Homework 7 Solutions

Nuclear Engineering 162

Due 2 April 2008

VI.1 Turner 12.1 (Page 390)
(a) What is the average absorbed dose in a 40cm^3 region of a body organ (density = 0.92g cm^{-3}) that absorbs $3 \cdot 10^5\text{MeV}$ of energy from a radiation field?

$$V = 40\text{cm}^3$$

$$\rho = 0.93\text{g/cm}^3$$

$$E_{ab} = 3 \cdot 10^5\text{MeV}$$

$$D = \frac{E_{ab}}{m} = \frac{E_{ab}}{\rho V} = \frac{3 \cdot 10^5\text{MeV}}{0.93\text{g/cm}^3 \cdot 40\text{cm}^3} \cdot \frac{1.609 \cdot 10^{-13}\text{J/MeV}}{10^{-3}\text{kg/g}} = 1.29\mu\text{Gy}$$

(b) If the energy is deposited by ionizing particles with an LET of 10 keV pm in water, what is the dose equivalent according to Table 12.1?

$$L = 10\text{keV}/\mu\text{m} \rightarrow \frac{5-2}{23-7} = \frac{5-Q}{23-Q} \rightarrow Q = 2.5625$$

$$H = QD$$

$$H = 2.5625 \cdot 1.29\mu\text{Gy} = 3.31\mu\text{Sv}$$

(c) Express the answers to (a) and (b) in both rads and rems as well as Gy and Sv.

$$D = 1.29\mu\text{Gy} = 0.129\text{mrad}$$

$$H = 3.31\mu\text{Sv} = 0.331\text{mrem}$$

VI.2 Turner 12.3 (Page 390)
A beam of X-rays produces 4 esu of charge per second in 0.08 g in air. What is the exposure rate in a) mRs^{-1} and b) SI units?

$$\dot{X} = \frac{\Delta\dot{Q}}{\Delta m} = \frac{4esu/s}{0.08g}\frac{3.336 \times 10^{16}C/esu}{10^{-3}kg/g} = 1.66 \times 10^{-5}\frac{C}{kgs}\frac{1 * R}{2.58 \times 10^{-4}C/kg}$$

a) $\dot{X} = 64.65mR/s$
b) $\dot{X} = 1.668 * 10^{-5}\frac{C}{kgs}$

VI.3 Turner 12.15 (Page 392)
State the Bragg-Gray principle and the conditions for its validity.

The Bragg-Gray principle states that if a gas is enclosed by a wall of the same atomic composition, then the energy absorbed per unit mass in the gas is equal to the number of ion pairs produced ther times the W-value divided by the mass, m of the gas. Furthermore, the absorbed dose in the gas, Dg is equal to the absorbed dose in the wall.

The principle is valid if the wall thickness is at least as great as the maximum range of secondary charged particles, but not so great that incident radiation is appreciably attenuated.

VI.4 Turner 12.29 (Page 393)
What is the average whole-body dose in a 22 g mouse that contains $1.85 * 10^5$ Bq of ^{14}C distributed in its body?

$$\dot{D} = \frac{A\bar{E}}{m} = \frac{1.85 * 10^5 Bq \times 0.0495 MeV}{22g} = 6.66 * 10^{-8} Gys^{-1}$$

VI.5 Turner 12.30 (Page 393)
A patient receives an injection of $1.11 * 10^8$ Bq of ^{131}I, 10% of which goes to the thyroid, having a mass of 20 g. What is the average dose rate in this organ?
From appendix D,

$$\bar{E} = 0.89 \times 0.192 MeV + 0.07 \times 0.097 MeV + 0.02 * 0.069 MeV = 0.18 MeV$$

$$\dot{D} = \frac{A\bar{E}}{m} = \frac{1.11 * 10^8 Bq \times 30\% \times 0.18 MeV}{20g} = 4.8 * 10^{-5} Gys^{-1}$$

