InkPhysics

ANSWER BOOK

Radionuclide imaging and PET

Medical physics · Year 13

AQA 3.10.6.1, 3.10.6.2, 3.10.6.3, 3.10.6.4, 3.10.6.5, 3.10.6.6
CIE 24.3.1, 24.3.2, 24.3.3, 24.3.4, 24.3.5, 24.3.6
OCR A 6.5.2(a), 6.5.2(b), 6.5.2(c), 6.5.2(d), 6.5.2(e)

18 questions · 49 marks

NAVY EDITION

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SECTION A · Warm-up

A1 A radioactive nuclide chemically attached to a biologically active molecule, such as a glucose analogue, which the body takes to wherever that molecule is used (1). The radiation it emits from there is detected to map the tracer's location (1). [2]

A2 Gamma photons are penetrating enough to escape the body and be detected outside (1); alpha particles are absorbed within a fraction of a millimetre of tissue and beta minus particles within a few millimetres, so both deliver dose but no image (1). (A PET tracer is a positron emitter, but there too it is photons that leave the patient: the pair of 511 keV gammas made when the positron annihilates.) The half-life must be long enough for the tracer to be prepared, administered and imaged, but short enough that the patient is not left radioactive for weeks (1). [3]

A3 X-ray and CT images show structure: what the anatomy looks like (1). A tracer image shows function: where the body is actually using the labelled molecule, so which tissue is active, inflamed or failing (1). [2]

A4 The hospital keeps a generator containing the longer-lived parent nuclide, molybdenum-99 (1). Technetium-99m forms continuously as the molybdenum decays, and is drawn off each day as it is needed (1). [2]

A5 Many tumours are metabolically very active and consume glucose faster than the tissue around them (1), so the tracer accumulates in the tumour and the annihilation photons come mostly from where the disease is (1). [2]

SECTION B · Standard

B1 The lead collimator admits only gamma photons travelling nearly parallel to its channels, so each detected photon's origin lies along a known line (1); oblique photons are absorbed by the slats (1). The scintillator converts each admitted gamma into a flash of light whose position is recorded, building a map of the tracer's location one photon at a time (1). [3]

B2 24 hours is four half-lives (1) [3]

$A/A_0 = (1/2)^4 = 0.0625$ (1)

$\approx 1/16$, about 6% (1)

B3 The positron and electron annihilate, so both particles vanish (1) and their rest energy becomes two gamma photons travelling in opposite directions (1). Each photon carries 511 keV, the rest energy of one electron through $E = mc^2$ (1). [3]

B4 $E = mc^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2$ (1) [3]
$E = 8.20 \times 10^{-14}$ J (1)
Dividing by 1.60×10^{-19} J eV^{-1} gives about 5.1×10^5 eV ≈ 511 keV (1)

B5 The electron-positron pair is very nearly at rest when it annihilates, so its total momentum is close to zero (1). Momentum is conserved, so the two photons must carry equal and opposite momenta: they leave back to back (1). [2]

B6 $1/T_E = 1/T_B + 1/T_P = 1/12 + 1/6.0$ (1), so $T_E = 4.0$ hours (1). Radioactive decay and biological clearance both remove activity from the patient at the same time, so together they act faster than either would alone (1). [3]

B7 As with a tracer, the nuclide rides the body's own chemistry: iodine is taken up and concentrated by the thyroid, so the radiation is delivered where it is wanted (1). The aim differs because the radiation is meant to deposit its energy in the thyroid and destroy the tissue (1). Absorption of radiation inside the patient, useless for imaging, is exactly what the treatment requires (1). [3]

SECTION C · Stretch

C1 The patient lies inside a ring of gamma detectors (1). When two 511 keV photons arrive at opposite sides of the ring at effectively the same instant, they are taken to come from one annihilation (1), which must lie on the straight line joining the two detectors (1). Recording hundreds of thousands of such coincidence lines, the scanner finds where they intersect: the places where the tracer, and so the biological activity, is concentrated (1). [4]

C2 $E = 511$ keV $= 8.20 \times 10^{-14}$ J (1) [2]
$f = E/h = 8.20 \times 10^{-14}/(6.63 \times 10^{-34}) = 1.24 \times 10^{20}$ Hz (1)

C3 One eighth is three half-lives (1) [2]
$t = 3 \times 110 = 330$ minutes, that is 5.5 hours (1)

C4 The scanner emits nothing: it is purely a detector, listening for gamma photons leaving the body (1). The radiation dose comes from the injected tracer itself, whose positrons annihilate inside the patient (1). Choosing a short half-life and a small activity keeps that dose low while still giving enough coincidences for an image (1). [3]

C5 One photon travels 2 × 4.5 = 9.0 cm further than the other; the ring radius cancels (1). $\Delta t = 9.0 \times 10^{-2}/(3.00 \times 10^{8}) = 0.30$ ns (1). A genuine pair from anywhere in the body must be accepted, and an annihilation near the edge of the ring can put nearly the full 80 cm difference between the paths, up to about 2.7 ns, so the coincidence window is a few nanoseconds wide and this 0.30 ns falls comfortably inside it. Timing much finer than a nanosecond is what a time-of-flight scanner adds, using the difference to locate the annihilation along the line between the detectors rather than to accept the pair (1). [3]

C6 Q should be chosen: its gamma photons escape the body to be detected (1), and a half-life of hours is long enough to prepare, administer and image, yet short enough that the dose falls away soon after the test (1). P is rejected because beta minus particles are absorbed inside the patient, giving dose but no image, and 8.0 days leaves the patient radioactive long afterwards (1). R is rejected because 30 minutes is 20 half-lives, so its activity would be almost entirely gone before imaging ends (1). [4]