(20 min) Cobalt-58 and cobalt-60 are two radioisotopes which are routinely monitored in the environment around nuclear power plants. Partial decay schemes for each are listed below:

\[
\begin{align*}
58^{\text{Co}} & \quad T_{\text{max}} (\beta^+): & 475 \text{ keV} & \quad (14.9\%) \\
 & \quad E_{\gamma}: & 811 \text{ keV} & \quad (99.4\%)
\end{align*}
\]

\[
\begin{align*}
60^{\text{Co}} & \quad T_{\text{max}} (\beta^-): & 318 \text{ keV} & \quad (100\%) \\
 & \quad E_{\gamma}: & 1.173 \text{ MeV} & \quad (100\%) \\
 & \quad E_{\gamma}: & 1.333 \text{ MeV} & \quad (100\%)
\end{align*}
\]

a.) Speculate on how these two radioisotopes might be produced in a reactor neutron environment given the following major and minor components in steel alloys used within plant equipment. List \textit{one} production mechanism for Co-58 and \textit{two} for Co-60.

\[\text{Naturally-Occurring Stable Isotopes}\]

\begin{align*}
\text{Major components:} & \quad \text{Chromium} & \quad 50^{\text{Cr}}, \, 52^{\text{Cr}}, \, 53^{\text{Cr}}, \, 54^{\text{Cr}} \\
 & \quad \text{Iron} & \quad 54^{\text{Fe}}, \, 56^{\text{Fe}}, \, 57^{\text{Fe}} \\
 & \quad \text{Nickel} & \quad 58^{\text{Ni}}, \, 60^{\text{Ni}}, \, 61^{\text{Ni}} \\
\text{Minor Alloys:} & \quad \text{Manganese} & \quad 55^{\text{Mn}} \\
 & \quad \text{Cobalt} & \quad 59^{\text{Co}}
\end{align*}

b.) A given environmental sample is counted on a HPGe semiconductor detector. A subsequent analysis of the gamma spectrum reveals that small concentrations of both cobalt radioisotopes exist in the sample. What peaks would you expect to find in the spectrum provided the count time is relatively long?

For each peak, give its energy in keV and briefly describe what physical interactions must have occurred to register counts in this particular channel. You may assume that the detector presents a relatively large solid angle to the source photons and that the detector/sample is enclosed within a lead shield.
2. (10 min) There are three categories of exposed individuals which form the bulk of our current knowledge of cancer and genetic risks from exposure to ionizing radiation. Of these three data sources, briefly describe the most widely utilized source of data and comment on its usefulness in establishing dose limits for occupational radiation workers.

3. (25 min) In understanding in detail the health impacts of radiation exposure, the health physicist must quantify more than solely the radionuclides that are present. Specifically, information on the chemical and physical conditions which the radioactive atoms are also needed.
   a.) (10 min) Since radiation damage results from nuclear decay processes, why are the chemical and physical conditions which the radioactive atoms assume important?
   b.) (15 min) Describe a program of measurement to determine the physical form of airborne radioactive species, i.e. the activity-size distribution, in as much detail as is required for the assessment of health risk.

4. (10 min) The use of respiratory protection devices to limit intakes of radioactive materials requires the establishment of a formal respiratory protection program. List and discuss the components of the respiratory protection program you would be required to establish to meet the legal requirements in an NRC-licensed facility.

5. (15 min) Two workers were exposed to airborne radioactive materials when a pressurized line was opened inadvertently. The air concentration in the work area was found to be $2 \times 10^{-8}$ μCi/cm$^3$ of $^{137}$Cs and the workers were in the area for two hours.
   a.) Estimate the intakes of the workers assuming worker A was not wearing respiratory protection and worker B was wearing a full-facepiece respirator with a protection factor of 50. List all assumptions you make.
   b.) If the DAC for $^{137}$Cs is $1 \times 10^{-9}$ μCi/cm$^3$ (assuming total body is the tissue of interest) provide a quick dose estimate for each worker.

6. (10 min) You are the Radiological Safety Officer at a research institution operating under a broad license.
   a.) (5 min) Describe how you would regulate the use of radioactive materials under this broad license.
   b.) (5 min) Describe how you would determine which radiation workers would be issued dosimeters. What factors are to be considered?

7. (10 min) As the facility Radiological Safety Officer, you are responsible for determining the appropriate dosimetry to be worn by the radiation workers at your facility. Describe "appropriate dosimetry" practice and the practical limitations for the following workers: (parts below are equally weighted)
   a.) A worker using 10 mCi of P-32 in the synthesis of labeled organic compounds.
   b.) A worker working on a daily basis in the operation of an X-ray diffraction unit.
   c.) A worker processing irradiated samples (beta/gamma emitters) at the research reactor facility for shipment to on-site and off-site "customers".
8. (20 min) Compare the chemical and radiation "Toxicity" of the following:

a.) bis (chloromethyl) ether tritiated with a specific activity of 1 mCi/g

TLV = 4.7 mg/m³ in air

DAC of $^3$H in air = $2.0 \times 10^{-5}$ μCi/mL

b.) benzene tagged with $^{14}$C - specific activity = 1 mCi/g

TLV = 32 mg/m³ in air

DAC of $^{14}$C in air = $1 \times 10^{-6}$ mCi/mL

c.) Natural U - specific activity = $3.3 \times 10^5$ pCi/g

TLV = 0.2 mg/m³ in air

DAC of $^{238}$U and $^{235}$U = $6 \times 10^{-10}$ μCi/mL

d.) Chemical Toxicity of coal dust - TLV - 2 mg/m³ in to Radiation Toxicity of Natural Uranium in air.