chapter 31: Dosimetry

How can the activity be measured?

- intensity (activity) of the emission ⇝ $\left|\frac{dN}{dt}\right| = R$
- effect a given type of radiation has on human body

∴ Much more important is the <u>absorbed radiation dose</u>

- The SI unit, gray (Gy) → 1 Gy = 1 J/kg
- non SI unit, Rad → 1 Gy = 100 RAD

→ energy deposited per unit mass of material

earliest non SI unit: $1R = 0.878 \times 10^{-2}$ J/kg

Relative Biological Effectiveness (RBE) → the number of rads of x-Ray or γ rays that produces the same biological damage

effictive dose → product of the dose (Physical absorbed one) times to the RBE factor

$$Ed = AD \times RBE$$

Ed: effictive dose; AD: Absorbed dose; RBE: Relative Biological effictivness

SI unit for the effective dose → Sievert (SV)

non SI unit → rem   1SV = 100 rem

31–5 Dosimetry

38. (I) 350 rads (AD) of α-particle radiation is equivalent to how many rads of X-rays in terms of biological damage?

350 α → rad X-Rays

1 α → 20 rad

7000 Rad of X-Ray

40. (II) How much energy (E) is deposited in the body of a 65-kg (m) adult exposed to a 2.5-Gy (AD) dose?

$AD = \frac{E}{m} \rightsquigarrow 2.5 = \frac{E}{65}$ $E = 162.5 J$

41. (II) A cancer patient is undergoing radiation therapy in which protons with an energy of 1.2 MeV (Energy radiated per proton) are incident on a 0.20-kg (m) tumor. (*a*) If the patient receives an effective dose of 1.0 rem (ED), what is the absorbed dose (AD)? (*b*) How many protons are absorbed by the tumor? Assume RBE ≈ 1.

$E \rightarrow 1.2\times10^{6} \times 1.602\times10^{-19}$ J

ED → 1 rem

m → 0.2 kg

(a) ED = AD * RBE

1 = AD * 1

AD = 1 Rad

↳ 0.01 gy

(b) $0.01\ gy * \frac{1\ \frac{J}{kg}}{1\ gy} * 0.2\ kg \times \frac{1\ eV}{1.602\times10^{-19} J} * \frac{P}{1.2\times10^{6} eV}$

$P = 1.04 * 10^{10}$

energy per decay

46. (II) $^{57}_{27}Co$ emits 122-keV γ rays. If a 65-kg person swallowed 1.55 μCi of $^{57}_{27}Co$, what would be the dose rate (Gy/day) averaged over the whole body? Assume that 50% of the γ-ray energy is deposited in the body. [*Hint*: Determine the rate of energy deposited in the body and use the definition of the gray.]

activity — 1.55 μCi; m — 65 kg

يعني بس 50% بياخذ

$$122\times10^{3}\times1.602\times10^{-19}\ \frac{\text{energy}}{\text{decay}}\times1.55\times10^{-6}\times3.7\times10^{10}\ \frac{\text{decay}}{\text{s}}=1.12\times10^{-9}\ \frac{\text{energy}}{\text{sec}}$$

energ per decay — activity $\frac{\text{decay}}{\text{second}}$

$$\text{Absorbed dose}=\frac{\text{energy}}{\text{mass}}$$

طالب $\frac{\text{gy}}{\text{day}}$ — gy ← Absorbed dose; day ← time → $\frac{1}{\text{day}}$

$$\frac{1.12\times10^{-9}\ \text{energy}}{65\ \text{kg}}\times\frac{1}{1\,\text{sec}\times\frac{1}{3600}\times\frac{\text{day}}{24}}\times0.5=7.44\times10^{-7}\ \text{gray/day}$$

0.5 → the person only absorbes 50%

47. (II) Ionizing radiation can be used on meat products to reduce the levels of microbial pathogens. Refrigerated meat is limited to 4.5 kGy. If 1.6-MeV electrons irradiate 5 kg of beef, how many electrons would it take to reach the allowable limit?