VI.6 Turner 12.36 (Page 394)
A worker inadvertently puts his hand at right angles into a uniform, parallel beam of 50 MeV protons with a fluence rate of 4.6×10^{10} protons per square cm per second. His hand was momentarily exposed for an estimated 0.5 s.
a) Estimate the dose that the worker received to the skin of his hand.
b) If the beam covered an area of 2.7 cm^2, what was the beam current?
a) From table 5.3,
$-\frac{dE}{\rho dx} = 12.4 MeV \frac{cm^2}{g}$ at 50 MeV
(12.23) $\dot{D} = \frac{\dot{\phi} A(-dE/dx)\Delta x}{\rho A \Delta x} = \dot{\phi}\frac{dE}{dx}$
$D = \dot{D}t = 4.6 * 10^{10} \frac{protons}{cm^2 s} \times 12.4 MeV \frac{cm^2}{g} \times 0.5s = 45.6 Gy$
b) $I = 4.6 * 10^{10} \frac{protons}{cm^2 s} \times 2.7 cm^2 \times e \frac{C}{proton} = 2.0 * 10^8 A = 20 nA$

VI.7 Turner 12.38 (Page 394)
When ^{38}S decays, a single 1.88-MeV gamma photon is emitted in 95% of the transformations. Estimate the exposure rate at a distance of 3m from a point source of ^{38}S having an activity of $(2.7 \cdot 10^{12}$Bq).

Energy Absorption Coefficients in Air, Dry (Near Sea Level)

Photon Energy (MeV)	μ/ρ(cm^2/g)
1.00	$2.780 \cdot 10^{-2}$
1.25	$2.666 \cdot 10^{-2}$
1.5	$2.547 \cdot 10^{-2}$
2	$2.345 \cdot 10^{-2}$

$$E_\gamma = 1.88 \text{MeV}$$

$$\frac{\mu}{\rho} \approx 0.024 \frac{\text{cm}^2}{\text{g}}$$

$$\dot{X}\left[\frac{\text{C}}{\text{g} \cdot \text{s}}\right] = \phi \frac{\text{decays}}{\text{s}} \cdot f \frac{\text{photon}}{\text{decay}} \cdot E_\gamma \frac{\text{MeV}}{\text{photon}} \cdot \frac{1.6 \cdot 10^{-13}\text{J}}{\text{MeV}} \cdot \frac{\mu}{\rho}\frac{\text{cm}^2}{\text{g}} \cdot \frac{1}{34}\frac{\text{C/kg}}{\text{J/kg}} \cdot \frac{1}{4\pi r^2}$$

$$\dot{X}\left[\frac{\mathrm{C}}{\mathrm{g}\cdot\mathrm{s}}\right] = 2.7{\cdot}10^{12}\frac{\text{decays}}{\mathrm{s}}{\cdot}0.95\frac{\text{photon}}{\text{decay}}{\cdot}1.88\text{MeV}{\cdot}\frac{1.6\cdot 10^{-13}\mathrm{J}}{\text{MeV}}{\cdot}0.024\frac{\mathrm{cm}^2}{\mathrm{g}}{\cdot}\frac{1}{34}\frac{\mathrm{C/kg}}{\mathrm{J/kg}}{\cdot}\frac{1}{4\pi(300\mathrm{cm})^2} = 5.4{\cdot}10^{-10}\frac{\mathrm{C}}{\mathrm{g}\cdot\mathrm{s}}$$

$$= 5.4\cdot 10^{-7}\frac{\mathrm{C}}{\mathrm{kg}\cdot\mathrm{s}} = 7.53\mathrm{R/hr}$$

VI.8 Turner 12.42 (Page 394)

A point source consists of a mixture of 4.2 Ci of ^{42}K and 1.8 Ci of ^{24}Na. Estimate the exposure rate at a distance of 40 cm.

^{42}K : 1.525 MeV (17.9%)

^{24}Na : 1.369 MeV (100%) and 2.754 MeV(100%)

with C in Ci, E in MeV and r in m.

$$\dot{X} = \frac{1}{w} * \frac{CE}{4\pi r^2} * \frac{\mu_{en}}{\rho} = 0.52\frac{CE}{r^2}[R/h] = 3.25CE[R/h]$$

$$\dot{X} = 3.25 * \sum iC_i * E_i = 3.25 * (4.2Ci \times 0.179 \times 1.525MeV + 1.8Ci \times 1 \times 1.369MeV|1.8Ci \times 1 \times 2.754MeV)$$

$$= 27.86R/h = 2\cdot 10^{-6}\frac{\mathrm{C}}{\mathrm{kg}\cdot\mathrm{s}}$$

VI.9 Turner 12.44 (Page 395)

The thermal neutron cross section for the ^{14}N(n,p)^{14}C reaction is 1.70 barns.

