February 1991

Ph.D. Qualifying Examination
Reactor Theory and Experimentation

1. (15 min.) Describe qualitatively the Doppler broadening of resonances and the role of the Doppler coefficient of reactivity in reactor dynamics for the following two reactor types:

   (a) Natural Uranium core
   (b) Fully enriched core ($\geq 95\%$ U^{235})

2. (15 min.) The infinite multiplication factor for a certain heterogeneous lattice of natural uranium fuel in a heavy water moderator is 1.28. In this particular lattice $L^2 = 175$ cm^2 and $\tau = 120$ cm^2.

   (a) Calculate the critical buckling using 1-group theory.
   (b) Calculate the critical buckling using 2-group theory.
   (c) Compare and discuss the results.

3. (10 min.)

   (a) (30%) Express the (total) reaction rate for a given type of reaction in terms of (integrals involving) the cross-section for that reaction and the angular flux.
   (b) (30%) Under a reasonable assumption (describe it explicitly) on the cross-section, express the reaction rate of the preceding problem in terms of the scalar flux.
   (c) (40%) In view of the fact that reaction rates are the ultimate quantities of interest in reactor neutronics, the preceding part indicates that one need only know the scalar flux, not the angular flux. Why then is the neutron transport equation formulated with the angular flux as the unknown, rather than the scalar flux.

4. (15 min.) Diffusion theory calculations for a small spherical thermal research reactor with an infinite graphite reflector have been performed with 1, 2, and 3 groups (upper group boundaries of 1 eV, 100 eV for the lowest two energy groups). Sketch the core and reflector group flux shapes in each case, emphasizing and explaining salient features.

5. (10 min.) Draw curves that illustrate the power, the control rod position and the xenon concentration as a function of time for a "thermal energy" nuclear reactor with the following power history:

   (a) Initial startup to 5 MW and operate for 40 hours
   (b) Increase power to 10 MW for 24 hours
   (c) Shutdown the reactor via scram and remain shutdown for 16 hours.
   (d) Restart to a power level of 5 MW and remain there for 80 hours.

   State all of your assumptions.

6. (20 min.) Fusion by inertial confinement occurs when a D-T pellet is heated and compressed by material being blown away from the pellet under the influence of externally applied energy. Calculate as a function of time the pressure which occurs on a spherical shell of constant radius positioned just at the pellet's surface. The velocity and density of the ablated material on the spherical surface are given below.

The general unsteady momentum equation is

$$\frac{d\vec{P}_{Tot}}{dt} = \rho_1 V_1^2 \vec{S}_1 - \rho_2 V_2^2 \vec{S}_2 + p_1 \vec{S}_1 - p_2 \vec{S}_2 - \vec{F} + m_{Tot}\vec{g} \quad ,$$

where

$$\vec{P}_{Tot} = \int \rho \vec{V} d v$$

v is volume
ρ is the density
$\vec{V}$ is the speed of the fluid
$\vec{S}$ is the surface area the fluid is passing through
p is the pressure at the surface S
F is the net force of the fluid on any structure it is in contact with
m_{Tot} is the total mass
$\vec{g}$ is the acceleration of gravity.

The subscript 1 indicates the entering surface and the subscript 2 indicates the leaving surface.

6. (20 min.) An oxide-fueled fast reactor is to have a core containing 3.5 percent by volume (v/o) $^{239}PuO_2$ (η=2.4), 26.5 v/o $^{238}UO_2$ (η=0.4), 25 v/o stainless steel clad and structure, and 45 v/o sodium as coolant.

(a) Compute the infinite multiplication factor for the core.

Pure Material	Σ_a (cm $^{-1}$)
$^{239}PuO_2$	0.060
$^{238}UO_2$	0.008
Na	4×10^{-5}
SS	0.0015

(b) Compute the diffusion length, material buckling, and the non-leakage probability for the core.

Pure Material	Σ_{tr} (cm $^{-1}$)
$PuO_2 + UO_2$	0.18
Na	0.08
SS	0.25

(c) What would be the radius of a bare critical spherical core?

7. (15 min.) When neutrons slow down in the presence of an absorber, the slowing down density "q" is no longer independent of the energy because neutrons are being lost by absorption.

The change in "q" arises from absorption of neutrons in the interval dE. Then the absorption rate is:

$$\Sigma_a(E)\,\phi\,(E)\,dE$$

and

$$\frac{\partial q(E)}{\partial E}\,dE = \Sigma_a(E)\,\phi\,(E)\,dE$$

We know absorption does not effect the "scattering in" of neutrons, so the rate is:

$$q\,(E')\,\frac{dE}{E'}$$

The rate of neutrons leaving the interval dE is:

$$[\Sigma_s(E) + \Sigma_a(E)]\,\phi\,(E)\,dE$$

Using the above <u>facts</u> derive an expression for q(E) for the energy range E to E_0.

<u>Show all your work!</u>

8. (20 min.) The point kinetics equations are given as follows:

$$\frac{dN(t)}{dt} = \frac{\rho(t) - \beta}{\Lambda} N(t) + \sum_{i=1}^{I} \lambda_i C_i(t) \qquad (1)$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} N(t) - \lambda_i C_i(t); \; i = 1, \ldots, I \quad (2)$$

where standard notation has been used.

An alternative form of the equation describing the neutron population is:

$$\frac{dN(t)}{dt} = \omega(t)\, N(t) \qquad (3)$$

where $\omega(t)$ is the instantaneous inverse reactor period. To solve the above equation for $N(t)$, it is necessary to obtain an equation for $\omega(t)$ in terms of the kinetics parameters and the delayed neutron precursors.

(70%) (1) Starting from equation (3) and using equations (1) and (2), derive a differential equation for $\omega(t)$.

(30%) (2) What is the numerical advantage of using the formulation described by equation (3), if any.