Theoretical Health Physics Qualifying Examination
Fall 2014.

Question 1 (20 min). a) Describe the phenomena of thermoluminescence and establish the energy diagram for first order kinetics. The equation below show the thermoluminescence process for first order kinetics.

First order:

\[ I(t) = \frac{dn}{dt} = ns \exp\left( \frac{E}{kT(t)} \right), \]

Where the temperature is given as \( T = T_0 + bt \)

- \( E \) the activation energy or trap depth (eV)
- \( t \) time (s)
- \( T \) the absolute temperature (K)
- \( \beta \) linear heating rate [K s\(^{-1}\)],
- \( T_0 \) initial temperature at time \( t = 0 \) (K),
- \( s \) constant characteristic of the electron trap, called the “pre-exponential frequency factor” or “attempt-to-escape frequency” [s\(^{-1}\)]. This parameter is proportional to the frequency of the collisions of the electron with the lattice phonons.
- \( N \) the total trap concentration [m\(^{-3}\)].
- \( n \) concentration of trapped electrons [m\(^{-3}\)] at time \( t \), which is equivalent to the number of trapped holes \( n_h \) in recombination centers.
- \( n_0 \) the initial concentration of trapped electrons [m\(^{-3}\)] at time \( t = 0 \).
- \( k \) Boltzmann's constant (eV K\(^{-1}\)).

b) Integrate the equation above assuming a linear heating rate \( \beta \) and obtain the following equation given below for first order kinetics (show your work).

\[ I(T) = n_0 s \exp\left( \frac{E}{kT} \right) \exp\left( \frac{s}{\tau_0} \int_{T_0}^{T} \exp\left( \frac{E}{kT'} \right) dT' \right). \]

c) Describe qualitatively the temperature profile \( T(t) \), the thermoluminescence intensity \( I(t) \) as a function of time, and the concentration of trapped holes \( n(t) \) in the recombination center as a function of time \( t \). Assume a constant linear heating rate \( \beta \).
**Question 2 (15 min).** A piece of Al is placed between two point sources that emits 100 keV photons and a point source with the same activity that emits 50 keV photons. If the separation between the sources is 1 m, where should the Al be placed such that the dose rate to the aluminum is the same from both sources? State any assumptions?

Given: 
- mass absorption coefficient for 100 keV photons in Al = 0.0386 cm$^2$ g$^{-1}$.
- mass absorption coefficient for 50 keV photons in Al = 0.184 cm$^2$ g$^{-1}$.
**Question 3 (15 min).** A child (25 kg) finds a closed $^{241}$Am source (about 1 mm of plastic surrounds the source) and swallows it. The source stays in the body for 24 hours, but it is intact when it leaves the body. The child suffers from acute radiation sickness (nausea, vomiting), but recovers fully within about a week, and is not sick again. Estimate the effective dose received by the child. Discuss the types of radiation and associated energies leading to this exposure. What is the approximate activity of the source based on your estimate of effective dose?
Question 4 (15 min).

a) Various types of radiation detector systems are used to measure relative dose distributions for diagnostic and therapeutic electron and photon beams. Most detectable signals from a radiation detector are correlated to the energy imparted $\varepsilon$ to the detector. This, in turn, is related to the absorbed dose in the detector, $D_{det}$. List a minimum of eight types of radiation detectors, their signals, and their relationship, including equations or relation to the dose, in the sensitive volume of the corresponding detectors. Indicate if the type of detector characteristics is relative or absolute, passive or active. Follow the table below.

<table>
<thead>
<tr>
<th>Type</th>
<th>Measured Quantity</th>
<th>Relation to $D_{det}$</th>
<th>Characteristics</th>
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<tbody>
<tr>
<td>1 Ionization Chambers</td>
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<td>2 Si Diode detectors</td>
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<td>3 TLD</td>
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<td>4 Fricke dosimeter</td>
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<td>5 Film</td>
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<td>6 Scintillation dosimeter</td>
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<td>7 Gel dosimeter</td>
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<td>8 Calorimetry</td>
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</table>

b) Which dosimetric techniques are suitable for absolute dosimetry and why?
**Question 5 (10 min).** Explain why the dose in a small bone region is higher than in the surrounding soft tissue for 250 kVp X-ray beam, yet is lower for a megavoltage machine, such as a linear accelerator. Establish the inequalities in terms of absorbed dose.
**Question 6 (5 min).** Label the graph in the figure below, which shows a characteristic curve for ionometry. What are the units on the axes in item (6) and to what scale?
Question 7 (20 min).

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.
Question 8. (15 min)

1. (5 min) Define Relative Biological Effectiveness (RBE) and Oxygen Enhancement Ratio (OER). Describe an experiment to measure the OER for a tumor cell line exposed to 200 MeV protons.

2. (10 min) Describe the damage that can occur on normal chromatin exposed to ionizing radiation and how the damage spectrum varies with LET of the incident radiation.