NUEN 301 Study Problems, Second Exam, 2009

Material: Notes through page 121.

1. a) Write down the **time-dependent energy-dependent neutron conservation equation**. Include prompt and delayed neutrons, and include an extraneous source.

   b) **Integrate** each term in this equation over an arbitrary volume $\Delta x \Delta y \Delta z$ and over all energies. What are the **units** of each integrated term? Give a **physical interpretation** of each integrated term – say in words what each term means. Pay special attention to the leakage term.

2. Write down the one-speed **steady-state** diffusion problem for a bare homogeneous cylindrical reactor of radius R and height H. This should be a **complete**, well-posed mathematical problem (which means it must include appropriate boundary and initial conditions). Let the center of the reactor have coordinates r=z=0. Allow for the presence of extraneous sources. Don't try to solve the equation – just write it down.

   Note: in an axisymmetric cylinder $\nabla^2\phi(r,z) = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\phi}{\partial r}\right) + \frac{\partial^2\phi}{\partial z^2}$

3. a) Write down the k-eigenvalue problem for the thermal scalar flux in a bare homogeneous cylindrical reactor of radius R and height H. This should be a **complete**, well-posed mathematical problem.

   b) Describe how this equation can be considered reasonably accurate even though it doesn't explicitly contain the flux of fast neutrons.

   c) Guess a separable solution – a product of a function of r and a function of z. Insert this into the equation and obtain two separate eigenvalue problems for the radial and axial functions (with eigenvalues called B_r^2 and B_z^2, respectively).

   d) Each of the two problems is equivalent to one we solved in class. Write down the solutions, then combine them to obtain the complete solution to the original k-eigenvalue problem.

   e) What is the geometric buckling in a bare homogeneous cylinder? What is the fundamental-mode scalar flux?

4. Define the following parameters, which appear in the Point Reactor Kinetics Equations:

   ρ (give name and give definition in terms of k)

   β (give name and physical definition ["the fraction of …"])

   Λ (give name, math definition, and the name and physical definition of any terms that appear in the math definition)

5. A large commercial power reactor is critical and operating at a steady-state power level of 1 kW (which is very low). The operators extract some control rods part of the way out of the reactor, introducing positive reactivity. Describe what happens:

   a) in the first second or two (is there a rapid change in power?)

   b) in the next few minutes (does the power increase according to some basic functional form?)

   c) after the power gets high enough to start increasing the reactor temperature

6. A nuclear reactor is operating in steady state with a source present.

   a) Is the reactor critical, subcritical, or supercritical?

   b) If the multiplication factor is k_0, what would you need to change it to in order to make the neutron population twice as high?

7. Imagine a setting in which neutrons can move only along the x axis in either the right or left direction. That is, all neutrons are constrained to move in either a mono-directional beam to the right or a mono-directional beam to the left. Suppose that all neutrons have the same speed, and pretend that there are no delayed neutrons. Suppose that when neutrons scatter, half the time they continue in the same direction and half the time they reverse directions.

   For this setting, derive the steady-state conservation equation for the two beam intensities, $I^+(x)$ and $I^-(x)$. Make sure you include absorption, scattering, and fission.

8. How quickly can we drop the power in a reactor from 1 GW to 1 kW? Your discussion should contain both qualitative and quantitative features.

9. If there were no delayed neutrons and no feedback, the basic time constant governing how rapidly the neutron population could change would be the prompt neutron lifetime, l_p, which is shorter than a millisecond. How do delayed neutrons change this – what is the effective neutron lifetime that governs population changes in the presence of delayed neutrons? [Hint: See problem 2 of HW5.]

10. Someone solved a two-region slab-geometry diffusion problem with the following characteristics:

    for $0<x<a$: D_F, $\Sigma_{a,F}$, $\nu\Sigma_{f,F}$,

    for $a<x<b$: D_M, $\Sigma_{a,M}$, $\nu\Sigma_{f,M}$,

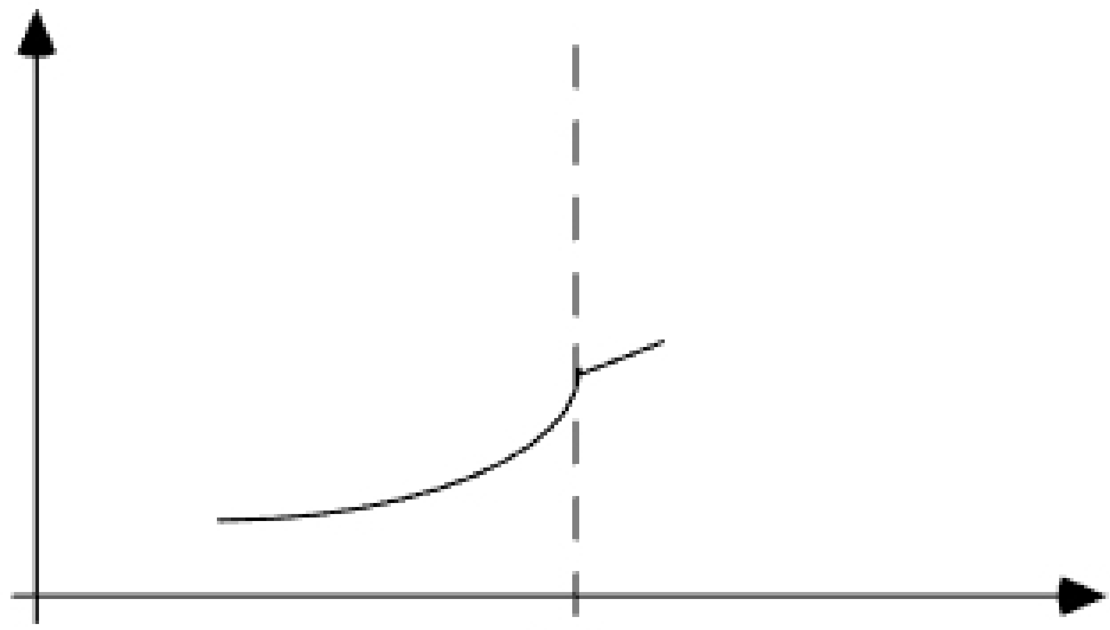
    She found the following solution:

$$\phi(x) = \begin{cases} A\cosh(x / L_F), & 0 \le x \le a, \\ C\exp(x / L_M) + E\exp(-x / L_M) + G, & a \le x \le b. \end{cases} \qquad (1)$$

    a) At what **net** rate per unit area are neutrons crossing **from** region "M" **to** region "F" across the surface at $x=a$?

    b) At what **net** rate per unit area are neutrons crossing **from** region "F" **to** region "M" across the surface at $x=a$?

    c) Suppose a plot of the solution near the interface at $x=a$ looked something like this:



Judging by this picture, which diffusion coefficient is larger, D_F or D_M? If scattering is isotropic in the lab frame in both regions, which region has the shorter mean-free path?

d) Given the solution described by Eq. (1) above, can you deduce what the boundary condition is at x=0? Explain your answer.

11. Fill in the blanks in the table below. One row has been done for you as an example.

reactor shape	B_g^2	$\phi_{fundamental}$
sphere, radius R		
cylinder, $R \times H$		
cylinder, $R \times \infty$		
"cylinder," $\infty \times H$		
rect. parallelepiped, $a \times b \times c$		
rectangle, $a \times b \times \infty$		
slab, $a \times \infty \times \infty$	$\left(\frac{\pi}{a+4D}\right)^2$	$\cos\left(\frac{\pi x}{a+4D}\right)$
cube, width w		