NE150 – Introduction to Nuclear Reactor Theory

Practice Exam

Spring 2007

Chapters 1 and 2

Points

1. The Cross Section

2 a. Give the formula for the macroscopic capture cross section for a mixture of nuclides and define in words each of the terms and provide the units.

2 b. Provide a physical interpretation of the cross section.

2. The Angular Flux and The Boltzmann Equation

4 a. Write the definitions of the one-dimensional, one-energy group scalar flux, $\phi(z)$, and current, $\vec{J}(z)$, in terms of integrals over the angular flux, $\phi(z, \mu.)$.

4 b. Write the one-dimensional, one-group Boltzmann transport equation and in words briefly explain each of the four terms.

4 c. In words, briefly explain the two general approaches for solving the Boltzmann transport equation (i.e. differential and integral).

3. The Diffusion Equation

3 a. Write the P-1 approximation that relates the one-group, one-dimensional angular flux to the scalar flux and current.

3 b. Write Fick's Law that relates the scalar flux to the neutron current and the one-group, one-dimensional neutron diffusion equation.

5 c. Write the two energy group, one-dimensional neutron diffusion equation in matrix form for a typical Light Water Reactor (Note: explain the approximation that are made for applications to a typical Light Water Reactor).

5 d. Use the following set of two energy group data to compute the k for an unreflected cylindrical l reactor with a radius of 50 cm and a height of 90 cm.

$$D_1 = 0.236cm, \Sigma_{a1} = 0.0121cm^{-1}, \nu\Sigma_{f1} = 0.0085cm^{-1}, \Sigma_{12} = 0.0241cm^{-1}$$
$$D_2 = 0.874cm, \Sigma_{a2} = 0.121cm^{-1}, \nu\Sigma_{f2} = 0.185cm^{-1}$$

Note: the buckling for cylindrical reactor is given by:

$$B^2 = (\frac{\pi}{H})^2 + (\frac{2.405}{R})^2$$

Chapter 3

6 *4.* Solution of Reactor Equation

Solve the 1-D neutron diffusion equation for a subcritical, homogeneous medium with a planar source emitting neutrons at a rate of S neutrons per square centimeter per second located at z=0 (i.e. at the boundary of each half-space):

$$\frac{d^2}{dz^2}\phi(z) - \frac{1}{L^2}\phi(z) = 0$$

8 5. Optimum Reactor Dimensions

Use the geometric buckling for a bare cylinder given in problem 3b to determine the optimum height to radius ratio for a bare cylinder.

Chapter 4

6. Scattering Kernel

5 a. Explain what is meant by the scattering kernel $K(E' \to E) = \frac{1}{(1-\alpha)E'}$, for $\alpha E' \le E \le E'$ (e.g. define α , E', E in words and/or equations)

5 c. Use the expression for the average lethargy change, ξ :

$$\xi = 1 + \frac{\alpha}{1-\alpha}\ln\alpha, where \alpha = (\frac{A-1}{A+1})^2$$

to estimate how many collisions would be required to slow a neutron down from 2 MeV to 0.025 eV in hydrogen (A=1), carbon (A=12), and Uranium (U=238).

Chapter 5

7. Breit-Wigner Formula

Consider the single level level Breit-Wigner Formula for reaction *j:*

$$\sigma_j(E) = 4\pi\lambda^2 g_R \frac{\Gamma_n \Gamma_j}{\Gamma^2} \frac{(\Gamma/2)^2}{(E - E_R)^2 + (\Gamma/2)^2}$$

4 Define each of variables in the formula and sketch the cross section versus energy clearly indicating the energies where the cross section reaches it's maximum value and where it achieves half of its maximum.

8. Resonance Integral

3 a. What is the resonance integral? (Answer in words and/or a formula and discuss how it relates to calculating the absorption cross section in the resonance energy region).

6 b. Explain and distinguish the phenomena of energy and spatial self-shielding. Describe the effect of spatial self-shielding on the resonance integral, the resonance escape probability and the k-infinite.

2 c. Explain the impact of temperature on the resonance integral. (Hint: Discuss the Doppler effect in terms of energy self-shielding)

3 d. Use the traditional six factor formula to explain qualitatively the physical impact of changes in the core temperature on the core reactivity. (Hint: How is the resonance integral related to the resonance escape probability). The six factor formula is given as:

$$k_{eff} = \eta \varepsilon p f P_f P_{th}$$

where P_f, P_{th} are the nonleakage probabilities for fast and thermal neutrons, respectively.

Chapter 6

9. P1 Equations

5 a. Express the transport cross section, $\sum_{tr}$, in terms of the absorption cross section, the scattering cross section, and the average cosine of the scattering angle.

5 b. Explain how Fick's Law is derived from the second of the P1 equations.

4 c. Use the definition of the transport cross section from part a to explain whether anisotropic scattering will increase or decrease the leakage rate for a given flux gradient.

15 **Derivations:** Choose **one** of the following two problems.

10a. The P-1 approximation that relates the angular flux to the scalar flux and current is given by:

$$\phi(z,\mu) = \frac{1}{2}\phi(z) + \frac{3}{2}\mu J(z)$$

Write the one-dimensional, one-energy group Boltzmann equation and derive the two P-1 equations. (Note: it is not necessary to show the details of the derivation of the scattering term). Show how the two P-1 equations are combined to provide the diffusion equation.

10b. Consider neutron slowing down in hydrogen with a constant scattering cross section σ_s and no absorption. Write the balance equation for the flux $\varphi(E)$ in an infinite medium where the neutron source is given by $\chi(E)S$ and derive an expression for the neutron flux.