**FUNDAMENTALS OF INDUSTRIAL HYGIENE, 6TH ED.**

**HOMEWORK #6**

**INDIVIDUAL MEASUREMENT OF RADIATION**

**Name: KEY *77 pts. possible***

**EXERCISES:** Perform the calculations identified below. Show your work neatly and clearly in a manner similar to the examples provided above (i.e., write the formula, define each variable in the formula where requested, show steps of your calculations).

**Part I: Calculation of Radiation Activity**

The average 70 *kg* adult human body contains approximately 7.0  1027 atoms. Almost 99% of the mass of the human body is made up of six elements: oxygen (43 *kg* – 65%), carbon (16 *kg* – 18%), hydrogen (7 *kg* – 10%), nitrogen (1.8 *kg* – 3%), calcium (1.0 *kg* – 1.4%), and phosphorous (0.78 *kg* – 1.1%). Of the remainder, about 0.85% is composed of another five elements: potassium (0.14 *kg* – 0.25%), sulfur (0.14 *kg* – 0.25%), sodium (0.10 *kg* – 0.15%), chlorine (0.10 kg – 0.15%), and magnesium (0.019 *kg* – 0.05%).

1a) Of the total 16 *kg* of carbon in the average human body, approximately 24 nanograms consist of C14.

Nano- (*n*) is the prefix used in the SI system of measurement to mean one-billionth (10-9). One gram contains one billion (1,000,000,000) nanograms. Therefore, 24 *ng* = 2.4  10-8 *g* (0.000000024 *g*).

What is the activity of the 24 *ng* of C14 in your body?

The weight of 1 mole (6.022  1023) of C14 atoms is ***14 grams*** . *(2 points)*

Therefore, the number of C14 atoms in 24 nanograms is:

$$N\_{1}=\left(\frac{2.4  10^{-8} g}{{14 g}/{mol}}\right)  \left(\frac{6.022  10^{23} atoms}{mol}\right)$$

$$N\_{1}=2.0  10^{-9} mol  \left(\frac{6.022  10^{23} atoms}{mol}\right)$$

$$N\_{1}=1.03  10^{15} atoms$$

The physical half-life of C14 (see Appendix A – do not use table in text) is ***5730 years*** . *(8 points)*

$A\_{1}=\left[\frac{0.693}{t\_{1/2}}\right]  N\_{1}$where: A1 = ***activity of a source***

 0.693 = ***natural log of 2***

$A\_{1}=\left[\frac{0.693}{5730 year}\right]  \left(1.03  10^{15} atoms\right)$ t1/2 = ***half-life of the material***

 N1 = ***number of atoms present***

$A\_{1}=\left[\frac{0.693 \left(1.03  10^{15} atoms\right)}{5730 year}\right]$

$A\_{1}=\left[\frac{7.14  10^{14} atoms}{5730 year}\right]$

$A\_{1}=\frac{1.25  10^{11} atoms}{yr}$

$A\_{1}=\frac{1.25  10^{11} atoms}{year}  \frac{year}{365 day}  \frac{day}{24 hr}  \frac{hr}{60 min}  \frac{min}{60 sec} $

$A\_{1}=\frac{3964 atoms}{s}$ *or* ***3964 Bq***

1b) In the above calculation, an activity of *3964 Bq* was calculated for 24 *ng* of pure C14.

What would the activity of that C14 be after a decay time (*t*2 – *t*1) twenty-five years? *(6 points)*

$A\_{2}=A\_{1}  e^{\left(\frac{-0.693  Δt}{t\_{1/2}}\right)}$ where: *A1*  = ***activity of a source***

 *e*  = ***inverse natural log***

$A\_{2}=\left(3964 Bq\right)  e^{\left(\frac{-0.693  25 year}{5730 year}\right)}$ *Δt*  = ***half-life of the material***

 *t1/2*  = ***number of atoms present***

$$A\_{2}=\left(3964 Bq\right)  e^{\left(-0.003\right)}$$

$$A\_{2}=3964 Bq  0.997$$

$$A\_{2}=3952 Bq$$

2a) Of the total 0.14 *kg* of potassium in the average human body, approximately 14 *mg* (0.014 *g*) consists

 of K40.

What is the activity of the 14 *mg* of K40 in your body?

