E \leq 100\text{keV}$, approximately what is $\Sigma_s(E' \to E)$? [We are looking for an expression containing one or more of the variables E' and E.]

b) (25 %) State reasonable assumptions that would allow the slowing-down equation to be solved analytically, in the energy range described in part (a), given a pure hydrogen medium.

c) (50 %) What is the solution of the slowing-down equation given the conditions described in part (a) and the assumptions stated in part (b)? Prove that this is a solution.

2. (10 min.) Describe how you might measure control-rod worth as a function of insertion depth for a control rod at the Nuclear Science Center.

3. (10 min.) Define each of the following quantities by describing them with short but precise and complete statements. Also give the mathematical symbols and the commonly used units for each quantity.

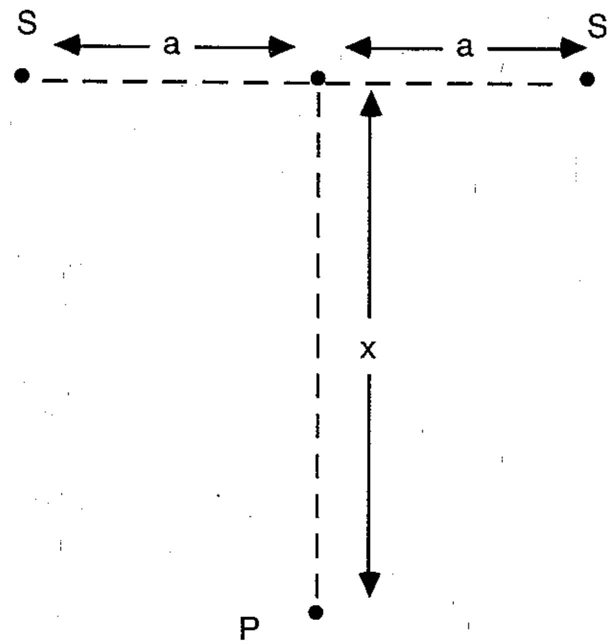
(a) Slowing Down Density
(b) Geometric Buckling
(c) Reactivity
(d) Temperature Coefficient
(e) Disadvantage Factor

4. (15 min.) (a) Write down the standard form of the point-kinetics equations for one delayed neutron group. Define all variables used in the equations.

(b) Derive a mathematical expression that enables you to calculate the ratio of delayed neutron precursors to neutrons which exist in a reactor that is in equilibrium.

(c) Physically and mathematically describe the prompt critical condition, and define one dollar of reactivity.

5. (20 min.) Two monoenergetic isotropic point sources each emitting S $\frac{\text{neutrons}}{\text{s}}$ are placed in an infinite diffusing medium as shown in the figure below.



(a) Find the flux at the point P.

(b) Find the current $\vec{J}$ at the point P.

Both ϕ and $\vec{J}$ should be expressed in terms of S, x, a and $L = \sqrt{\frac{D}{\Sigma_a}}$.

6. (15 min.) You are given a large block of graphite that contains a small tritium target on which 150-keV deuterons from an accelerator impinge (the tritium target can be assumed to be a steady state, point source of 14.1-MeV neutrons). You also have in your possession indium foils (95.7 atom percent, In-115) and cadmium covers for the foils. Assume that you have the ability to place the foils (with or without cadmium covers) wherever you wish in the graphite block. Finally, you have a proportional counter that can detect beta particles emitted by the decay of In-116 (55 minute half life). Describe how you would perform an experiment to determine the Fermi age from 14.1-MeV to 1.45 eV (the energy of the large neutron capture resonance of In-115) using the just described equipment. Be sure to state 1) your experimental procedure, 2) the properties of indium and cadmium, if necessary, that make these materials attractive for measuring the Fermi Age to a particular energy and 3) how the Fermi age from 14.1 MeV to 1.45 eV is obtained from the experimentally measured quantities.

7. (15 min.) Write down the steady-state monoenergetic transport equation for plane and azimuthal symmetry and isotropic scattering. (Note: The angular flux is a function of x and μ, only). Derive from it the P_1 equations under suitable, clearly stated assumptions (Hint: $P_2(\mu) = 3/2(\mu^2 - 1/3)$). Obtain a diffusion approximation by eliminating the neutron current ($\vec{J}$) from the P_1 equations.

8. (15 min.) A certain homogeneous mixture of natural uranium and water has infinite multiplication factor of $k_\infty = 1.25$. According to the Fermi Age Theory, what is the extrapolated radius of a critical sphere of this material ?

τ = Fermi Age = 120 cm^2

L = diffusion length = 10 cm