February 1992

Ph.D. Qualifying Examination
Reactor Theory and Experimentation

1. (15 min.) A uranium-fueled bare sphere, of radius R_1, is just critical. A second uranium-fueled bare sphere, of radius $R_2 = 1.25\, R_1$, is also just critical. Derive an expression, under carefully-stated simplifying assumptions, that relates the enrichment of the second sphere to the first sphere.

   Recall that

$$k_{eff} = k_\infty \frac{1}{1 + L^2B^2}$$

   and that the critical geometric buckling for a bare sphere = $\left(\frac{\pi}{R}\right)^2$.

2. (20 min.) Calculate the material buckling for a mixture of 250 moles of graphite per mole of 5 percent enriched uranium. For a critical core of these materials at 20°C, what is the thermal non-leakage probability?

k_∞	=	1.198 for the mix of materials
ρ (graphite)	=	1.6 gm/cm^3
ρ (uranium)	=	18.9 gm/cm^3

Cross Sections

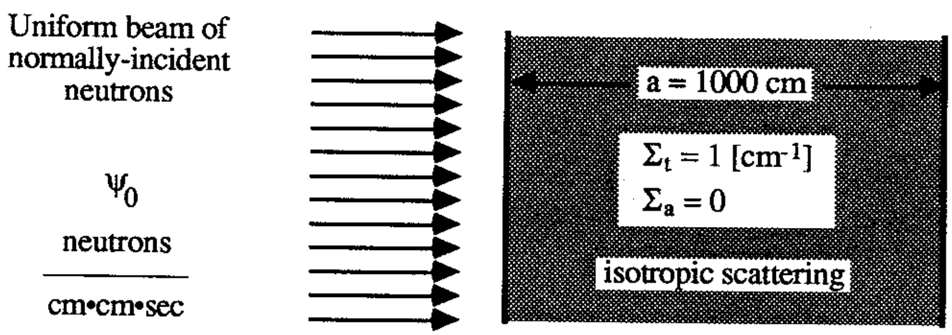
σ_s(graphite)	=	4.8 barns	Scattering
σ_s(uranium)	=	8.3 barns	Scattering
σ_a^{235}	=	694 barns	Absorption
σ_a^{238}	=	2.73 barns	Absorption
σ_a(graphite)	=	0.0034 barns	Absorption

3. (15 min.) An average of five sequential 2-minute counts of a long-lived radioactive source gave a resulting value (mean) of 2162.4 cpm. A second experimenter then used the same source and detector in identical conditions and arrived at a value of 2131.1 cpm based on four sequential 5-minute counts. Comment (and support with calculations) whether the difference between these two results are statistically significant.

Recall that the standard deviation, σ_C, of a quantity C, when $C = A + B$ and A, B are statistically distributed is given by

$$\sigma_C = \left(\sigma_A^2 + \sigma_B^2\right)^{\frac{1}{2}}$$

4. (25 min.) An infinitely wide, uniform beam of neutrons is normally incident on a thick, homogeneous, purely-scattering slab. We are interested in the scalar flux, $\phi(x)$, in the slab. The problem is sketched below:



a) Calculate the scattering source, $S_u(x)$, due to neutrons suffering their first collision.

b) The scalar flux of neutrons that have suffered at least one collision is well-approximated by diffusion theory. Write down the appropriate diffusion equation for this scalar flux. Include boundary conditions.

c) Solve the diffusion equation.

d) What is the scalar flux at the left face of the slab?

5. (20 min.) In a reactor startup channel, one or more boron-trifluoride counters are used.

a) What energy range of neutrons will this type of counter detect? Write the reaction equation.

b) The total kinetic energy liberated in the reaction is about 2.5 MeV. Calculate the size of the pulse produced by the counter assuming:

gas amplification A	=	100
specific ionization W	=	30 eV/ion pair
counter capacitance C	=	10 μf

c) For neutrons with energies above thermal, explain qualitatively counter sensitivity variation.

6. (25 min.) a.) (30%) You are asked to develop a reactivity meter for on-line use in a reactor. Starting from the standard form of the point kinetics equation derive an expression for the reactivity in terms of the neutronic power and the kinetics constants.

b.) (35%) Assume that a reactivity meter is governed by the following equation:

$$\rho(t) = \beta + \frac{\Lambda}{P(t)}\left(\frac{dP(t)}{dt}\right) - \frac{1}{P(t)}\sum_{i=1}^{6} \beta_i \lambda_i S_i(t)$$

with

$$S_i(t) = \int_0^{\infty} P(t-u)e^{-\lambda_i u}du$$

being the power history profile. How would you further approximate this expression for use with standard reactor instrumentation, i.e. power channel and period meter.

<u>Note</u>: List two such approximations.

c. (35%) What are the limitations of the approximations you have made in part (b).