September 2000

Ph.D. Qualifying Examination
Interactions

1. (15 min.) Briefly discuss the relative merits and uses for the following photon detectors.

   a.) NaI
   b.) HgI
   c.) HPGe
   d.) SiLi
   e.) TLDs
   f.) Photographic film

2. (10 min.) You have been asked to help the laboratory technician optimize the available counting time he uses in the performance of his duties. The laboratory calibration source was counted for 10 minutes and yielded 4,000 counts. A background count, also taken for 10 minutes, gave 2,500 counts. If the available time for sample and background counting is 60 minutes, how should the time allocation between the sample and background counts be optimized?

3. (20 min.) The radionuclide ^{90}Sr (Z=38) decays by beta emission to ^{90}Y (Z=39), which then decays by beta emission to ^{90}Zr (Z=40), which is stable. The half-lives for these two radionuclides are given below:

^{90}Sr	29.12 years
^{90}Y	64.2 hours

   (a.) (20%) What are the mean lifetimes of the ^{90}Sr and ^{90}Y atoms?

   (b.) (20%) What are the specific activities of these two radionuclides (in SI units)?

   (c.) (60%) Starting with a pure sample of ^{90}Sr at time $t = 0$, a researcher finds that the ^{90}Y activity is 3.4 mCi at $t = 72.0$ hours. What was the activity of the ^{90}Sr at $t = 0$?

4. (20 min.) A sample is placed in a counter for exactly 15 minutes and 2128 counts are registered. The sample is then removed and 2561 background counts are observed in exactly 90 minutes. What is the net count rate and the standard deviation of the net count rate from the sample? How long should the sample be counted to be 95% certain that the measured count rate is within +/-5% of its true value? (Recall that the confidence range on the mean for the 95% confidence level is +/- 1.96 times the standard deviation.)

5. (10 min.) Calculate the Q-value for the following (decay) reaction:

$$^{226}Ra \rightarrow {}^{222}Rn + {}^{4}He$$

What is the kinetic energy in MeV of the alpha particle (^{4}He) that is produced?

Use the following atomic mass data:

Mass of one ^{226}Ra atom is 226.025408 amu,
Mass of one ^{222}Rn atom is 222.015760 amu,
Mass of one ^{4}He atom is 4.0026032 amu.

6. (10 min.) There is a serious need for instruments that can measure the energy spectra of neutrons on spacecraft. However, this has proven to be a particularly difficult problem because the fluence of directly ionizing charged particles (protons, helium nuclei, etc.) is many times larger than the neutron fluence. Most detectors cannot distinguish between energy deposited by an incident proton and a recoil proton produced by a neutron, so the typical neutron spectrometer depends on an anticoincidence shield to identify the directly ionizing particle events. One alternative is to use a scintillator that detects the energy deposited as the neutron slows to thermal energy, and the energy deposited when the thermal neutron is captured by boron incorporated in the detector.

(a.) Describe the physical characteristics needed for the detector and electronics needed to make this system work. (You do not need to provide numerical values, just criteria that the system would have to meet.)

(b.) Describe the primary mechanism leading to misidentification of charged particles as neutrons, and identify the system parameter (one of the characteristics you listed in (a) that controls this error).

7. (10 min.) Federal regulations allow for use of two types of photon sources for food irradiation, gamma rays from ^{60}Co or ^{137}Cs or x-rays produced by electrons up to 5 MeV. The primary advantage of the x-ray source is that it can be turned off, and presents no residual radiation hazard. The disadvantage (aside from cost) is the broad spectrum of photon energies produced.

(a.) Assuming that design options for target material are limited to titanium (Z=22), zirconium (Z=40) or tantalum (Z=73) (mostly because of workability and high temperature corrosion properties), which material would you choose to maximize the x-ray yield for a 5 MeV electron beam?
(b.) Considering the angular distribution of bremsstrahlung production, how would you position the electron beam and x-ray target relative to the line from the x-ray target to the object to be irradiated?
(c.) Since the electron beam penetrates the target there is some filtering of the x-rays by the target material itself. Which photon interaction processes dominate the filtering process for bremsstrahlung produced at 5 MeV?
(d.) What changes will this filtering make in the shape of the photon spectrum at the material to be irradiated?

8. (10 min.) Suppose that a neutron (half-life $t_{1/2}$ = 10.6 minutes) leaves the solar corona with a velocity of $v=2.7\text{x}10^8$ m/s in the direction of the earth. Assume the distance from the sun to the earth is $d=1.5\text{x}10^8$ km. What is the probability that the neutron will become a cosmic ray (i.e. enter the earth's atmosphere)?

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9. Suppose you have an engineered, porous material for which the total mass M, in grams, depends on its average linear dimension, ℓ, in centimeters, where

$$\ell = [(\text{maximum edge dimension})+(\text{minimum edge dimension})]/2$$

and

$$M = 1.5 \times \ell^{2.1}$$

Assume the density of the pore-free, solid form of the material is 2 gm/cm^3.

a. (10 min) If the linear attenuation coefficient through the pore-free, material for a beam of a certain energy photon is 0.2 cm^{-1}, calculate the linear attenuation coefficients of these photons through a 1 cm cube and through a 10 cm cube of the porous material, assuming the beams are perpendicularly incident upon the cubes and the location of the incident beam on the face of a cube is not important.

b. (5 min) If the material is comprised of 20 nm diameter solid spheres, what is the total surface area of the 1 cm cube if you assume negligible surface is occupied by the contact points between spheres?