E (energy per electron) M

$$AD = \frac{\text{Energy}}{\text{mass}} \rightarrow \frac{J}{kg} \times kg \times \frac{eV}{J} \times \frac{e^-}{1\,eV}$$

allowable limit

$$4.5\times10^{3}\ \frac{J}{kg} \times 5\,kg \times \frac{1\,eV}{1.602\times10^{-19}\,J} \times \frac{\text{num of } e^-}{1.6\times10^{6}\,eV}$$

$$= 8.77\times10^{16} \approx 9\times10^{16}\ e^-$$

44. (II) A 1.6-mCi source of $^{32}_{15}P$ (in $NaHPO_4$), a β emitter, is implanted in a tumor where it is to administer 32 Gy. The half-life of $^{32}_{15}P$ is 14.3 days, and 1.0 mCi delivers about 10 mGy/min. Approximately how long should the source remain implanted?

→ dose

$T_{1/2}$

dose = time * rate
??

rate ⇒ 1 mCi → 10 mGy/min
1.6 mCi → x Gy/min

$$\text{time} = \frac{\text{dose}}{\text{rate}}$$

$$= \frac{32\,Gy}{\frac{10\times10^{-3}\,Gy}{min}}$$

$$\frac{32\,min}{1.6\times10\times10^{-3}} \times \frac{1\,hour}{60\,min} \times \frac{1\,day}{24\,hour}$$

$= 1.38$ days

42. (II) A 0.035-μCi sample of ${}^{32}_{15}P$ is injected into an animal for tracer studies. If a Geiger counter intercepts 35% of the emitted β particles, what will be the counting rate, assumed 85% efficient?

Particle/second

$0.035\times10^{-6}\times3.7\times10^{10}\ \frac{decay}{sec}\times\frac{1\ \beta\ Particle}{1\ decay}\times0.35\times0.85=385.265$ Count/sec

decay/sec — energy/decay

Q5) A 2 μCi radioactive source emits neutrons each with 2.4 MeV energy. The radiated energy (in μJ per hour) is: (μCi = 10^{-6} Ci and 1Ci = 3.70×10^{10} decays/sec, 1 eV = 1.6×10^{-19} J)

A) 23 B) 42 C) 102 D) 150 E) 250

$2\times10^{-6}\times3.7\times10^{10}\ \frac{decay}{sec}\times2.4\times10^{6}\times1.6\times10^{-19}\ \frac{energy}{decay}\times\frac{3600\ sec}{1\ hour}$

$=1.02\times10^{-4}$ J

102×10^{-6} J

(102 μJ)

1Sv=100rem

Q8) A 2 mSv (milli sievert) is equivalent to:

A) 0.2 rem B) 0.2 rad C) 2 Gy D) 20 rem E) 20 rad

$2\times10^{-3}\ Sv\times\frac{100rem}{1\ Sv}=0.2$ rem

Q9) Three radioactive sources have the same activity. The decay modes, energy of each emitted particle and the corresponding RBE values are given in the following table. Arrange the three sources according to their danger to biological tissues from least to most dangerous. (Assume the **absorbed dose** from each source to be equal).

A) 2, 3, 1
B) 1, 2, 3
C) 3, 2, 1
D) 2, 1, 3
E) 1, 3, 2

Source	Decay mode	Energy per emitted particle	RBE
1	protons	3MeV	2
2	Fast neutrons	1MeV	10
3	Alpha particles	1 MeV	20

→ as much damage as 2 rad
→ 10 rad
→ 20 rad

Most		least
α	fast neutrons	protons
3	2	1

$1<2<3$

Q10) A 70-kg laboratory technician exposed to α-particles absorbs 0.03 mJ of energy. The relative biological effectiveness (RBE) for α-particles is 20. What is his effective dose (in mrem)? $\times100\times10^{-3}$

A) 1.20 B) 1.09 C) 1.00 D) 0.92 E) 0.86

$Ed=AD\times RBE\rightarrow\frac{0.03\times10^{-3}}{70}\times20\rightarrow8.57\times10^{-6}$ Sv

(III) Assume a liter of milk typically has an activity of 2000 pCi due to $^{40}_{19}K$. If a person drinks two glasses (0.5 L) per day, estimate the total effective dose (in Sv and in rem) received in a year. As a crude model, assume the milk stays in the stomach 12 hr and is then released. Assume also that roughly 10% of the 1.5 MeV released per decay is absorbed by the body. Compare your result to the normal allowed dose of 100 mrem per year. Make your estimate for (*a*) a 60-kg adult, and (*b*) a 6-kg baby.

