22.01, Problem Set 3

Complete all the assigned problems, and do make sure to show your intermediate work.

Part I

Skill-Building Problems (50 points, individual write-ups)

1 Conceptual Questions

Learning Objective: These problems will make sure you can restate key concepts from the lectures and readings in your own words.

1. Explain why an alpha particle never contains as much kinetic energy as the Q-value for its decay reaction.
2. Explain why one so rarely observes the energy of a beta particle to be the Q-value for its decay reaction.
3. What is a "primordial nuclide?" Explain in terms of half lives or decay constants.
4. Explain, quantitatively, why one does not have to model every isotope in the radon decay chain to calculate how much radiation humans receive from breathing radon.
5. Explain why radioisotope production by radioactive decay and by intentional particle absorption can be modeled the same way, using dimensional analysis.

2 Activity and Half Lives

Learning Objective: Perform typical radioactivity calculations for realistic scenarios, taking into account precision, significant digits, and uncertainty.

1. You have a source of ^{60}Co, calibrated to have an activity of 8 μCi on December 1, 2011.
   (a) What is the decay constant of ^{60}Co?
   (b) What is its radioactivity in μCi today? How many average radioactive decay products (α,β^-,γ...) are given off per second by this isotope? Pay attention to significant digits in your answer.

2. Calculate the expected rise in specific activity in the ocean **today** due to the release of cesium (Cs) from the Fukushima Daiichi accident. You will have to look up and cite key values from the review paper on the Canvas site, as well as the mass of the ocean. Why is the measured specific activity rise so much higher than that which you just calculated?

3. You have an unknown mixture of total mass M of n isotopes, each of which only undergo alpha decay, and each emitting only alpha particles at one energy. Write a compact equation for the radioactivity of this mixture of n isotopes as a finite series. At what time will the radioactivity of this mixture of n isotopes reach 10% of its original radioactivity at $t = 0$? **Hint:** Read the reading for series decays carefully...

Part II

Noodle Scratchers (50 points, team write-ups OK)

3 Primordial Nuclide Analysis (answer not given)

Learning Objective: Pose and solve a multi-step problem involving the the use of half lives (decay constants) and other nuclear data, finding data/constants to use in this model, and solving for original activities of isotopes.

Given the half lives and modern-day abundances of the three natural isotopes of uranium (which you should look up on the Table of Nuclides), calculate the isotopic fractions of uranium when the Earth first formed 4.5 billion years ago. **Hint:** One of these isotopes has a very short half life compared to the age of the Earth! How could it possibly be naturally occurring? In other words, where could it have come from if not from the formation of the Earth?

4 Radioactive Dating (answers given)

Learning Objectives: These problems develop two skills at once: (1) Usage of radioactive decay equations, and (2) finding primary sources of quantitative information. They best represent the open-ended problems which would be posed to you if you were to be a nuclear scientist in charge of radioactive dating of real objects.

1. What is the expected specific activity of ^{14}C of the muslin (pure cotton) wrappers of Tutankhamun's mummy? You will have to look up *and cite* a primary source stating the chemical composition of muslin to determine the amount of carbon in cotton.
   Answer: $\mathbf{\frac{68.17\,Bq}{kg\ muslin}}$

2. What is the expected argon gas atom fraction to be found in VHK (very high K) basalt rocks from the moon? How is such a quantity of argon actually detected (in other words, what technique is used to determine if the rock in question is real or fake)? You will have to determine *and cite* how much potassium exists in VHK basalt.
   Answer: $\mathbf{5.772 \cdot 10^{-7}}$ (**577 ppb**)