Name: Josh Whitehead UID: U1069343

Homework #2 – Due on March 6th, 2022

1. A sample of spent nuclear fuel was found to contain 650.0 Ci of ^{241}Pu. We must safely store the spent nuclear fuel for 10,000 years. Assume that only ^{241}Pu was present at t = 0. (1 point)

   Using the Bateman equation, what is the activity of ^{237}Np after a decay time of 10,000 years?

$$^{241}_{94}Pu \xrightarrow{\beta^-, t_{1/2}=14.325y} {}^{241}_{95}Am \xrightarrow{\alpha, t_{1/2}=432.6y} {}^{237}_{93}Np \xrightarrow{\alpha, t_{1/2}=2.144\times10^{6}y} {}^{233}_{91}Pa \xrightarrow{\beta^-, t_{1/2}=26.975\,d} {}^{233}_{91}U \xrightarrow{\alpha, t_{1/2}=2.592\times10^{5}y} {}^{229}_{91}Th$$

A = Pu

B = Am

C = Np

$$\cancel{A_{Np} = A^0_{Pu}\left[1 - \frac{1}{\lambda_{Am}-\lambda_{Pu}}\left(\lambda_{Am}e^{(-\lambda_{Pu}t)} - \lambda_{Pu}e^{(-\lambda_{Am}t)}\right)\right]}$$

$$N_C = C_A e^{-\lambda_A t} + C_B e^{-\lambda_B t} + C_C e^{-\lambda_C t}$$

$$C_A = \frac{\lambda_A\lambda_B}{(\lambda_B-\lambda_A)(\lambda_C-\lambda_A)}N_A^0 \qquad C_B = \frac{\lambda_A\lambda_B}{(\lambda_A-\lambda_B)(\lambda_C-\lambda_B)}N_A^0$$

$$C_C = \frac{\lambda_A\lambda_B}{(\lambda_A-\lambda_C)(\lambda_B-\lambda_C)}N_A^0$$

$$\lambda = \frac{\ln(2)}{t_{1/2}} \rightarrow \lambda_A = 4.83872377\times10^{-2}\ \frac{1}{Yr}$$

$$\lambda_B = 1.602281971\times10^{-3}\ \frac{1}{Yr}$$

$$\lambda_C = 3.232962595\times10^{-7}\ \frac{1}{Yr}$$

$$\rightarrow \boxed{N_{Np} = 648.0369785375933\ Ci}$$

2. A sample of spent nuclear fuel was found to contain 650.0 Ci of ^{241}Pu. We must safely store the spent nuclear fuel for 10,000 years. Assume that only ^{241}Pu was present at t = 0. (1 point) Using the Bateman equation, what is the activity of ^{233}U after a decay time of 10,000 years?

$$^{241}_{94}Pu \xrightarrow{\beta^-, t_{1/2}=14.325y} {}^{241}_{95}Am \xrightarrow{\alpha, t_{1/2}=432.6y} {}^{237}_{93}Np \xrightarrow{\alpha, t_{1/2}=2.144\times10^6 y} {}^{233}_{91}Pa \xrightarrow{\beta^-, t_{1/2}=26.975\ d} {}^{233}_{91}U \xrightarrow{\alpha, t_{1/2}=2.592\times10^5 y} {}^{229}_{91}Th$$

A B C D E F

$$N_E = C_A e^{-\lambda_A t} + C_B e^{-\lambda_B t} + C_C e^{-\lambda_C t} + C_D e^{-\lambda_D t} + C_E e^{-\lambda_D t}$$

$$C_A = \frac{\lambda_A \lambda_B \lambda_C \lambda_D}{(\lambda_B - \lambda_A)(\lambda_C - \lambda_A)(\lambda_D - \lambda_A)(\lambda_E - \lambda_A)} N_A^0$$

$$C_B = \frac{\lambda_A \lambda_B \lambda_C \lambda_D}{(\lambda_A - \lambda_B)(\lambda_C - \lambda_B)(\lambda_D - \lambda_B)(\lambda_E - \lambda_B)} N_A^0$$

$$C_C = \frac{\lambda_A \lambda_B \lambda_C \lambda_D}{(\lambda_A - \lambda_C)(\lambda_B - \lambda_C)(\lambda_D - \lambda_C)(\lambda_E - \lambda_C)} N_A^0$$

$$C_D = \frac{\lambda_A \lambda_B \lambda_C \lambda_D}{(\lambda_A - \lambda_D)(\lambda_B - \lambda_D)(\lambda_C - \lambda_D)(\lambda_E - \lambda_D)} N_A^0$$

$$C_E = \frac{\lambda_A \lambda_B \lambda_C \lambda_D \lambda_E}{(\lambda_A - \lambda_E)(\lambda_B - \lambda_E)(\lambda_C - \lambda_E)(\lambda_D - \lambda_E)} N_A^0$$