R

t =

a) $ED = AD \times RBE$

$\frac{\text{total } E}{kg} \times RBE$

$1.5 \times 10^{6} \times 1.6 \times 10^{-19} \frac{J}{\text{decay}} \times 2000 \times 10^{-12} \times 3.7 \times 10^{10} \frac{\text{decay}}{L \cdot s} \times 12\,hr \times \frac{3600\,s}{1\,hr} \times 0.1 \times \frac{0.5\,L}{\text{day}} \times \frac{365\,\text{day}}{\text{year}}$

$= 1.4 \times 10^{-5} \frac{J}{\text{year}}$

$1.4 \times 10^{-5} \frac{J}{\text{year}} \times \frac{1}{60\,kg} \times 1 = 2.33 \frac{Sv}{\text{year}} \rightarrow 0.023 \frac{mrem}{\text{year}}$

6. Ionizing radiation can be used on meat products to reduce the levels of microbial pathogens. Assume that for refrigerated meat the upper allowed limit is 3.8 kGy . If a beam of electrons, each of energy 1.6 Mev irradiates 3.0 Kg of beef , how many electrons should the mass of beef absorb to reach the upper allowed limit ?
   A. 4.5×10^{16}
   B. 4.5×10^{10}
   C. 3.8×10^{16}
   D. 3.8×10^{10}
   E. 1.6×10^{10}

$\frac{J}{kg} \times kg \times \frac{eV}{1 J} \times \frac{e^-}{eV}$

$3.8\times10^{3} \frac{J}{kg} \times 3 kg \times \frac{1 eV}{1.602\times10^{-19} J} \times \frac{\text{num of } e^-}{1.6\times10^{6} eV} = 4.447\times10^{16} e^-$

Answer: A

7. A biological tissue of mass m is exposed to 90 rad of alpha radiation. How many rads of slow neutrons can cause the same biological damage to the same tissue? (For alpha RBE=20, for slow neutrons RBE=5).
   A. 20
   B. 100
   C. 90
   D. 360
   E. 1800

$90 rad \times 20\alpha \rightarrow 5 rad \times x$

$\frac{90\times20}{5} = 360$

Answer:D

4. A 70-Kg researcher absorbs 4.5×10^{8} neutrons in a workday , each of energy 1.2 MeV. The relative biological effectiveness (RBE) for these neutrons is 10 . What is the equivalent dosage of the radiation exposure for this researcher, in mrem ?
   A. 3.7
   B. 0.39
   C. 0.77
   D. 1.2
   E. 12

$ED = AD * RBE$

energy / neutron; neutrons

$\frac{1.2\times10^{6}\times1.6\times10^{-19}\times4.5\times10^{8}}{70} \times 10 = 1.23\times10^{-5} Sv \times 10^{3} \times 100 = 1.23$ mrem

Answer: D

5. A 3.0-mCi source of ^{32}P is implanted in a tumor to give it a 24-Gy dose. The half-life of ^{32}P is 14.3 days, and 1 mCi delivers 10 mGy/min. How long (in min) should the source remain implanted?
   A. 143
   B. 300
   C. 240
   D. 720
   E. 800

1 mCi → 10 mGy/min

3 mCi → x mGy/min

30 mGy/min

rate × time = dose

time = dose / Rate

$time = \frac{24 Gy}{30\times10^{-3} Gy/min}$

= 800 min

Answer: E

Q2) A 55-kg person has absorbed a 20-rad dose. How many joules of energy are deposited in his body?