Calculate

a) the Q value for the reaction

$$Q = M_n + M_{^{14}\mathrm{N}} - (M_p + M_{^{14}\mathrm{C}}) = \Delta_n + \Delta_{^{14}\mathrm{N}} - (\Delta_p + \Delta_{^{14}\mathrm{C}}) = 8.0714 + 2.8637 - 7.289 - 3.0198$$
$$= 0.626MeV$$

b) the resulting dose in soft tissue per unit fluence of thermal neutrons.

$$D = \frac{\phi n\sigma E}{\rho}$$

$N(^{14}\mathrm{N}) = 1.29\cdot 10^{21}\frac{atoms}{cm^3} \times 0.99635 = 1.285\cdot 10^{21}\frac{atoms}{cm^3}$ in soft tissue.

$E = Q = 0.626MeV$ and $\rho = 1g/cm^3$

$$\frac{D}{\rho} = \frac{1.285\cdot 10^{21}atoms^{14}\mathrm{N}/cm^3 \times 1.7\cdot 10^{-24}cm^2 \times 0.626MeV}{1g/cm^3}\cdot\frac{10^3 g}{kg} = 2.19\cdot 10^{-13}\mathrm{Gy}\cdot\mathrm{cm}^2$$

VI.10 Turner 12.54 (Page 396)

A 22 g mouse is irradiated simultaneously by a beam of thermal neutrons, having a fluence rate of $4.2 * 10^7 cm^{-2}s^{-1}$, and a beam of 5 MeV neutrons, having a fluence rate of $9.6 * 10^6 cm^{-2}s^{-1}$.

a) calculate the dose rate to the mouse from the thermal neutrons.

b) Calculate the dose rate from the 5 MeV neutrons, interacting with hydrogen only.

c) Estimate the total dose rateto the mouse from all interactions, approximating the cross sections of the heavy elements by that of carbon(Fig 9.2)

a) Thermal neutrons in N

Assumptions: use soft tissue data for a 22 g mouse. ^{14}N(n,p)^{14}C is the dominant reaction with thermal neutrons.

$$N(^{14}\mathrm{N}) = 1.29 \cdot 10^{21}\frac{atoms}{cm^3} \times 0.99635 = 1.285 \cdot 10^{21}\frac{atoms}{cm^3}$$

$$\dot{D} \approx \frac{\dot{\phi}N(^{14}\mathrm{N})\sigma E}{\rho} = \frac{9.6 \cdot 10^6 cm^{-2}s^{-1} \times 1.285 \cdot 10^{21} atoms^{14}\mathrm{N}/cm^3 \times 1.7 \cdot 10^{-24} cm^2 \times 0.626 MeV}{1g/cm^3} \cdot \frac{10^3 g}{kg} \cdot 1.602 \cdot 10^{10}$$

$$= 9.2 \cdot 10^{-6} Gys^{-1}$$

b) 5 MeV neutrons in H

$$Q_{ave} = 2.5 MeV$$

$$\dot{D}_H \approx \frac{\dot{\phi}N(^1\mathrm{H}\sigma_H Q_{ave}}{\rho} = \frac{9.6 \cdot 10^6 cm^{-2}s^{-1} \times 5.98 \cdot 10^{22} atoms/cm^3 \times 1.61 \cdot 10^{-24} cm^2 \times 2.5 MeV}{1g/cm^3} \cdot \frac{10^3 g}{kg} \cdot 1.602 \cdot 10^{10}$$

$$= 3.7 \cdot 10^{-4} \mathrm{Gy} \cdot \mathrm{s}^{-1}$$

c) Total Dose Rate Similar calculations to thse done in part b) with O, C and N nuclei in soft tissue give $2.3 \cdot 10^{-5} Gy \cdot s^{-1}$,$7.6 \cdot 10^{-6} Gy \cdot s^{-1}$ and $2.3 \cdot 10^{-6} Gy \cdot s^{-1}$ respectively.

$$D_{tot} \approx 9.2 \cdot 10^{-6} + 3.7 \cdot 10^{-4} + 2.3 \cdot 10^{-5} + 7.6 \cdot 10^{-6} + 2.3 \cdot 10^{-6} = 4.1 \cdot 10^{-4} \mathrm{Gy} \cdot \mathrm{s}^{-1}$$