**PHYS102 - Good Nukes, Bad Nukes, Fall, 2012 - Practice Set #2**

1. If Professor Sullivan received a dose of $75 \times 10^{-3}$ rad (75 mrad) while standing 1.2 meter from a $\gamma$ ray source for 20 minutes, how much dose would he receive standing 6.1 meter from the same source for the same amount of time? Explain why you could not use the same method of calculating dose if the source was an $\alpha$ emitter.

2. Calculate the equivalent dose a person would receive from a 1.5 mrad dose of $\alpha$ radiation. Re-calculate for $\beta$ radiation. Finally, re-calculate for X radiation.

3. If Mr. Loveland were to stand next to a source of $\gamma$ radiation for 1 hour and receive an equivalent dose of $5x10^{-3}$ rem (5 mrem), how much equivalent dose would he receive if he stood next to the source for 2 hours and 20 minutes?

4. How much energy (in MeV) is released in the fusion of ${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{1}H + {}^{1}_{1}H$. (Use data on the mass of isotopes from a website like webelements.com. and the mass-to-energy conversion factor from the lectures.)

5. Calculate the energy release (in MeV) in the fission reaction $^{235}_{92}U + n^0 \rightarrow {}^{140}_{54}Xe + {}^{94}_{38}Sr + 2n^0$. (Use data on the mass of isotopes from a website like webelements.com you will also need to look up the mass of the neutron to the same precision as the mass of the isotopes.)

6. Explain how a natural uranium reactor core becomes and stays hot. Explain the roles of both naturally occurring isotopes of uranium, the moderator, and the control rods in the reactor.

7. Assume a nuclear reactor is operating and is just at its point of criticality (taking into account delayed neutrons). The generation time is 0.1 seconds. If the control rods are then partially removed so that after one generation time the power output increases by 2%, by how much (in percent) will the power output have increased in 3.1 seconds?

8. In the class on radiometric dating, we discussed the radioactive decay chains of $^{238}_{92}U$ and $^{235}_{92}U$ that end in (different) isotopes of Pb (lead). The first four "links" in the radioactive decay chain of $^{238}_{92}U$ are: $^{238}_{92}U \rightarrow {}^{234}_{90}Th \rightarrow {}^{234}_{91}Pa \rightarrow {}^{234}_{92}U$. I also noted that the half-life of the first decay ($4.47 \times 10^9$ years) was by far the longest half-life of any of the other decays at the beginning of the chain.

By looking up the decays in a reference like webelements.com, work through the next four links in the chain. (You may find examples where there is more than one possible decay mode for an isotope. Ignore all but the most probable decay. To check that you are doing it right, see if you can determine the first four isotopes in the decay chain and compare with the list above.) Looking at the half-lives of the decays you found, is it true that the $4.47 \times 10^9$ year half-life for $^{238}_{92}U \rightarrow {}^{234}_{90}Th$ is by far the longest half-life in the chain?

9. A gram of carbon in the atmosphere today has an activity of 14 decays per minute (dpm). Imagine that a collector brings you a piece of wood that he claims was used in the construction of a Greek temple in 650 BC. You carbonize a sample of the piece of wood obtaining 43 grams of carbon. What activity (in dpm) would you expect to measure for the carbonized sample? (Just apply the radioactive decay law in a straightforward way.)

10. Assume a sample of carbon taken from a campfire associated with an ancient human habitation is found to have a concentration of ${}^{14}_{6}C$ only 21% of that of a sample taken from a contemporary campfire. Just applying the radioactive decay law in a straightforward way, determine the age of the ancient campfire.

11. Constructing isochrones: Consider a hypothetical rock that contains three minerals: A, B, and C. When the rock was formed: a) none of the minerals contained any $^{206}_{82}Pb$; b) mineral A contained no $^{238}_{92}U$; c) mineral B contained 0.1 moles of $^{238}_{92}U$ per kilogram of mineral; d) mineral C contained 0.25 moles of $^{238}_{92}U$ per kilogram of mineral. (A mole is just a unit of numbers of atoms.)

Calculate the amount of $^{238}_{92}U$ per kilogram and $^{206}_{82}Pb$ per kilogram in each mineral after one (effective) half-life of the $^{238}_{92}U$ decay chain has passed since the rock was formed. Repeat the calculation for a time of two half-lives after the rock was formed. (If you find yourself doing any complicated calculations you are working too hard. These should be easy.)

Finally, using Excel or other plotting program, create a scatter plot with the vertical axis the amount of $^{206}_{82}Pb$ per kilogram in a mineral and the horizontal axis the amount of $^{238}_{92}U$ per kilogram in a mineral. Plot points corresponding to each mineral (A, B, and C) and for the three times: when the rock was formed, after one half-life, and after two half-lives after the rock was formed. Print out your plot and draw lines connecting points at the same (Greek: iso) times (Greek: chronos). You should find that your isochrones are straight lines on your plot, with later times having lines of larger slope. Hint: Your spreadsheet should be organized something like this (where I have filled in the known information and you need to fill in the empty cells with your calculated values):

| time | $^{238}U$ in A | $^{206}Pb$ in A | $^{238}U$ in B | $^{206}Pb$ in B | $^{238}U$ in C | $^{206}Pb$ in C |
|---|---|---|---|---|---|---|
| (half-lives) | (moles/kg) | (moles/kg) | (moles/kg) | (moles/kg) | (moles/kg) | (moles/kg) |
| 0 | 0 | 0 | 0.1 | 0 | 0.25 | 0 |
| 1 | | | | | | |
| 2 | | | | | | |