1. (20 min.) For each of the work environments below, select the personnel dosimeter most suitable for establishing primary dose records. In each case, justify your choice. Limit your selections to those given below:

a.) a film badge with 300 mg cm$^{-2}$ plastic filtration over all areas except for a 14 mg cm$^{-2}$ mylar window.
b.) a TLD albedo badge containing both Li-6 and Li-7 elements.
c.) a TLD albedo badge containing both Li-6 and B-11 elements.
d.) a calcium sulfate, manganese activated TLD element in a tissue-equivalent holder.
e.) a proton recoil film badge.
f.) a four-element TLD badge with lithium borate phosphors, 300 mg cm$^{-2}$ plastic filtration over two phosphors, aluminum over the third element, and lead over the fourth element.
g.) a four-element TLD badge with lithium borate phosphors, a thin mylar filter over one element, a plastic filter over a second element, an aluminum filter over a third element, and lead of 1000 mg cm$^{-2}$ covering the fourth element.
h.) a natural lithium fluoride TLD.
i.) a calcium sulfate, dysprosium-activated TLD element in a tissue-equivalent holder.
j.) a two-element TLD with lithium borate phosphors and 300 mg cm$^{-2}$ plastic filters.

Work Environments:

1. an accelerator facility using tritiated targets with 14 MeV deuteron beams.
2. a mixed neutron and gamma field where the gamma dose dominates.
3. an industrial radiography facility using a 320 kV$_p$ x-ray machine.
4. a BWR turbine area and a radiation field dominated by 6 MeV photons.
5. a field of mixed beta and gamma radiation. The average energy of the beta radiation is 200 keV and the gamma radiation has an energy of 800 keV.

2. (15 min.) For practical purposes an end-window GM counter can be considered an aperture detector, i.e., particles entering the front face of the detector are all counted, but nothing else is counted. For a point source emitting radiation isotropically, and a detector face that has a circular surface 90 cm$^2$ in area, what is the ratio of the counts when the detector face is 1.2 cm from the source to when it is 2.4 cm from the source? The point source is on the centered normal vector outward from the detector face. Show all work.
3. (10 min.) A maintenance worker, I. M. Sloppy, had the following exposures during the calendar year 1998. Answer the following questions:

a.) What is an estimate of the committed effective dose equivalent for his intakes? Assume all of the annual limit on intake (ALI) values listed are based on controlling stochastic exposure.
b.) What is an estimate of the annual total effective dose equivalent for Mr. Sloppy?
c.) Were any federal regulations exceeded? Explain your answer.

<table>
<thead>
<tr>
<th>External Exposure</th>
<th>Intake</th>
<th>ALI (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st quarter 125 mrem</td>
<td>$^{137}$Cs (D)</td>
<td>$5 \times 10^4$ Bq</td>
</tr>
<tr>
<td>2nd quarter 280 mrem</td>
<td>$^{137}$Cs (D)</td>
<td>$7 \times 10^4$ Bq</td>
</tr>
<tr>
<td>3rd quarter 220 mrem</td>
<td>$^{137}$Cs (D)</td>
<td>$1 \times 10^5$ Bq</td>
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<tr>
<td>4th quarter 460 mrem</td>
<td>$^{90}$Sr (Y)</td>
<td>$4 \times 10^4$ Bq</td>
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<tr>
<td></td>
<td>$^{90}$Sr (Y)</td>
<td>$9 \times 10^4$ Bq</td>
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<tr>
<td></td>
<td>$^{60}$Co (Y)</td>
<td>$2 \times 10^4$ Bq</td>
</tr>
<tr>
<td></td>
<td>$^{60}$Co (Y)</td>
<td>$8 \times 10^4$ Bq</td>
</tr>
</tbody>
</table>

4. (20 min.) One recent proposal of the Environmental Protection Agency is an amendment to the safe drinking water act wherein the dissolved radon level in public drinking water systems would be regulated to limit household airborne radon concentration. An in-line filter is one method for accomplishing mitigation that will be required in some systems to meet the proposed dissolved-radon concentration limit. You have been asked to assess the external exposure hazard, if any, afforded by such a filter. The filter in question will be located in a person’s backyard near their water supply line.

Given:
The average dissolved radon concentration for the system in question is 3,000 pCi per liter.
Household water usage is 500 liters per day.
Filter efficiency for radon collection is 98%.
Filter efficiency for non-gaseous radionuclides is 100%.

a.) Determine the exposure rate five meters from the filter assembly, in R per hour, after the filter has been on-line for one year.
b.) What is the approximate dose rate based on your calculated exposure rate?
c.) Does your calculated dose rate exceed any federal (10CFR20) limits for exposure of members of the general public?
d.) How would your answers change if there was a significant radium-226/228 content in the supply-line water?

List/discuss all of your assumptions.
5. (10 min.) Explain what information would be necessary (and why this information would be necessary) to perform a detailed fetal dose assessment for maternal radionuclide burdens that were introduced during gestation.

6. (15 min.) A source produces a gross count rate of 100 cps (i.e., 100 cps are produced by the source and the background). If the total counting time for counting both the gross counts and background counts is fixed at two hours, what is the maximum background count rate that yields 1% accuracy?

The following formulae are from Knoll:

\[ \sigma_s = \left( \frac{S + B}{T_{S+B}} + \frac{B}{T_B} \right)^{1/2} \]

\[ \left[ \frac{T_{S+B}}{T_B} \right]_{opt} = \sqrt{\frac{S + B}{B}} \]

7. (10 min.) A neutron radiography facility has received a large contract for inspection of small plastic parts. This requires using a much lower neutron energy than has been used previously. As facility Health Physicist, you have been asked to review the impact of this change on the health physics facilities and procedures currently in use.

a.) Discuss the adequacy of the current shielding, which utilizes boron loaded polyethylene blocks and provides a modest safety margin with the 2 MeV neutrons currently used.

b.) Discuss the personnel dosimetry system, which is based on \(^7\)Li and \(^6\)Li albedo dosimetry measurements.
8. (20 min.) To meet state licensing requirements, you need an active radiation monitor with a sensitivity of 10 nGy per hour, which can be left operating unattended for long periods of time. After some investigation the choice has been narrowed to an atmospheric ion chamber or a plastic scintillator. Both detectors would operate in current mode, i.e., you measure the current from the ion chamber or photomultiplier, not the individual pulses. You do not want to use detector currents less than $10^{-12}$ amps in order to avoid excessive errors due to electrometer drift. Assume

$W$ in air is 32 ev/ion pair
$1.6 \times 10^{-19}$ J/ev
clectron charge = $1.6 \times 10^{-19}$ coulombs
photomultiplier gain of $10^4$
combined photon collection efficiency and cathode sensitivity of 0.2
scintillator sensitivity = 100 ev/photon
density of scintillator is 1 g/cc
density of air = $10^{-3}$ g/cc

a.) Calculate the minimum ion chamber volume to achieve the required sensitivity. What is the relative standard deviation of a 1 second measurement (assuming the radiation source is constant)?

b.) Calculate the minimum scintillator volume to achieve the required sensitivity. What is the relative standard deviation of a one second measurement with this detector is exposed to 10 nGy/hr?