The weight of 1 mole (6.022  1023) of K40 atoms is ***40 grams*** . *(1 point)*

Therefore, the number of K40 atoms in 14 milligrams is: *(1 point)*

$$N\_{1}=\left(\frac{0.014 g}{{40 g}/{mol}}\right)  \left(\frac{6.022  10^{23} atoms}{mol}\right)$$

$$N\_{1}=0.00035 mol  \left(\frac{6.022  10^{23} atoms}{mol}\right)$$

$$N\_{1}=2.11  10^{20} atoms$$

The physical half-life of K40 (see Appendix A – do not use table in text) is ***4.6  1011 days***  . *(3 points)*

$A\_{1}=\left[\frac{0.693}{4.6  10^{11} day}\right]  \left(2.11  10^{20} atoms\right)$

$A\_{1}=\left[\frac{0.693 \left(2.11  10^{20} atoms\right)}{4.6  10^{11} day}\right]$

$A\_{1}=\left[\frac{1.46  10^{20} atoms}{4.6  10^{11} day}\right]$

$A\_{1}=\frac{3.17  10^{8} atoms}{day}$

$A\_{1}=\frac{3.17  10^{8} atoms}{day}  \frac{day}{24 hr}  \frac{hr}{60 min}  \frac{min}{60 sec} $

$A\_{1}=\frac{3673 atoms}{s}$ *or* ***3673 Bq***

2b) In the above calculation, an activity of *3673 Bq* was calculated for 14 *mg* of pure K40.

What would the activity of that K40 be after a decay time (*t*2 – *t*1) of eighty years? *(3 points)*

$A\_{2}=\left(3673 Bq\right)  e^{\left(\frac{-0.693  29200 day}{4.6  10^{11} day}\right)}$ where: 80 years = ***29200*** days

$$A\_{2}=\left(3673 Bq\right)  e^{\left(-4.4  10^{-8}\right)}$$

$$A\_{2}=3673 Bq  0.9999$$

$$A\_{2}=3673 Bq$$

3) Conduct a brief research on “background radiation” using at least the following internet sources:

http://en.wikipedia.org/wiki/Background\_radiation

http://web.princeton.edu/sites/ehs/osradtraining/backgroundradiation/background.htm

http://w1.rso.utah.edu/train/Natbkg.html

http://www.nrc.gov/reading-rm/basic-ref/glossary/background-radiation.html

a) What is “background radiation”? What is the average exposure to background radiation in the U.S.?

 *(2 points)*

***Background radiation is the term that describes non-occupational exposure to radiation sources.***

***The level of background radiation can vary depending on geographic location, and other factors.***

***The average exposure from background radiation for a person living in the U.S. is given variously as 3.0 - 3.6 mSv (300 – 360 mrem) per year.***

b) What are the two broad sources of background radiation? How much radiation is received from each source annually? Identify three specific radiation sources within each broad source. *(10 points)*

Source #1: ***Natural Sources*** Amount from Source #1: ***3.6 mSv (360 mrem)***

Specific Sources: ********

 ***cosmic radiation***

 ***internal exposure from naturally occurring radioisotopes (e.g., C14, K40)***

Source #2: ***Artificial Sources*** Amount from Source #2: ***0.6 mSv (60 mrem)***

Specific Sources: *****medical procedures***

 ***consumer products***

 ***fallout from nuclear tests/accidents***

c) Explain the role of C14 and K40 in the ‘background radiation’ dose received by humans (± all mammals). *(5 points)*

***The elements of both isotopes are incorporated into the organs and tissues of the organism.***

***Both isotopes have long half-lives, which means they exhibit very little decrease in radiation activity over time (especially considering the short lifespan of animals).***

***Since they become incorporated into the living tissue, they represent internal radiation sources.***

***Combined, C14 and K40 are significant contributors to the natural background radiation organisms are exposed to, representing approximately 11% of the total.***

1) Complete the table, calculating the effective half-lives for P32, Sr89, Sr90, I123, I131, and Tc99m *(6 points)* and show your calculations for two of the isotopes *(2 points)*.

 (See Appendix A for physical and biological half-lives – do not use table in text.)

