NUCLEAR ENGINEERING

QUALIFYING EXAMINATION – FALL 2009

INTERACTIONS, RADIATION, AND MEASUREMENTS

1. These questions refer to the terms "fissile" and "fissionable" as used in the context of current fission power reactors.

a. (2 min) Describe what is meant if a nucleus is described as fissile; that is, define *fissile*.

Describe what is meant if a nucleus is described as fissionable; that is, define *fissionable*.

b. (8 min) For a given nucleus, give the quantities and energy conditions that determine if the nucleus is fissile or fissionable.

2. (10 minutes) When using a high pressure hydrogen proportional counter to measure a fast neutron energy spectrum,

a. What limits the minimum physical size of the detector?
b. How does the typical recoil proton pulse differ from the typical pulse created by absorption of a gamma ray in the proportional counter?

3. (10 min) In the famous "Rutherford backscattering" experiment, alpha particles (Z=2) of approximately 7 MeV were used to bombard a Au (Z=79) film. Rutherford derived the scattering formula by treating an incident alpha particle and a Au target atom as two point charges with their charge numbers equal to their atomic numbers. This assumption, however, is not accurate in describing general ion solid interactions. Explain

(a) why was Rutherford's approach successful in his experiments?

and

(b) under what conditions deviation from Rutherford scattering formula will occur?

4. (15 min) Charcoal found in a deep layer of sediment in a cave is found to have an atomic ratio of $^{14}C / {}^{12}C$ only 15% of that of a sample from a higher level with a known age of 3000 years. What is the age of the deeper layer? $T_{1/2}(^{14}C) = 5730$ years.

5. (20 min) Consider an infinite homogeneous medium that does not scatter particles (pure absorber), and consider a spherical volume whose radius *R* is << one mean free path in the medium.

a) Consider an isotropic point source emitting S_0 particles/s at the origin of the sphere. What is the scalar flux as a function of *r* (*r* = distance from source) inside the sphere?

b) What is the *average* scalar flux in the sphere? (Integrate the scalar-flux function over the volume of the sphere and divide by the volume.) Your solution should be in terms of S_0 and *R*.

c) What happens to the average scalar flux in the limit as *R* gets very small?

d) Suppose that instead of a *point* source the sphere contains a uniformly *distributed* isotropic source of strength *Q* particles/cm^3-s. What is the average scalar flux in the sphere? [Hint: scalar flux integrated over the volume is the total path-length traveled by the particles per second in the volume. The average chord length in a sphere is 4R/3.]

6. (17 minutes) A gold foil, 1 cm in diameter and 0.013 cm thick, was irradiated by a constant thermal neutron flux for a period of 7 days. The foil was counted immediately after the end of the irradiation period and found to have an activity of 100 Bq (2.7 nCi). What was the thermal flux at the point at which the foil was irradiated?

Given: : The foil is pure Au-197; the 2200 m/s cross-section for Au-197 is 98.5 barns; the density of gold is 19.32 g/cm^3, and the half-life of Au-198 is 2.7 days.

7. (20 minutes) Let ${}^{A}_{Z}X$ denote a nuclide with atomic number Z and mass number A, let M'(Z,A) denote the mass of the nucleus in *amu*, let M(Z,A) denote the neutral atomic mass of the nuclide in *amu*, and let m_0 denote the mass of the electron and the positron in *amu*. Assume that the annihilation of 1 *amu* of mass yields 931.5 Mev of energy.

a. What is the product nuclide resulting from positron decay of ${}^{A}_{Z}X$?
b. What is the product nuclide resulting from electron capture by ${}^{A}_{Z}X$?
c. Give an expression for the Q-value in *MeV* associated with position decay in terms of nuclear masses.
d. Give an expression for the Q-value in *MeV* associated with electron capture in terms of nuclear masses.
e. If positron decay is energetically feasible, what is implied about the energetic feasibility of electron capture? Explain your answer.
f. Re-express the Q-value for positron decay in terms of neutral atomic masses by adding and subtracting an equal number of electron masses.
g. What error is made when this is done?

8. (18 min) Preparing to count a radioactive sample, you do a quick 5-minute gross count and a quick 5-minute background count. The gross count is 900 counts and the background is 50 counts.

a) Calculate the optimum counting times for 120 minute total count time.

b) What is the expected optimal gross count and expected background count?

c) What is the expected error in the net count rate?