1. (15 min.) Often x-rays are used to image opaque materials, but other radiations can be used as well. A typical test object is called a “step wedge” and consists of a long rectangular piece of plastic that is thin at one end, and the thickness increases in constant steps as you move to the other end. Assume there are 10 different thicknesses, including the minimum and maximum, and that the height of each step is the same.

   a.) Consider a beam of 5 MeV protons and a step wedge with maximum thickness equal to twice the range of the protons placed between the source and a piece of photographic film. Describe the best image of the step wedge that will be produced on the film. Explain the cause of this image.

   b.) Consider a similar experiment using 300 MeV protons, for which the plastic has a significant nuclear absorption cross section, and the same plastic wedge. Describe the image that will be produced with the optimum exposure, and the physical process that produces it.
2. (20 min.) During a planned experiment, a circular gold foil, 0.15 centimeters thick, weighing 1.00 gram is to be exposed to a pure 2200 m/s neutron beam. The foil can be assumed to be aligned perpendicularly to the beam, i.e., the flat surface of the foil faces the beam. After irradiation, the foil is to be counted on a HPGe (high purity germanium detector) and gamma ray spectral analysis is used to determine the activity of the Au-198 produced in the foil at the end of irradiation. If the 2200m/s neutron flux in the beam is 5x10E+12 n per cm2-sec, find the amount of time that the foil needs to be irradiated, including a correction for the neutron flux depression, if the foil is to have an activity of 10 Ci at the end of irradiation.

Some potentially useful information follows:

Natural gold consists of 100% Au-197
Atomic weight of natural gold is 196.967 amu
Density of gold is 19.32 grams per cubic centimeter
The half life of gold 198 is 2.65 days
Depletion of the Au-197 may be ignored.
Neutron capture by Au-198 may be ignored.

Elastic scattering cross section of Au-197 = 0.0 barns
The 2200m/s radiative capture cross section of Au-197 = 100.0 barns
Absorption non 1/ν factor for gold Au-197 = 0.95
The neutron temperature corresponding to 2200m/s = 293.61 degrees K

3. (15 min.) Discuss the relative merits of:

1) a NaI(Tl) detector
2) a standard HPGe detector, and
3) a SiLi detector

to:

a) measure Fe-55 x-ray activity
b) quantify mixed radioactive waste
c) measure N-16 gamma ray activity (hv = 6.13 MeV)
4. (20 min.) An infinite slab of thickness \( t \) contains uniformly distributed, isotropic, and monoenergetic gamma sources of strength \( S_\gamma \) photons/cm\(^2\)-sec. The linear attenuation coefficient of the slab is \( \mu \) cm\(^{-1}\), and the slab is surrounded by vacuum. Using the transport equation, find the uncollided angular flux density and the uncollided scalar flux density in the slab. Place the origin of coordinates at the center of the slab. Express your result for the scalar flux density in terms of the exponential integrals. Recall:

\[
\eta \frac{\partial \psi}{\partial z} + \mu \psi(z, \hat{\Omega}) = S(z, \hat{\Omega}),
\]

\[
E_n(x) = \int_0^1 w^{n-2} e^{-x/w} dw.
\]

5. (20 min.) Consider the \(^6\)Li(n, \( \alpha \)) reaction induced by a thermal neutron.

(25%)(a) Derive the relevant relation and then find the excitation energy in MeV of the compound nucleus.

(25%)(b) Derive the relevant relation and then find the binding energy in MeV of the neutron in the compound nucleus.

(50%)(c) Derive the relevant relation and then find the kinetic energy of the recoil nucleus.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Atomic Mass (amu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^6)Li</td>
<td>6.015122</td>
</tr>
<tr>
<td>(^7)Li</td>
<td>7.016003</td>
</tr>
<tr>
<td>(^4)He</td>
<td>4.002603</td>
</tr>
<tr>
<td>(^3)H</td>
<td>3.016049</td>
</tr>
<tr>
<td>n</td>
<td>1.008665</td>
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</table>
6. (10 min.) For a HPGe detector setup as shown below, sketch what the measured output would look like. Label and briefly explain pertinent features of your sketch. Assume that the source is a relatively high activity $^{137}$Cs source sitting directly on the detector.

![Diagram of HPGe detector setup with $^{137}$Cs source and Pb shields]

$^{137}$Cs

55 $^{137}$Cs

$\beta^-$

$\beta^-$

Pb Shields

"hot" Cs-137 Source

Small HPGe detector

$^{137}$Cs

56 $^{137}$Ba

$\beta^-$

$\beta^-$

$^{137}$m Ba

$\beta^-$

$\beta^-$

$^{137}$m Cs

$\beta^-$

$\beta^-$

$^{137}$m Cs

$\beta^-$

$\beta^-$

$^{137}$m Cs

$\beta^-$

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$^{137}$m Cs

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$^{137}$m Cs

$\beta^-$

$\beta^-$

$^{137}$m Cs
7. (20 min.) The Department of Food Science at Texas A&M wants to build a food irradiation facility. They have asked you to assist them with their shielding calculations, although the design has tentatively been set. The current design assumes that the irradiation source will be $^{60}$Co with an initial activity of 10 MCi. The source will be located in the center of a “cubical room” which has inside dimensions of 5m x 5m x 5m. The concrete walls of the room are 1 m thick. For this arrangement:

a) Calculate the exposure rate at a distance of 3 meters from the unshielded source.
b) Calculate the maximum fluence rate (in photons cm$^{-2}$ s$^{-1}$) on the exterior surface of the shield wall.
c) What is the exposure rate at this exterior point?

Ignore air scatter and scatter from the walls other than the wall between the reference point and the source. The table below and the attached graph may be of use to you in solving this problem. State all assumptions and show all your work.

Useful data: $\Gamma (^{60}\text{Co}) = 13.2$ R cm$^2$ h$^{-1}$ mCi$^{-1}$

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>$\mu$ (1/cm)</th>
<th>$B$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$u_x = 7$</td>
<td>$u_x = 10$</td>
</tr>
<tr>
<td>0.5</td>
<td>0.204</td>
<td>16.6</td>
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<tr>
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<td>0.140</td>
<td>11.0</td>
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<tr>
<td>1.25</td>
<td>0.135</td>
<td>10.7</td>
</tr>
<tr>
<td>1.33</td>
<td>0.130</td>
<td>10.4</td>
</tr>
<tr>
<td>1.5</td>
<td>0.121</td>
<td>9.7</td>
</tr>
</tbody>
</table>
Fluence rate, photons/cm²-sec to give 1 R/hr

Energy fluence rate, MeV/cm²-sec to give 1 R/hr

Photon energy (MeV)