Dec. 20, 1996 Name: ______________________________

Final Examination

NE-630: APPLIED REACTOR THEORY

PART A: Closed books and notes. Hand in before beginning Part B.

1. At a particular location in a homogeneous reactor core, the thermal neutron flux density $\phi_T = 5 \times 10^{12}$ cm^{-2} s^{-1}. At this location the core material has the following thermal averaged cross sections: $\overline{\Sigma}_a = 0.015$ cm^{-1}, $\overline{\Sigma}_s = 0.085$ cm^{-1}, $\overline{\Sigma}_f = 0.010$ cm^{-1}.

   (a) What is the rate per unit volume that thermal neutrons are absorbed without causing a fission (i.e., the reaction rate for (n,γ) reactions) *[5 points]*

   (b) What is the probability that a thermal neutron, when it interacts, will cause a fission? *[5 points]*

2. Make a sketch of the neutron life cycle in a thermal reactor. Start with N fast neutrons and complete the cycle to obtain the number of second generation fast neutrons. Show all neutron losses and gains and identify them with short labels and with expressions using the symbols of the 6-factor formula for k_{eff}. *[10 points]*

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Part B: Open books and notes. Begin only after handing in Part A. *Do Problem 7 and any three of the other problems (Problems 3–6).*

3. For the following one-speed, steady-state diffusion problem (i) sketch the geometry showing your coordinate system, (ii) write the appropriate form of the diffusion equation for each region in which this equation holds, (iii) write the general solution for each region including any particular solution, and (iv) write the boundary/source conditions you would use to determine the values of the arbitrary constants in your general solution.

   (a) An infinite homogeneous slab, composed of a diffusing material, has a thickness $3T$. The slab is irradiated uniformly and normally on its right surface by a neutron beams of intensity I_o cm^{-2} s^{-1}. The slab contains a volumetric source $S(x)$ which varies with the distance x from the left surface as

$$S(x) = \begin{cases} S_o e^{\alpha x} & \text{for } 0 < x < T \\ 0 & \text{for } T < x < 3T \end{cases}$$

   where α is a constant. Finally, at a distance $x = 2T$ from the left surface, there is an infinite plane isotropic neutron source of strength S_p cm^{-2} s^{-1}. Assume the slab is surrounded by vacuum. *[16 points]*

4. Calculate the change in (i) velocity, (ii) lethargy, and (iii) Fermi age of a neutron that goes from 1 MeV to 100 keV in a homogeneous medium composed of atoms with mass number $A = 6$ and whose cross sections are independent of energy (i.e., constant) over this energy range. In particular, $\Sigma_s = 0.15$ cm^{-1} and $\Sigma_a = 0$ between 100 keV and 1 MeV. *[16 points]*

   Useful constants: neutron mass = 1.675×10^{-24} g; 1 eV = 1.602×10^{-12} erg.

5. An experimental assembly is composed of three long thin fuel rods that are composed of ^{235}U and positioned in water such that their axes are parallel and 10 cm from each other. During operation of the reactor in which this assembly is placed, the fission rate in each rod is 10^5 fission cm^{-1} s^{-1} (uniformly along the length of each rod). Estimate the number of neutrons born in these rods that slow to thermal energies per second in a unit volume of water at a position equidistant from each rod. Neglect absorption during slowing down. *[16 points]*

6. Consider a bare homogeneous sphere of radius R that contains a central void of radius R_o. The central void is filled with a perfect absorber. By determining the condition for a non-trivial solution of the buckling equation, show that the critical buckling is

$$B = \frac{\pi}{\overline{R} - \overline{R}_o}$$

   where $\overline{R} = R + \delta$ and $\overline{R}_o = R_o - \delta$, the dimensions corrected for the extrapolation distance δ at a free surface. *[16 points]*

7. A bare spherical critical core 800 cm in diameter is to be constructed from a homogeneous mixture of ^{235}U and graphite. *[32 points]*

   (a) Explain why $\epsilon p \simeq 1$ for this mixture.

   (b) Calculate the critical fuel-to-moderator ratio. Assume room temperature.

   (c) Calculate the mass (in kg) of the ^{235}U needed for criticality.

   (d) Estimate k_{eff} of the core formed by deforming the bare critical spherical core into a cube of the same volume.