## Theoretical Health Physics Examination

### Spring 2010

**FINAL REVIEW**

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| Total    | 120        |
1. (20 minutes).
A. (15 minutes). Estimate the dose to a monolayer of 10 micrometer diameter spherical cells (isolated in space) that is hit by a beam of protons from an accelerator. Assume that the stopping power of the particles is 10 keV/micrometer, the beam current is $10^{-14}$ amp/cm$^2$, and the exposure time is 10 seconds. List the assumptions that are necessary for you to do this calculation.

B. (5 minutes). Do all of the cells in the monolayer receive the same energy deposited? Explain how you reached this conclusion.
2. (15 minutes). The CSDA range of a charged particle is an inverse function of its mass stopping power integrated over all energies as follows:

$$R_{CSDA} = \frac{E_0}{\int_0^1 \left( \frac{dE}{dx} \right)^{-1} dE}$$

The mass stopping power is defined by the Bethe-Bloch approximation given by

$$\left( \frac{dE}{dx} \right) = 0.3071 \rho \left( \frac{Z}{A} \right) \left( \frac{z^2}{\beta^2} \right) \left[ 13.84 + \ln \left( \frac{\beta^2}{1 - \beta^2} \right) - \beta^2 - \ln(I) \right],$$

where

- $\rho$ is density of the material in which the charged particle interacts,
- $Z$ is the effective charge of the material,
- $A$ is the effective mass of the material,
- $z$ is the charge of the particle passing through the material,
- $\beta = \frac{v}{c}$ is the relativistic velocity of the moving charged particle,
- $I$ is the ionization potential of the material,
- $E_0$ is the initial energy of the particle,
- $\beta$ is related to particle energy by

$$\beta^2 = \left[ 1 - \left( \frac{1}{E/(m_0 c^2) + 1} \right)^2 \right],$$

and

$m_0 c^2$ is the rest mass energy of the particle (proton = 938.28 MeV, alpha = 3727.41 MeV), and $c$ is the speed of light

If a 6 MeV alpha particle (initial $(dE/dx) = 28.1$ keV/µm) has a range of about 50 µm in water, what is the initial energy and stopping power of a proton with the same range?
3. (15 minutes). After a minor earthquake, a subterranean fissure opens to provide a pathway for Rn-222 to diffuse to the earth’s surface or into dwellings. Suppose a dwelling above the fissure has a rarely used, 500 m$^3$ basement that is well sealed from the upper floors and generally has no air exchange. A week after the earthquake, you measure the radon activity to be at the EPA action level of 4 pCi/l. In order that you can design a sub-basement ventilation system to divert the radon away from the house, you must know the infiltration rate of the radon gas into the basement. Estimate the rate. Assume a constant infiltration rate that began at the time of the earthquake. Recall that

$$^{222}Rn \rightarrow^{t_{1/2}=3.8d}^{218}Po.$$
4. (20 minutes). Ion chamber measurements can be carried out under Bragg-Gray conditions or Electron Equilibrium Conditions (Charged Particle Equilibrium, CPE). Answer the following questions that compare the two main conditions under which ion chamber measurements can be carried out.

a. For which photon energy range can the conditions be fulfilled?
   i) Bragg-Gray conditions:
   ii) Electron equilibrium conditions:

b. What should the wall material of the chamber be equivalent to?
   i) Bragg-Gray conditions:
   ii) Electron equilibrium conditions:

c. How thick should the wall of the chamber be?
   i) Bragg-Gray conditions:
   ii) Electron equilibrium conditions:

d. Where do most of the secondary electrons, which are detected in the chamber, arise?
   i) Bragg-Gray conditions:
   ii) Electron equilibrium conditions:

e. Can one determine Kerma under the conditions below, (i) and (ii), and what corrections need to be applied?
   i) Bragg-Gray conditions:
   ii) Electron equilibrium conditions:

f. Why should the ionization chamber be small (in addition to having a good spatial resolution)?
   i) Bragg-Gray conditions:
   ii) Electron equilibrium conditions:
5. (15 minutes). In a Monte Carlo simulation of radiation transport, a probability density function (PDF) gives the probability of an event occurring at a certain point in space; for example, the likelihood of a photon interaction being a particular distance from a previous interaction point, or the probability of each scattering angle in a Compton collision.

a. Given that the probability of a photon interaction per unit path length is $\mu$, show that the PDF for interaction after traveling a distance $x$ is

$$f(x) = \mu e^{-\mu x}$$

Use the fact that the probability of interaction is the product of the probability that a photon at $x$ will interact and the probability that it has not already interacted before it reaches $x$.

b. The quantity used for selecting a variable, such as distance to next interaction, is the cumulative density function (CDF). This is the indefinite integral of the PDF and for this example is

$$F(x) = 1 - e^{-\mu x}.$$ 

To choose the distance $x$, a random number between 0 and 1 is generated and set equal to $F(x)$. The CDF is then inverted (if possible) and solved for $x$. In this example what does the cumulative probability distribution $F(x)$ physically represent, and why must this be the case? For the above $F(x)$, what is the equation for $x$ as a function of a random number $R$?

c. Why is a value of $x$ corresponding to the steepest part of the CDF curve most likely to be obtained? Hint: To which part of the PDF does this correspond?

d. If the CDF is not invertable (i.e. it is too complex), how might $x$ be found?
6. (10 minutes). Explain why the absorbed dose in a small bone region is higher than in the surrounding soft tissue for a spectrum of X rays generated by a 250 kVp X-ray machine, yet is lower for high-energy X rays generated by a megavoltage machine, such as a linear accelerator. Establish the inequalities in terms of absorbed dose.

![Graph showing mass attenuation coefficient vs. energy]
7. (10 minutes). Define or explain the following terms as they are used in internal dose assessment:
   a. source organ
   b. target organ
   c. absorbed fraction of energy
   d. specific absorbed fraction of energy
8. (15 minutes). What is the sodium activity concentration (Bq/cm$^3$) in blood 24 hours a person receives an acute whole body dose of 500 rem from fission spectrum neutrons? Assume 5 liters of blood in the body containing 140 mmoles/liter. The properly averaged resonance cross section may be taken as 0.32 barns. The half-life of Na-24 is 14.95 hours. The flux to dose conversion factor for fission neutrons may be taken to be 3.3 rad/n/cm$^2$. 