Solution to EXAM-6 (Closed Book)   14:30; June 2, 2004

Problem-1 (30 points)   a) What are the biological effects due to radiation exposure to bone?

b) What are the absorbed fractions of each radiation type of α, β, and γ for bone surfaces (BS) and red bone marrow (RM) from trabecular and cortical bones, respectively.

c) Find the dose equivalent rates to bone surface (BS) due to 10 MBq of Ra-226 uniformly distributed in bone (neglect the activities distributed in bone surfaces).

Data for Ra-226:   radiations per transformation: 4.78 MeV-α (95%), 4.60 MeV-α (5%)

AF(T$\leftarrow$S) for   -emitters uniformly distributed in the bone

(1) AF(BS$\leftarrow$trabecular bone) = 0.025

(2) AF(BS$\leftarrow$cortical bone) = 0.01

effective half-life of Ra-226 in bone = 44 years

mass of trabecular bone = 1 kg

mass of cortical bone = 4 kg

mass of bone surface (BS) = 120 grams (masses of bone surfaces of both types of bone are the same: 60 grams for each type)

(Solution)

a)   There are two types of bones in the human body: 1) trabecular bone and 2) cortical bone. On average, a man has 1 kg of trabecular bone (without bone marrow) and 4 kg of cortical bone. The biological effects to the bone are on:

1)   red bone marrow (RM) which is the haematopoietic stem cells of marrow within the trabecular bone (1,500 g), which induces "leukemia", and

2)   bone surfaces (BS) which is the osteogenic tissue on endosteal surfaces and certain epithelial cells close to bone surface (10 m from the relevant bone surfaces) in the trabecular and cortical bones (= 120 g), which induces "osteosarcoma (bone cancer)". The masses of bone surface of two types of bone are equal (60 grams each).

b) Radiations are classified for the convenience of dose calculation in the bone as follows:

1) photons

2) α-particles uniformly distributed in the bone

3) α-particles on bone surfaces

4) β-particles uniformly distributed in the bone

5) β-particles on bone surfaces ($\overline{E_\beta}$ $\geq$0.2 MeV)

6) β-particles on bone surfaces ($\overline{E_\beta}$ < 0.2 MeV)

The absorbed fractions, AF(T$\leftarrow$S) are:

1) for photon emitters: given in ICRP publication 23

2) for other radiations:

effects	source organ (S)	target organ (T)	α in bone	α in BS	β in bone	β in BS $\overline{E_\beta} \geq$ 0.2MeV	β in BS $\overline{E_\beta} <$ 0.2MeV
osteo-sarcoma	trabecular	BS	0.025	0.25	0.025	0.025	0.25
	cortical	BS	0.01	0.25	0.015	0.015	0.25
leukemia	trabecular	RM	0.05	0.5	0.35	0.5	0.5
	cortical	RM	0	0	0	0	0

c) The dose-equivalent rate to target organ (T) from source organ (S) by the activity of radioisotope i, $q_i(t)$ is given by:

$$\dot{H}(T \leftarrow S)_j = 1.6x10^{-10} SEE(T \leftarrow S)_j \, q_j(t) \quad \text{Sv/sec}$$

$$SEE(T \leftarrow S)_j = \frac{\sum_R f_R E_R AF(T \leftarrow S)_R w_R N_R}{M_T}$$

where, MeV/g.t

$q_i(t)$ = activity of radioisotope i, in source organ (S) in Bq.

Since the activity in bone does not vary much with respective time due to the long half-life of Ra-226 in bone (=44 years), $q_i(t)$ can be considered as a constant as follows:

$q_{Ra\text{-}226}$ = 10 MBq=$10^7\,Bq$

Assuming the uniform distribution, since the masses of trabecular and cortical bones are 1 kg and 4 kg, respectively, the activity in both types of bone are:

$q_{trabecular\ bone}$ = 0.2x $q_{Ra\text{-}226}$ = 0.2 ($10^7\,Bq$)= 2x10^6 Bq

$q_{cortical\ bone}$ = 0.8x $q_{Ra\text{-}226}$ = 0.8 ($10^7\,Bq$)= 8x10^6 Bq

For bone surfaces of 120 g, the dose-equivalent rate is:

$$\dot{H}(BS)_{Ra-226} = \sum_s \dot{H}(BS \leftarrow S)_{Ra-226}$$

$$= \dot{H}(BS \leftarrow trabecular\, bone)_{Ra-226} + \dot{H}(BS \leftarrow cortical\, bone)_{Ra-226}$$

$$= 1.6x10^{-10}\, q_{Ra-226}\left[0.2\, SEE(BS \leftarrow trabecular\, bone)_{Ra-226} + 0.8\, SEE(BS \leftarrow cortical\, bone)_{Ra-226}\right]$$

where,

$$SEE(BS \leftarrow trabecular\, bone)_{Ra-226}$$

$$= \frac{(0.95)(4.78MeV)(0.025)(20)(1) + (0.05)(4.60MeV)(0.025)(20)(1)}{60g} = 3.98x10^{-2}$$

$$SEE(BS \leftarrow cortical\, bone)_{Ra-226}$$

$$= \frac{(0.95)(4.78MeV)(0.01)(20)(1) + (0.05)(4.60MeV)(0.01)(20)(1)}{60g} = 1.59x10^{-2}$$