A)1.1
B) 20
C)11
D) 55
E) 1100

1gray = 100 rad

$\frac{E}{kg} = AD$

$\frac{E}{55} = \frac{20}{100}$ → 11J

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6) A 63-kg researcher absorbs 2.6×10^8 neutrons in a work day. The energy of each neutron is 6.5 MeV. The quality factor (QF) for fast neutrons is 10. The biologically equivalent dosage of the radiation, in mrem (mrem = 10^{-3} rem), is closest to (Note: 1 rad = 0.01 J/kg and 1ev = 1.6×10^{-19} J)

A) 43
B) 1.3
C) 2.7
D) 13
E) 4.3

ED = AD x RBE

$\frac{J}{kg}$ x RBE → $\frac{6.5 \times 10^6 \times 1.6 \times 10^{-19} \times 2.6 \times 10^8 \times 10}{63}$

$= 4.29 \times 10^{-5}$ Sv $\times 100 \times 10^3 = 4.29$ mrem

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15) A radioactive source emits 2.4 MeV neutrons at the rate of 9200 neutrons per second. The number of atoms in the source is 4.0×10^9. The activity of the source, in nCi, is closest to: Hint (nCi = 10^{-9} Ci) and (1Ci = 3.70×10^{10} decays/sec.)

A) 2500
B) 92
C) 920
D) 25
E) 250

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activity → $\frac{decay}{sec}$

$9200 \frac{decay}{sec} \times \frac{1 sec \ Ci}{3.7 \times 10^{10} decay}$

$= 2.48 \times 10^{-10}$ Ci

248×10^{-9} Ci

248 nCi

14) The maximum permissible workday dose for occupational exposure to radiation is 26 mrem. A 63 kg laboratory technician absorbs 2.1 mJ of 0.7 MeV gamma rays in a work day. The quality factor (QF) for gamma rays is 1.0. The ratio of the equivalent dosage received by the technician to the maximum permissible equivalent dosage is closest to: (mrem = 10^{-3} rem, 1rad = 0.01 J/kg and 1ev = 1.6×10^{-19} J)

A) 0.18 B) 0.14 C) 0.17 D) 0.13 E) 0.15

$ED = AD \times RBE$

$\frac{2.1 \times 10^{-3}}{63} \times 1 = 3.33 \times 10^{-5}$ SV $\times 100 \times 10^{3} =$ 3.33 mRem

Ratio → $\frac{absorbed}{max} = \frac{3.33}{26} = 0.128$

17) The radioactive nuclide ^{60}Co is widely used in medical applications. It undergoes beta decay, and the energy of the decay process is 2.82 MeV per decay event. The half-life of this nucleus is 272 days. Suppose that a patient is given a dose of 6.9 microCurie of ^{60}Co. If all of this material decayed while in the patient's body, what would be the total energy (in J) deposited there? Hint: (1Ci = 3.70×10^{10} decays/sec.) and 1ev = 1.6×10^{-19} J.

A) 3.9 B) 11.0 C) 14.0 D) 8.63×101^{12} E) 4.15×10^{6}

tot Energy = num of decay $\times \frac{J}{decay}$

$8.68 \times 10^{12} \times 2.82 \times 10^{6} \times 1.6 \times 10^{-19}$

$= 3.9$

$\lambda = \frac{\ln(2)}{T_{1/2}}$

$\frac{\ln(2)}{272 \times 24 \times 60 \times 60}$

$2.94 \times 10^{-8} \frac{1}{s}$

$R = \lambda N$ → N: number of decay

$R = 6.9 \times 10^{-3} \times 3.7 \times 10^{7} = 2.94 \times 10^{-8} N$

$N = 8.68 \times 10^{12}$

سُبْحَانَ اللَّهِ ، وَالْحَمْدُ لِلَّهِ
وَلَا إِلَهَ إِلَّا اللَّهُ ، وَاللَّهُ أَكْبَرُ
وَلَا حَوْلَ وَلَا قُوَّةَ إِلَّا بِاللَّهِ