***Physical, Biological, and Effective Half-Lives of Selected Isotopes (in days)***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Isotope** | **Type of Radiation** | **Physical Half-Life***t*1/2(*phy*) | **Biological Half-Life***t*1/2(*bio*) | **Effective Half-Life***t*1/2(*eff*) |
| H3 | *beta* | *4500* | *10* | *9.98* |
| P32 | *beta* | *14.3* | *1155* | *14.13* |
| Sr89 | *beta* | *50.6* | *18000* | *50.46* |
| Sr90 | *beta* | *10548* | *18000* | *6650.69* |
| I123 | *gamma* | *0.54* | *138* | *0.54* |
| I131 | *beta* | *8* | *138* | *7.56* |
| Tc99m | *gamma and beta* | *0.25* | *1* | *0.20* |

a) Isotope #1: P32 b) Isotope #2: Sr89 c) Isotope #3: Sr90

$t\_{^{1}/\_{2}}\left(eff\right)=\frac{14.3 d  1155 d}{14.3 d+ 1155 d}$ $t\_{^{1}/\_{2}}\left(eff\right)=\frac{50.6 d  18000 d}{50.6 d+ 18000 d}$ $t\_{^{1}/\_{2}}\left(eff\right)=\frac{10548 d  18000 d}{10548 d+ 18000 d}$

$t\_{^{1}/\_{2}}\left(eff\right)=\frac{16516.5 d^{2}}{1169.3 d}$ $t\_{^{1}/\_{2}}\left(eff\right)=\frac{910800 d^{2}}{18050.6 d}$ $t\_{^{1}/\_{2}}\left(eff\right)=\frac{189864000 d^{2}}{28548 d}$

$t\_{^{1}/\_{2}}\left(eff\right)=14.13 d$ $t\_{^{1}/\_{2}}\left(eff\right)=50.46 d$ $t\_{^{1}/\_{2}}\left(eff\right)=6650.69 d$

d) Isotope #4: I123 e) Isotope #5: I131 f) Isotope #6: Tc99m

$t\_{^{1}/\_{2}}\left(eff\right)=\frac{0.54 d  138 d}{0.54 d+ 138 d}$ $t\_{^{1}/\_{2}}\left(eff\right)=\frac{8 d  138 d}{8 d+ 138 d}$ $t\_{^{1}/\_{2}}\left(eff\right)=\frac{0.25 d  1 d}{0.25 d+ 1 d}$

$t\_{^{1}/\_{2}}\left(eff\right)=\frac{74.52 d^{2}}{138.54 d}$ $t\_{^{1}/\_{2}}\left(eff\right)=\frac{1104 d^{2}}{146 d}$ $t\_{^{1}/\_{2}}\left(eff\right)=\frac{0.25 d^{2}}{1.25 d}$

$t\_{^{1}/\_{2}}\left(eff\right)=0.54 d$ $t\_{^{1}/\_{2}}\left(eff\right)=7.56 d$ $t\_{^{1}/\_{2}}\left(eff\right)=0.20 d$

2) Based on the behavior and half-lives of the radioisotopes only (i.e., ignore the energy levels of emitted radiation), respond to the following questions. *(2 points each – 8 pts. total)*

a) Why is Technetium (T99m) a favorite for diagnostic scans, having been used for over 40 million procedures and accounting for 80% of all nuclear medicine procedures worldwide?

***Emits powerful enough radiation to escape the body.***

***T99m has both a short physical half-life and a short biological half-life (also accept effective half-life).***

b) For strictly imaging purposes, which radioisotope of Iodine would you recommend? Why?

***I123, since it has a much shorter physical half-life.***

***I123 emits gamma rays and would provide for better imaging.***

***I131 emits beta rays and, while not as potentially damaging, they do not provide enough penetration to provide for detailed imaging.***

c) Identify a concern you would have about recommending a bone scan using P32.

***Although it has a short physical half-life, because it becomes incorporated into bone and teeth, it has a long biological half-life.***

***Decays by emitting beta particles that are powerful enough to irradiate bone marrow.***

d) Of the radioisotopes identified in the table, which is the most hazardous? Why?

