

Nuclear Medicine and Radiation Safety

Answer key with worked solutions

A. Understanding

1. Units.

(a) **Becquerel:** 1 decay per second (activity). **Gray:** 1 J of energy absorbed per kg of tissue (absorbed dose). **Sievert:** absorbed dose $\times$ radiation weighting factor (equivalent dose, reflecting harm). (b) Alpha particles deposit their energy along a **very short, dense track**, causing many ionizations close together, which damages DNA far more severely than the same energy spread out by gamma rays.

2. Choosing an isotope.

Technetium-99m: it emits **gamma rays** that leave the body to reach the camera, and its **short half-life** (6.01 h) keeps the dose low. Iodine-131's beta particles add dose without helping the image, and its half-life is longer. Radium-223 emits **alpha** particles, which cannot be detected outside the body and would damage tissue. Carbon-14 emits only beta particles and its half-life (5730 yr) is far too long.

B. Dose

3. Tissue dose.

$$(a) \frac{1.20 \times 10^{-3} \text{ J}}{0.0250 \text{ kg}} = 0.0480 \text{ J/kg} = \mathbf{0.0480 \text{ Gy}}$$

$$(b) \text{Beta (factor 1): } 0.0480 \text{ Gy} \times 1 = 0.0480 \text{ Sv} = \mathbf{48.0 \text{ mSv}}$$

$$(c) \text{Alpha (factor 20): } 0.0480 \text{ Gy} \times 20 = 0.960 \text{ Sv} = \mathbf{960. \text{ mSv}}$$

C. Protection

4. Inverse-square law.

$$(a) 40.0 \text{ }\mu\text{Sv/h} \times \left(\frac{1.00 \text{ m}}{0.500 \text{ m}} \right)^2 = 40.0 \text{ }\mu\text{Sv/h} \times 4.00 = \mathbf{160. \text{ }\mu\text{Sv/h}}$$

$$(b) \left(\frac{1.00 \text{ m}}{d} \right)^2 = \frac{1.00 \text{ }\mu\text{Sv/h}}{40.0 \text{ }\mu\text{Sv/h}}, \text{ so } d = 1.00 \text{ m} \times \sqrt{40.0} = \mathbf{6.32 \text{ m}}$$

5. Dose from time.

$$t = 15.0 \text{ min} \times \frac{1 \text{ h}}{60 \text{ min}} = 0.250 \text{ h}; \text{ dose} = 10.0 \text{ } \mu\text{Sv/h} \times 0.250 \text{ h} = \mathbf{2.50 \text{ } \mu\text{Sv}}$$

6. Shielding.

(a) $\frac{1.20 \text{ mm}}{0.30 \text{ mm}} = 4$ half-value thicknesses; $\left(\frac{1}{2}\right)^4 = 0.0625$, so **6.25 %** passes through

(b) $\frac{1}{32} = \left(\frac{1}{2}\right)^5$: 5 half-value thicknesses = $5 \times 0.30 \text{ mm} = \mathbf{1.5 \text{ mm}}$

D. Isotopes in use

7. Fluorine-18.

$$t = 2.00 \text{ h} = 120. \text{ min}; n = \frac{120. \text{ min}}{110 \text{ min}} = 1.091$$
$$A = 370 \text{ MBq} \times \left(\frac{1}{2}\right)^{1.091} = \mathbf{174 \text{ MBq}}$$

8. Annihilation energy.

$$E = mc^2 = (9.109 \times 10^{-31} \text{ kg})(2.998 \times 10^8 \text{ m/s})^2 = 8.187 \times 10^{-14} \text{ J}$$
$$\frac{8.187 \times 10^{-14} \text{ J}}{1.602 \times 10^{-13} \text{ J/MeV}} = 0.511 \text{ MeV} = \mathbf{511 \text{ keV}} \checkmark \text{ (a positron has the same mass, so each of the two gamma rays carries 511 keV)}$$

E. Challenge

9. Benefit and risk.

(a) $\frac{7.0 \text{ mSv}}{2.4 \text{ mSv/yr}} = \mathbf{2.9 \text{ years}}$ of natural background. (b) The extra risk from this dose is small, while the scan can **diagnose a serious illness** early and guide treatment; when the expected **benefit outweighs the risk**, the scan is justified. Doctors still keep the dose as low as reasonably achievable and avoid unnecessary scans.