1. (10 minutes) Define stochastic and deterministic effects of radiation and give two examples of each type of effect. If it was proven that all biological effects of radiation have defined thresholds, discuss the impact of thresholds on the current recommendations for protecting workers from occupational exposures.

2. (15 minutes) You are called by a physician working in an emergency room. A radiation worker has drunk 10 grams of fully tritiated water ($^{2}H_{2}O$) in an apparent suicide attempt. The physician has calmed the patient with sedatives but the patient is not isolated from medical personnel. He wants you to suggest treatment and what radiological precautions he might have to take. What do you tell the doctor? Tritium has a biological half-life of 9.4 days.

3. (20 minutes) Describe in your own words the basic concept of cavity theory (25%). What are the two principle assumptions of Bragg-Gray cavity theory (25%)? Express in mathematical terms the Bragg-Gray relationship taking into consideration the energy spectrum of the charged particles crossing the cavity. Let us assume that the medium is water (w) and the detection volume is a gas (g), where the charge generated can be collected and measured, what is the absorbed dose to the gas cavity and the medium (50%)?

4. (20 minutes) $^{41}$Ar emits a 1293 keV gamma 99.1% of the time. Using the information below, calculate the submersion dose rate for a semi-infinite volume of $^{41}$Ar, i.e., the dose to someone on the ground submerged in an infinite cloud, which has a uniform source strength of $S \text{ Bq/m}^3$:

- $\mu_{en}/\rho \text{ (air)} = 0.242 \text{ cm}^2/\text{g} \text{ (at 1293 keV)}$
- $\mu_{en}/\rho \text{ (tissue)} = 0.0265 \text{ cm}^2/\text{g} \text{ (at 1293 keV)}$
- $\mu/\rho \text{ (air)} = 0.147 \text{ cm}^2/\text{g} \text{ (at 1293 keV)}$
- $\mu/\rho \text{ (tissue)} = 0.160 \text{ cm}^2/\text{g} \text{ (at 1293 keV)}$
- density of air = 1.0 g/cm$^3$
- density of tissue = 1.0 g/cm$^3$

5. (10 minutes) A 1-µm diameter sphere of tissue, embedded near the center of a much larger tissue volume, is exposed to a point source of fluorescence X rays located 1 µm from its center. The range of the photoelectrons produced by these photons is 0.5 µm. List the requirements for secondary particle equilibrium and indicate if each requirement is met in this case.

6. (15 minutes) If a tissue, made up of 9-µm diameter spherical cells (the mean chord length for random lines through the cell is 6 µm), is exposed to 1 MeV neutrons and receives an absorbed dose of 0.01 Gy, what fraction of the cells will receive energy deposited by a recoil proton track? Assume that the average stopping power of recoil protons produced by 1 MeV neutrons is 70 keV/µm, the mass of each cell in the tissue is $38 \times 10^{-14}$ kg, and that the dose is entirely due to the recoil protons. List any other assumptions that you find you need to make.
7. (15 minutes) “Hot” particles, in the context of radiation safety, are small quantities of highly radioactive material (tens of micrometers or smaller in nominal diameter). They are usually considered to be very hazardous due to the possibility of their direct inhalation and deposition in the upper respiratory tract. A second and possibly more hazardous property of such particles is their microscopic fragmentation. This fragmentation can occur via radioactive decays that essentially shatter the surface of the particle, resulting in the emission of extremely small fragments of the material. Assume, as a model system, 10 \( \mu \)m radius particles containing \( 6.02 \times 10^{13} \) molecules of \( ^{134}\text{CsCl} \), where the decay constant of \( \lambda_{\text{Cs}} = 1.1 \times 10^{-9} \text{s}^{-1} \). Assume here that a single decay within the 10 \( \mu \)m particle liberates, on average, ten CsCl molecules. How long would be required for ten 10 \( \mu \)m particles per m\(^2\) to generate 0.01 Bq/liter of the ultrafine particles?

8. (15 minutes) A 1999 accident at a nuclear fuel processing plant in Tokaimura, Japan was the result of having too much liquid uranium solution present in a mixing tank. The solution in the tank reached criticality and workers in the immediate area were suddenly exposed to very high neutron and gamma fluences. Since the natural sodium in the human body is activated when exposed to a neutron fluence, the doses that the employees received from the accident could be deduced hours later by measuring the radiation emitted from the body after the exposure. The effective doses to the three employees closest to the tank were found to be about 18 Sv, 10 Sv, and 2.5 Sv. One employee attempting to stop the chain reaction after the accident received about 120 mSv. Around 100 people received between 1 and 10 mSv.
   a. Suggest a detector type, that would uniquely identify the specific radiation following neutron absorption in natural sodium, and give the two gamma energies expected to be seen in the measurement. Explain the reasoning behind your choice (67%).
   b. If any, how many deaths are expected and how many people would show symptoms of radiation sickness (33%).