$\lambda_A \approx 9.38543124 \frac{1}{Yr}$

$\lambda_E = 2.674178937 \times 10^{-6} \frac{1}{Yr}$

$$\boxed{N_U = 1.9384561196\ Ci}$$

3. A uranium mineral was found to contain the Pb isotopes ^{204}Pb, ^{206}Pb, and ^{207}Pb in the ratio of 1:1000:400. Estimate the age of this mineral. (1 point)

$$\frac{\left(\frac{207}{204Pb}\right) - \left(\frac{207}{204}\right)_0}{\left(\frac{206}{204}\right) - \left(\frac{206}{204}\right)_0} = \frac{1}{137.818} \cdot \frac{e^{\lambda_{235} t} - 1}{e^{\lambda_{238} t} - 1}$$

natural:

$^{207}Pb = 22.1\%$

$^{206}Pb = 0.241$

$^{204}Pb = 0.014$

$$\rightarrow \frac{\frac{400}{1} - \frac{0.221}{0.014}}{\frac{1000}{1} - \frac{0.241}{0.014}} = \frac{1}{137.818} \cdot \frac{e^{\lambda_{235} t} - 1}{e^{\lambda_{238} t} - 1}$$

$\lambda_{235} = 9.84584 \times 10^{-10} \frac{1}{Yr}$

$\lambda_{238} = 1.55136 \times 10^{-10} \frac{1}{Yr}$

$$\boxed{\therefore t = 3.87566 \times 10^{9} \text{ Yrs}}$$

4. Calculate the specific activity of natural uranium. Uranium has three naturally occurring isotopes. ^{238}U currently accounts for 99.284% of U on earth while ^{235}U is 0.711% and ^{234}U is 0.0055%. (1 point)

$$\cancel{SA = \frac{\lambda}{m} = \frac{0.99284\,\lambda_{238} + 0.00711\,\lambda_{235} + 0.000055\,\lambda_{234}}{16000\ \text{kg}}}$$

$$\cancel{m \approx 16\ \text{tons} \approx 16000\ \text{kg}}$$

$$\cancel{\lambda_{238} = 1.55136\times10^{-10}\ \frac{1}{Yr}}$$

$$\cancel{\lambda_{235} = 9.84584\times10^{-10}\ \frac{1}{Yr}}$$

$$\cancel{\lambda_{234} = 2.82341\times10^{-6}\ \frac{1}{Yr}}$$

OK

$$\cancel{M_{235} = 235.0439281\ \frac{g}{mol}}$$

$$\cancel{M_{238} = 238.0507869\ \frac{g}{mol}}$$

$$\cancel{M_{234} = 234.0409503\ \frac{g}{mol}}$$

$$M_u = 238.03\ \frac{g}{mol}$$

$$N_A = 6.022\times10^{23}$$

$$\cancel{\therefore SA = 1.97}$$

$$A = \lambda N \rightarrow SA = \frac{\lambda N}{m} = \frac{\lambda \cancel{N}}{M \cdot \frac{1}{N_A} \cdot \cancel{N}} = \frac{\lambda N_A}{M}$$

$$\therefore SA_u = 0.99284\left(\frac{\lambda_{238} N_A}{M}\right) + 0.00711\left(\frac{\lambda_{235} N_A}{M}\right) + 0.000055\left(\frac{\lambda_{234} N_A}{M}\right)$$

$$= 8.00\times10^{11}\ \frac{\text{atom}}{Yr \cdot g} = \boxed{2.54\times10^{4}\ \frac{Bq}{g}}$$

5. The bones of an old whale carcass were discovered in Olympic National Park in WA. The carcass is believed to be roughly 1,000 years old. (1 point)

What detector could be used to measure the activity of ^{14}C?

Geiger Counters because ^{14}C decays primarily by β^-

The specific activity of the sample was measured with a radiation detector that had a counting efficiency of 90% to be 12.114 cpm/g of C. The current specific activity of that equilibrium is 15.003 dpm/g of C. What is the actual age of the whale carcass?

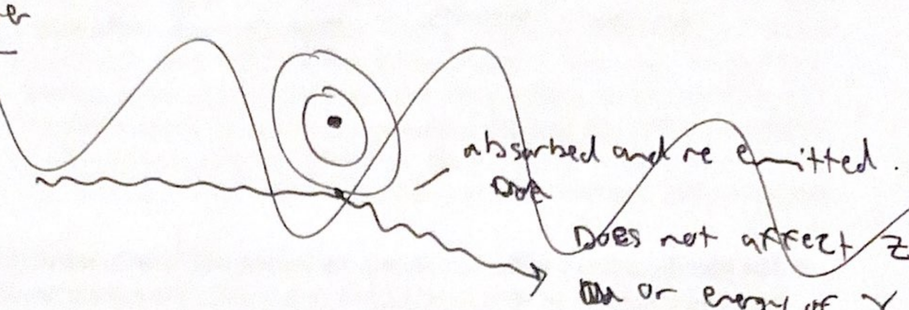
$$SA = SA_{eq}\, e^{-\lambda t} \rightarrow \frac{12.114}{0.9} = 15.003\, e^{-\lambda t}$$

$$\lambda = 1.22 \times 10^{-4} \frac{1}{Yr}$$

$$\boxed{\therefore t = 892.47 \text{ Yrs}}$$

6. Draw the three primary modes of gamma interaction with matter. Describe each interaction in terms of their prevalence changing gamma ray energy and the Z of the absorber material. (1 point)