Hence, the dose-equivalent rate to BS becomes;

$$\dot{H}(BS)_{Ra-226} = (1.6x10^{-10})(10^7\,Bq)\left[(0.2)(3.98x10^{-2}) + (0.8)(1.59x10^{-2})\right]$$

$$= 3.31x10^{-5}\ Sv/\sec$$

$$= 1.19\,x10^2\ mSv/hr$$

Problem-2 (10 points) Let's consider an ionization chamber whose volume is 10 cm^3 filled with 750 mmHg dry air at 0^{o}C. Find the exposure rate when the external current shows 0.01 μA in an ammeter.

(Solution)

The exposure (# of ion pairs produced in the STP air by gamma- or X-radiation) rate is:

$$\dot{X} = \frac{10^{-8} C/\sec}{\left[(10cm^3)(1.293x10^{-6} kg/cm^3)\right]} \times \frac{273}{273} \times \frac{760}{750}$$

= 7.84x10^{-4} C/kg per sec (= Xunit/sec)

= 3.04 R/sec

Problem-3 (20 points) Using a BF_3 counter whose volume is 100 cm^3 and is filled with 100% enriched $B^{10}F_3$ gas (p=300 mmHg, T=10^{o}C), when a thermal neutron counting rate is 500 cpm, what is the thermal neutron flux?

Data:

Thermal absorption X-section for 0.0253 eV neutron = 4,010 b

Efficiency of BF_3 detector = 0.5 -count per reaction

(Solution)

# of B-10 atoms in the counter,

$$N=\frac{(100)(10^{-3})\ell}{22.4\ell}\left(\frac{30}{76}\right)\left(\frac{273}{283}\right)\left(6.02x10^{23}\right)=1.02x10^{21}\,atoms$$

The average absorption X-section of B-10 (1/v-absorber) at 0^{o}C is,

$$\overline{\sigma_a}(0^\circ C)=\frac{\sqrt{\pi}}{2}\left(\frac{293}{283}\right)^{1/2}(4010b)=3616b$$

The total reaction rate becomes,

N σ_a Φ = (0.5)(1.02x10^{21})(3616x10^{-24}) . = 500 cpm = 500/60 counts/second =8.33 cps

(1 reaction = 0.5 α -count)

$\therefore \Phi$ = 4.51 neutrons/cm^{2}sec

Problem-4 (20 points) a) The measurement of a radioactive source for a time period of 5 minutes showed 1,000 counts. What are the count rate and its statistical error in the form of standard deviation in cpm? b) If the background count measured for 20 minutes showed 500 counts, find the net count rate in cpm with its statistical error in the form of standard deviation.

(Solution)

a) The count rate is:

$$r_g = \frac{n_g}{t_g} = \frac{1000}{5} = 200cpm$$

And the standard deviation is:

$$\sigma_g = \sqrt{\frac{r_g}{t_g}} = \sqrt{\frac{200}{5}} = 6.32cpm$$

$$r_g \pm \sigma_g = (200 \pm 6.32)\ cpm$$

b) The net count rate is:

$$r_n = r_g - r_b = \frac{n_g}{t_g} - \frac{n_b}{t_b} = \frac{1000}{5} - \frac{500}{20} = 200 - 25 = 175cpm$$

And the standard deviation for net count is:

$$\sigma_n = \sqrt{\frac{r_g}{t_g} + \frac{r_b}{t_b}} = \sqrt{\frac{200}{5} + \frac{25}{20}} = 6.42cpm$$

$$r_n \pm \sigma_n = (175 \pm 6.42)\ cpm$$

Problem-5 (20 points): Let's consider a pocket dosimeter whose free volume is 4 cm^3 filled with STP dry. The electric capacitance across the dosimeter is 4 pF. When the original voltage across the chamber was 200 V, which was discharged to 180 V after gamma-radiation exposure. Find the exposure rate (R/hour) and the absorbed dose received in rad for the soft tissue.

(Solution)

Let's assume the exposure time is 1 hour.
The average exposure rate is

$$\dot{X} = \frac{(C)(\Delta V)}{(V)(\rho)(\frac{1}{2} hr)} = \frac{(4x10^{-12} F)(200V - 180V)}{(4cm^3)(1.293x10^{-6} kg/cm^3)}$$

= $1.547x10^{-5}$ Xunit/hr

= 0.06 R/hr

1 rad = (0.877)(1.1) ≈ 1 R for soft tissue.

The absorbed dose is
D = 0.06 rads for 1 hr