***Strontium (Sr90) is very bad news in the environment.***

***It mimics calcium and therefore gets incorporated into bone.***

***This gives it a very long physical half-life accompanied by a very long biological half-life, making it doubly dangerous.***

***Decays by emitting beta particles that are powerful enough to irradiate bone marrow.***

***Other radioisotopes may have longer biological half-lives, but 18000 days (49 years) of continuous bone marrow irradiation would likely result in the demise of the recipient.***

**Part III: Calculation of Dose Equivalent and Effective Dose Equivalent**

1) Calculate the Dose Equivalent of 0.055 (5.5  10-2) *Gy* resulting from exposure to a 5.59 *mEV* alpha source emitter. *(4 points)*

*DE* = ***Dose  Q*** where:  ***Dose = energy deposited (in Sv)***

 ***Q = radiation quality factor***

*DE* = *(0.055 Gy)  (20)*

*DE* = ***1.1 Sv (11 rem)***

2) Given that the lungs are the organ/tissue suffering the greatest exposure, calculate the Effective Dose Equivalent. *(4 points)*

*EDE* = ***Σ(DE  Wt)***  where:  ***DE = dose equivalent (in Sv)***

 ***Wt = tissue weighting factor***

*EDE* = *1.1 Sv  0.12*

*EDE* = ***0.132 Sv***

3) Calculate the Dose Equivalent of 0.023 (2.3  10-2) *Gy* resulting from exposure to a 7.78 *MeV* alpha source emitter and a simultaneous 0.069 (6.9  10-2) *Gy* resulting from exposure to a 0.19 *MeV* gamma source emitter. *(2 points)*

*DE* = ***[(0.023 Gy)  (20)] + [(0.069 Gy)  (1)]***

*DE* = *0.46 + 0.069*

*DE* = ***0.53 Sv (53 rem)***

4) Given that the radiation source in the above example is a self-luminous wristwatch with radium-painted dials, and owner never takes the watch off and sleeps with his arm draped across his chest such that the watch dial lies directly over his right breast, calculate the Effective Dose Equivalent. *(2 points)*

*EDE* = ***[(0.46 Sv  0.15)] + [(0.069 Sv  0.15)]***

*EDE* = *0.069 Sv + 0.010 Sv*

*EDE* = ***0.079 Sv***

**Part IV: Calculation of Radiation Distance Factor**

1) If the dose rate at 2 *cm* from a small-sized Ra226 source is 0.34 *Sv/h* (34 *rem/h*), the dose rate at 17 *cm* is calculated: *(4 points)*

$DR\_{2}= DR\_{1}  \frac{r\_{1}^{2}}{r\_{2}^{2}}$ where:  ***DR1 = dose rate at distance r1 from source (in Sv/h)***

  ***DR2 = dose rate at distance r2 from source (in Sv/h)***

$$DR\_{2}=\left(0.34 Sv/h\right)  \frac{2 cm^{2}}{17 cm^{2}}$$

$$DR\_{2}=\left(0.34 Sv/h\right)  \frac{4}{289}$$

$$DR\_{2}=\left(0.34 Sv/h\right)  0.014$$

$DR\_{2}=\left(0.0048 Sv/h\right)$ ***or* (4.8  10-3)**

2) If the dose rate at 275 *cm* from the Ra226 source is known to be 0.000018 (1.8  10-5) *Sv/h*, the dose rate at 56 *cm* is calculated: *(2 points)*

$$DR\_{2}=\left(0.000018 Sv/h\right)  \frac{275 cm^{2}}{56 cm^{2}}$$

$$DR\_{2}=\left(0.000018 Sv/h\right)  \frac{75625}{3136}$$

$$DR\_{2}=\left(0.000018 Sv/h\right)  24.12$$

$DR\_{2}=\left(0.00043 Sv/h\right)$ ***or* (4.3  10-4)**

3) **BONUS:** If the acceptable dose rate for a particular radioactive material has been established at 0.027 *Sv/h* and the dose rate at 16 *cm* has been determined to be 0.004 *Sv/hr*, how far away must workers be kept from the source? *(2 points)*

$$0.027 Sv/hr=\left(0.004 Sv/h\right)  \frac{16 cm^{2}}{r\_{2}^{2}}$$

$$\frac{0.027 Sv/hr}{0.004 Sv/hr}= \frac{256 cm^{2}}{r\_{2}^{2}}$$

$$6.75=\frac{256 cm^{2}}{r\_{2}^{2}}$$

$$r\_{2}^{2}  6.75=256 cm^{2}$$

$$r\_{2}^{2}= \frac{256 cm^{2}}{6.75}$$

$$r\_{2}^{2}=37.9 cm^{2}$$

$\sqrt{r\_{2}^{2}}= \sqrt{37.9 cm^{2}}$

$$r\_{2}=6.16 cm$$