Coherent Scatter

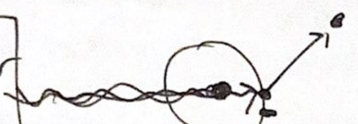


absorbed and re emitted.

Does not affect Z or energy of γ

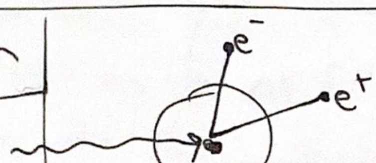
Photo electric

more likely for lower energy γ and larger Z



γ absorbed by atom ejects e^- because excites the atom

Pair Production

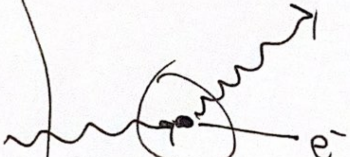


nucleus absorbs γ and produces e^- and e^+

more likely for higher energy γ and lower Z

Compton Scattering

More likely for higher energy γ and large Z



γ absorbed and re emitted @ a lower energy with e^-

7. Energy Solutions, a radioactive waste disposal company headquartered in Salt Lake City, has petitioned the Utah state government to allow it to bury sealed 55 gallon steel, plastic lined drums of depleted uranium in its disposal site in Clive, UT. Depleted uranium is a term for isotopically nearly pure ^{238}U. In your new job as the radioactive waste expert for the state's Division of Air and Water Quality you must advise the legislature on the potential near term radioactive hazards of this waste disposal proposal. Using sound scientific logic and based upon your knowledge of ^{238}U, what will you tell the legislature? You must defend your position carefully to receive credit for this question. For the purposes of this question, you may assume that the 55 gallon drums will allow any generated gases to vent without rupturing the drum. You may also assume that the 55 gallon drum will be impervious to water penetration for over 100,000 years. Your answer should take at most two paragraphs. (1 point)

While radioactive waste is dangerous when exposed to humans, Burying it is a good solution in this case because ^{238}U decays by α emission. α particles ~~are~~ do not travel far because they are heavy and would be stopped before they could leave the drums, and burrying it insures that even if α particles leave the drum, they still won't come in contact with a person.

along the decay chain of ^{238}U, there will be isotopes that decay by β decay. β particles travel farther than α but the plastic should still stop them.

8. How can you identify positron emission from negatron emission? Be sure to describe the detector and what is being detected to receive full credit. (1 point)

You can use a semiconductor detector ~~the~~ to detect γ rays because β^+ decay is followed by 2 annihilation photons

9. For the following radionuclides, identify their most likely mode of decay and explain the ideal detector(s) for each isotope that will yield a high detection efficiency and good energy resolution (1 point).

a. $^{40}K \rightarrow \beta^-$

Organic Scintillators

b. $^{148}La \rightarrow \beta^-$

Organic scintillators

c. $^{239}Pu \rightarrow \alpha$

Geiger-Mueller Counter

10. You suspect that because where your house is built that the basement may have high levels of radon. To ease your fears, you call a local company that specializes in radon detection. Their representative arrives at your house and walks around the basement with a Geiger-Muller counter in hand. The counter emits enormous amounts of noise while the inspection occurs. After the inspection, the representative informs you that your basement is full of radon and suggests several remediation tasks that his company will perform for you. Before signing on the dotted line you must decide whether to spend all that money. Based on your nuclear knowledge, what should you do? Explain fully your decision. (1 point)

~~First I would ask about the type of detector they~~ ~~[illegible]~~

First, I would ask about the sensitivity of their detector. It may be noisy because the sensitivity is too high.

Then I would ask what the recomended limit of radiation is to see if what they're detecting is ~~[illegible]~~ above that limit.

Once I see that ~~[illegible]~~ their counter is at the right setting, I will pay them

11. Alexander Litvinenko was poisoned using ^{210}Po. ^{210}Po decays by emission of an alpha particle. (2 points)

a. What does ^{210}Po decay to?

^{206}Pb

b. Could the doctors detect the Po inside his body? Explain your answer

No because the α particles would be stopped before they ~~reach~~ could go through the skin

c. What type of detector would be needed to determine the exact isotope of Po that was used to poison Alexander

Semiconductor