1. (20 min.) Assume:

- 300,000 occupationally exposed radiation workers
- Average annual radiation exposure:
  - 0.275 rad photon absorbed dose
  - $2 \times 10^6$ fast neutrons per sq. cm (fission spectrum)
  - 0.030 rad internal alpha absorbed dose (whole body)
- Macroscopic fast neutron scattering (energy absorption) cross section for tissue = 5 cm$^2$g$^{-1}$

A. Calculate the average annual equivalent absorbed dose (i.e., the dose equivalent) to this group based on current regulatory guidance.

B. What effect would proposed changes in the quality factor (Q) values (i.e., NCRP-91 recommendations) have on the dose equivalent value calculated in Part A?

C. Using accepted risk factors, how many excess cancer cases would you anticipate in this group over their lifetime from a dose equal to one year's exposure as described here?

2. (20 min.) For each of the 5 different radiation exposure scenarios shown in the following table, describe the expected biological effects that would be observable in the first ten weeks after exposure. Assume that the exposures are acute, there is no recent history of exposure, and that reasonable medical care is provided. Briefly explain the uncertainties in scenario (e).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Exposure</th>
<th>Exposure Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0.25 Gy gamma</td>
<td>Whole Body</td>
</tr>
<tr>
<td>b</td>
<td>3.0 Gy gamma</td>
<td>Whole Body</td>
</tr>
<tr>
<td>c</td>
<td>3.0 Gy gamma</td>
<td>Hands</td>
</tr>
<tr>
<td>d</td>
<td>3.0 Gy beta</td>
<td>Hands</td>
</tr>
<tr>
<td>e</td>
<td>0.5 Gy slow neutron, 1.0 Gy fast neutron, 1.0 Gy gamma</td>
<td>Whole Body, Mixed Field</td>
</tr>
</tbody>
</table>

3. (10 min.) According to the methodology of ICRP 26 and 30, define the annual limit on intake (ALI). How is it calculated for a given radionuclide? (Be specific - use equations and symbols as needed).
4. (15 min.) 100 mCi of Co-60 in a solution is spilled over a circular area 50 cm in diameter. What is the gamma ray dose rate at a height of 30 cm? Note that for a spill of uniform activity per unit area (Caucieus per unit area) of a gamma emitter whose source strength is \( \Gamma \), the dose rate at a point \( p \) at a distance \( h \) from an infinitesimal area \( dA \) is given by

\[
\Gamma (Co-60) = 1.32 \text{ (R-m}^2/\text{Ci - hr)}
\]

5. (10 min.) Beta particles are found to be emitted with a continuous energy distribution ranging from zero to the theoretically expected value based on mass-energy considerations for the particular beta transition. This seems to violate energy-mass conservation laws.

a. (20%) What process occurs in beta decay that accommodates the requirement for energy mass-conservation?

b. (20%) When the energy of a beta particle is stated, what energy is given on the chart of the nuclides.

c. (60%) Design an experiment to determine the beta "energy" of emission for a particular radionuclide.
6. (20 min.) A nuclear worker, I.M. Sloppy, had the following exposures during the last calendar year. Assume that the facility was working under the recommendations of the ICRP as contained in ICRP Publications 26 and 30 and answer the following questions.

a) Did the worker exceed the dose limitation system specified by the ICRP?
b) What is the effective whole body dose equivalent for the exposures due to internally deposited radionuclides?
c) What is the total dose equivalent from these exposures?

**EXTERNAL**

1st Qtr. - 515 mrem
2nd Qtr. - 273 mrem
3rd Qtr. - 610 mrem
4th Qtr. - 273 mrem

**INTERNAL**

137Cs - 5 x 10^4 Bq (D)
137Cs - 7 x 10^3 Bq (D)
137Cs - 1 x 10^5 Bq (D)
60Co - 2 x 10^4 Bq (Y)
60Co - 5 x 10^3 Bq (Y)
90Sr - 5 x 10^3 Bq (Y)
90Sr - 9 x 10^4 Bq (D)

From ICRP Publication 30, Part 1 the ALTs are:

137Cs = 6 x 10^6 Bq (D)
60Co = 1 x 10^6 Bq (D)
90Sr = 1 x 10^5 Bq (Y)
90Sr = 7 x 10^5 Bq (D)

(bone surf)
8 x 10^5 Bq

7. (10 min) In an accident, two species of α-active atoms of comparable half-lives are released into the air in a closed room. Species 1 reacts chemically and physically to form stable molecules and molecular clusters; species 2 initiates a sequence of reactions that leads to its growth into stable particles in the 1-2 μm range. Assuming both atoms have comparable decay energies, discuss the factors which determine the risk to personnel who enter the room.
8. (20 min) Suppose, for the purposes of computing removal of radioactive aerosol to the respiratory system, that the regions of the respiratory system can be treated as if they were straight tubes in series with laminar airflow. If the cells of the tracheobronchial (T-B) region are 2 times as likely, per decay, to undergo mutation as cells in the nasopharyngeal (N-P) region, what is the risk of cancer induction of the two regions relative to each other under the conditions specified below?

In a room, a rare gas actinide has an activity of 20 pCi/liter and its decays result in the formation of radioactive atoms which are in equilibrium with the parent. These daughter atoms go either to a molecular or to a clustered state with corresponding diffusivities \( D_m \) and \( D_c \) respectively. Assume 1/2 of these radioactive daughter atoms end up in each state. In the questions, refer to the following data:

\[
D_m = 5 \times 10^{-2} \text{ cm}^2/\text{sec} \quad D_c = 1 \times 10^{-5} \text{ cm}^2/\text{sec} \quad Q = 200 \text{ cm}^3/\text{sec}
\]

Assume the fractional penetration of particles through a tube is given by

\[
F_p = \exp(-100 \mu) \quad \text{where } \mu = DL/Q
\]

Here,

\[
\begin{align*}
Q &= \text{gas volumetric flow through tube in cm}^3/\text{sec}, \\
L &= \text{length of tube in cm}, \\
D &= \text{diffusion coefficient of particle in cm}^2/\text{sec}.
\end{align*}
\]

<table>
<thead>
<tr>
<th>Respiratory Region</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-P</td>
<td>1 cm diameter; 20 cm long</td>
</tr>
<tr>
<td>T-B</td>
<td>0.5 cm dia.; 30 cm long</td>
</tr>
<tr>
<td>Alveolar</td>
<td>0.1 cm dia.; 100 cm long</td>
</tr>
</tbody>
</table>