NERS555: Introduction to Radiological Physics and Radiation Dosimetry
Assignment 6 & Take-home Exam 2 (double-weight) Fall 2018

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Due Wednesday April 18, 2018 at 5:00 pm. (Slide under door if not there.)

Please note, this is not the final version of the exam.
When it is finalized, there will be an email announcement.

1. Write a paragraph between 500–1000 words, regarding the the impact of radiation equilibrium in medical physics, with respect to radiation dosimetry **and** dose calculation. There should also be at least one reference to Fano's theorem in your text.

2. Sketch a representative central axis depth dose profile that one would obtain from a measurement of dose due to a megavoltage, broad beam of monoenergetic electrons. On the plot identify all the following features, and explain each of them in a sentence or two.

   (a) Surface dose. Provide an expression for it.
   (b) Surface dose, under the assumption of δ-ray equilibrium. Provide an expression for it.
   (c) δ-ray buildup region.
   (d) Depth of onset of δ-ray quasi-charged particle equilibrium.
   (e) The fluence "hump".
   (f) Region of particle loss.
   (g) Energy-range straggling.
   (h) Bremsstrahlung tail. Provide an approximate mathematical form for it.
   (i) What does "broad beam" mean? How would the plot change if the beam was not "broad"?

3. Sketch a representative central axis depth dose profile that one would obtain from a measurement of dose due to a megavoltage, monoenergetic photons. Overlay, on top of this plot, the dose one would calculate in the collision kerma approximation. On the plot identify all the following features, and explain each of them in a sentence or two.

   (a) Surface dose. Why is the surface does not zero?.
   (b) Buildup region. Explain the shape qualitatively.
   (c) Peak region. What determines the depth of the peak dose?
   (d) Fall off region. Explain the shape, and provide an approximate mathematical form.
   (e) Region of transient charged particle equilibrium.
   (f) Explain the offset between the dose and collision kerma in the region of transient charged particle equilibrium.

4. Discuss the meaning of standard and reference dosimetry, and explain how a measurement in a Standards' Laboratory is used to calibrate a beam in a hospital.

5. What is the difference between a large cavity and a small cavity detector? How is the intermediate case handled?

6. How is an ionization chamber reading corrected for recombination effects?

7. Explain the difference between Brag-Gray and Spencer-Attix cavity theory.

8. The ratio of ionization collected in an air gas cavity ionization chamber is $Q_1/Q_2 = 0.95$, for $V_1 = 100$ Volts and $V_2 = 200$ Volts when subject to continuous ionizing radiation.

   (a) What are the physical meanings of "initial" or "columnar" recombination and "general" or "volume" recombination.

   (b) Assuming you know that the chamber is in the "initial" or "columnar" recombination regime between 100 and 200 Volts, what is the recombination correction at 100 and 200 Volts, assuming the ionization in the chamber is nearly all collected?

   (c) Assuming you know that the chamber is in the "general" or "volume" recombination regime between 100 and 200 Volts, what is the recombination correction at 100 and 200 Volts, assuming the ionization in the chamber is nearly all collected?

   (d) What if you do not know the saturation characteristics of this chamber between 100 and 200 Volts. How should you proceed?

9. Consider a hypothetical ion chamber composed of 3mm thick graphite walls containing a sealed cavity of graphite gas at an atmospheric pressure, P_0, of 1 atmosphere. When placed at a measurement position 100 cm from a ^{137}Cs source (662 keV monochromatic photon source), a current of I_0 is measured on an electrometer. (See the accompanying data tables.) You may assume that all correction factors other than mass stopping power ratios and mass attenuation coefficients do not change in scenarios (a), (b), (c) below.

   (a) The pressure of the graphite gas is raised to P atmospheres. *Do not do this experiment at home!* Assuming that the chamber walls remain perfectly rigid, what current is measured under otherwise the same irradiation conditions?

   (b) Now the graphite gas is replaced with dry air at an atmospheric pressure of 1 atmosphere. What current is measured under otherwise the same irradiation conditions? (You may assume that the average Compton electron recoil energy is tightly centered at 200 keV.)

   (c) Now the dry air is raised to an atmospheric pressure of P atmospheres. The pressure is so high than you can assume that all the ionization that is collected is produced by electrons that were set in motion within the cavity. What current is measured under otherwise the same irradiation conditions?

10. The following expressions describe the dose to the sensitive material of a cavity type detector in modern cavity theory.

$$\begin{aligned} D_{\mathrm{g}} &= \frac{1}{V_{\mathrm{g}}} \int \mathrm{d}E_e \int \mathrm{d}\vec{x}\ \varphi_{\mathrm{g}}(E_e, \vec{x}) R_{\mathrm{g}}(E_e, \vec{x}) \\ &= \int \varphi_{\mathrm{g}} R_{\mathrm{g}} \qquad \text{(compact notational form)} \\ &= \left(\int \tilde{\varphi}_{\mathrm{w}}^{0,||} R_{\mathrm{w}} \right) \overline{s}_{\mathrm{w}}^{\mathrm{g}} A_{\mathrm{scat}} A_{\mathrm{att}} A_{\mathrm{fl}} A_{\mathrm{an}} \\ &= K_{\mathrm{c,g}} \left(\overline{\mu}_{\mathrm{en}} \right)_{\mathrm{g}}^{\mathrm{w}} \overline{s}_{\mathrm{w}}^{\mathrm{g}} A_{\mathrm{scat}} A_{\mathrm{att}} A_{\mathrm{fl}} A_{\mathrm{an}} \end{aligned}$$

   (a) Explain what every symbol in the above equations means, including the domains of the integrations.

   (b) Using the compact notational form, what are the expressions in terms of ratios of integrals for

   $$\left(\overline{\mu}_{\mathrm{en}} \right)_{\mathrm{g}}^{\mathrm{w}},\ \left(\overline{s} \right)_{\mathrm{w}}^{\mathrm{g}},\ A_{\mathrm{scat}},\ A_{\mathrm{att}},\ A_{\mathrm{fl}},\ A_{\mathrm{an}}$$

   (c) Under what approximations do the above equations reproduce Bragg-Gray and Spencer-Attix theories?