1. (15 minutes) At a university radiochemistry facility, a cyclotron produces large activities of radioactive gases with short half-lives ($^{11}\text{C}$, $^{13}\text{N}$, $^{15}\text{O}$ and $^{18}\text{F}$). These nuclides are transported via a carrier gas through plastic tubing into a laboratory hood. Radiochemical processing occurs in a shielded reaction vessel in the hood. An accident occurred when a ceiling tile dislodged and knocked loose the gas line, allowing $^{15}\text{O}$ to be released at a constant rate into the laboratory room air.

Assume instant and complete mixing of $^{15}\text{O}$ with room air. Room ventilation occurs only through hood exhaust, and volume exhaust rate is 30 m$^3$/min. Room size is 6 m x 6 m x 3 m

$^{15}\text{O}$ release rate = $2.6 \times 10^9$ atoms/s

$^{15}\text{O}$ half life = 122 s

a. What type of radiation do $^{11}\text{C}$, $^{13}\text{N}$, $^{15}\text{O}$, $^{18}\text{F}$ emit?

b. Will room ventilation or radioactive decay be the dominant removal mechanism? Justify.

c. Identify two health physics concerns which would result from the use of plastic transport lines for $^{11}\text{C}$, $^{13}\text{N}$, $^{15}\text{O}$, $^{18}\text{F}$.

2. (15 minutes) In the early days luminous dials contained $^{226}\text{Ra}$ ($T_{1/2} = 1600$ years). The radium solution was applied with paintbrushes to the hands and dials of the clocks. The dial painters, a profession traditionally practiced by women only, wetted the paintbrushes frequently with their lips causing a partial incorporation of the radium radioisotope. Calculate the 50-year committed dose equivalent of a dial painter after a single, acute incorporation of 1 µg of $^{226}\text{Ra}$, if the whole-body biological half-life of radium is assumed to be 300 days. Assume that the radium decay chain to the stable lead isotope $^{208}\text{Pb}$ yields a total energy of 33 MeV of $\alpha$ particles, 3 MeV of $\beta$ particles, and 1.5 MeV of $\gamma$ rays. Assume the weight of a person is 50 kg. State your assumptions in developing your calculations.

3. (15 minutes total) List the types of damage to chromatin that may occur when a mammalian cell is exposed to ionizing radiation.
   a. (5 minutes) List them in order of ease/speed of repair.
   b. (5 minutes) Discuss how the spectrum of chromatin damage varies with LET and dose.
   c. (5 minutes) Explain why damage from ionizing radiation to chromatin is harder to repair than damage induced by enzymatic action.
4. (15 minutes) Suppose an accident produces an externally mixed radioactive aerosol (externally mixed means distinct particles) consisting of one set of particles of 100 Bq per liter of air (Bq/L) with 1 minute half-life and another set of particles of 1 Bq/L with 1 hour half-life. These 2 distinct sets of particles differ in their respiratory deposition properties. If inhalation of the mixed aerosol results in 50% respiratory deposition efficiency and retention for the shorter-lived material and 10% respiratory deposition efficiency and retention for the longer-lived material, develop a formula giving the activity of the material deposited in the body as a function of time for an individual breathing at the rate of 10 L/min who is exposed to the aerosol from the time it is formed. Assume no mechanical or biological clearance.

5. (20 minutes)
   a) (3 minutes) Explain the difference between kerma and absorbed dose.
   b) (7 minutes) Name the condition which must occur in order for kerma to equal absorbed dose, and describe the target geometry which assures that this condition is achieved.
   c) (10 minutes) Which is larger, kerma or absorbed dose, in each of the cases below? Explain the reasoning which leads to your answer.
      a. At a point 10 micrometers inside a sphere of tissue surrounded by air and in a uniform field of 1 MeV photons.
      b. In dry air 10 micrometers from the surface of a tissue sphere irradiated by a uniform field of neutrons.

6. (10 minutes) How long will it take for 99.9 % of $^{137}$Cs to decay, if its half-life is 30 years?

7. (15 minutes) Three collimated gamma-ray beams of equal fluence rates, whose quantum energies are 2, 5, and 10 MeV, respectively, are incident upon a 5 cm thickness of lead. What is the ratio of the emergent uncollided fluence rates?

\[
\begin{align*}
\mu_{2\text{MeV}} &= 0.0455 \text{ cm}^2/\text{g} \\
\mu_{5\text{MeV}} &= 0.0424 \text{ cm}^2/\text{g} \\
\mu_{10\text{MeV}} &= 0.0484 \text{ cm}^2/\text{g} \\
\rho_{\text{Pb}} &= 11.35 \text{ g/cm}^3
\end{align*}
\]

8. (15 minutes) A worker has an uptake of a nuclide with a physical half-life of 2.5 days and a biological half-life of 3±1 days. Assume that the physical half-life has negligible uncertainty and the nuclide remains uniformly dispersed while in the body (as would tritium, for example). If the initial dose rate is 2 rad/day,
   a) (5 minutes) What is the committed dose, and
   b) (10 minutes) What is its associated uncertainty?