1. (15 min) You are in charge of waste operations at CCNL and receive a 200 liter drum of waste (gross weight = 190 kg) from the Transuranic Processing Facility. The manifest accompanying the drum shows that the drum (tare weight = 5 kg) contains:

\[< 10 \text{ g Th} \]
\[< 25 \text{ g U} \]
\[< 4 \times 10^{10} \text{ dpm gross alpha} \]

Is this drum TRU waste*?
State any assumptions.

* Transuranic (TRU) waste is defined as waste material not classified as HLW or Spent Fuel that is contaminated with alpha-emitting radionuclides with a half-life > 20 years of elements with atomic number greater than 92 and a concentration > 100 nanocuries per gram of waste.

2. (10 min) Compare the chemical toxicity of natural uranium to its radiotoxicity. Assume that the DAC (radiotoxicity) and TLV (chemical toxicity) are equivalent measures of toxicity. Repeat the comparison for 10% enriched uranium.

\[^{238}\text{U specific activity} = 3.3 \times 10^5 \text{ pCi/g-nat U} \]
\[^{235}\text{U specific activity} = 1.54 \times 10^4 \text{ pCi/g-nat U} \]

TLV of uranium = 0.2 mg/m\(^3\) in air

DAC of \(^{238}\text{U}\) and \(^{235}\text{U}\) in air = \(6x10^{-10}\) μCi/mL

3. (20 min) A closed, 60 m\(^3\) room is suspected to have a high level of radon accumulation. To investigate this question, you first fill a 100 mL Lucas, or scintillation, cell with filtered room air and find 1 Bq of activity present. During a 10 second sampling period, you then draw 1 liter of room air through an absolute sampling filter arranged so that you can measure the activity deposited on the filter for 20 seconds without any delay following the cessation of air flow. Assume that \(^{222}\text{Rn}\) and its decay products are the only radioactive atoms present in the room. The decay scheme is:

\[^{222}\text{Rn} \rightarrow ^{218}\text{Po} \rightarrow ^{214}\text{Pb} \rightarrow ^{214}\text{Bi} \]

\[t_{1/2} = 3.82 \text{ days} \]
\[t_{1/2} = 3.05 \text{ min} \]
\[t_{1/2} = 26.8 \text{ min} \]
\[t_{1/2} = 19.7 \text{ min} \]

If this 1 Bq per 100 mL is the constant background level of \(^{222}\text{Rn}\) in the room, at what volumetric flow rate should the room air be recirculated through a high efficiency filter in order that the activity of the first daughter atom be 1% of its secular equilibrium value?
4. (10 min.) There are five basic requirements for a respiratory program regardless of whether or not radiation is an airborne hazard in the workplace. List these five requirements and state what is needed to formulate a minimally acceptable respiratory protection program.

5. (10 min.) **Qualitatively, discuss** whether a 20% HpGe detector or a 3x3 NaI(Tl) detector would have the lowest LLD for a particular radionuclide concentration.

Remember, the formula for Lower Limit of Detection (mCi g⁻¹ or mCi cm⁻³) is:

\[
LLD = \frac{4.66\sqrt{B}}{T \cdot 37,000 \cdot \varepsilon \frac{Y}{d} \cdot V \cdot Y},
\]

where \(B\) is the number of background counts in the peak to be analyzed, \(T\) is the acquisition time in seconds, 37,000 is the number of disintegrations per second per microcurie, \(\varepsilon\) (= ec/d) is the counting efficiency of the instrument being used in disintegrations per second, \(V\) is the sample size (in units of g or cm³), \(Y\) is the fractional radiochemical yield (when necessary).

6. (10 min.) Over the years there have been a number of approaches taken to neutron dosimetry. One popular approach is to use thermoluminescence dosimeters (TLDs) in a personnel monitoring badge.

(a) What TLD materials are used in the badge?
(b) How do these materials detect neutrons?
(c) What are some pitfalls in the use of these types of TLDs in a mixed neutron and gamma radiation environment?

7. (15 min.) Answer the following questions regarding the new 10CFR20 regulations on occupational radiation exposure:

(a) What is a planned special exposure and what exposure limits apply?

(b) How are medical exposures (i.e., diagnostic or therapeutic) accounted for in keeping up with the exposure history of the individual, if the exposed individual is also an occupationally exposed worker?

(c) What is a "declared pregnant female" and what is the radiation exposure limit for the embryo/fetus?

(d) If the limit set for the embryo/fetus has been exceeded at the time of the declaration of pregnancy, what responsibility does the licensee have?
8. (10 min.) You have been asked to set up a radiation protection program at a facility that manufactures precision castings. The protection program is needed because the castings are made using naturally occurring thorium sands for creating molds for the parts. There is approximately 10 tons of the sand on site in an open-sided shed at the rear of the building. The radiation field is approximately 60 mR/hr at the side of the shed. The company has been in business doing this fabrication for over 20 years. Outline the basic program you would recommend. Discuss what remedial work might be necessary and what baseline measurements might be necessary.

9. (20 min.) The wicked director of the NSC has directed you "check his calculation" concerning his cesium-137 production program. His idea is to irradiate 100% enriched $^{136}$Xe ($\sigma_\gamma = 0.26$ barns) to make pure $^{137}$Cs, which can be induced to plate onto spherical thin metal shells 1 foot in diameter. A test run has shown that plating efficiency is 99% (i.e., 99% of the cesium plates uniformly on the outside of the spherical shell). For an initial charge of 10 grams of $^{136}$Xe and 100 hours of thermal neutron exposure at $1.0 \times 10^{13}$ n/cm$^2$-s (2200 m/s flux), what is the dose at the center of the sphere? (Cs-137 yields a 662 keV photon 85% of the time.) List all assumptions.