MRTY 1036 – HEALTH PHYSICS
AND RADIATION BIOLOGY

SOLUTION

Section A

MCQs

1. d
2. c
3. c
4. a
5. a
6. b
7. a
8. b
9. d
10. b
11. c
12. c
13. a
14. d
15. c
16. d
17. b
18. c
19. b
20. c
Section A

Question 1

(a)
The radiopharmaceutical produces gamma rays in the body. The gamma rays pass out of the body.

1/2 mark

The gamma rays pass through the collimator and hit the scintillation crystal. The gamma rays are converted into light.

1/2 mark

The light reaches the photocathode and produces an electron. The electron is multiplied by dynodes in the photomultiplier tube.

1/2 mark

The electrons leave the PMT as a pulse. The position of the pulse is recorded as signal. The pulses build up the image.

1/2 mark

(b)

(i)
A collimator is a sheet of lead with small holes which is placed in front of the camera face.

Good explanation of what it is – 1 mark

It only allows radiation that is perpendicular to the camera face to reach the camera. Any radiation which is scattered will be travelling at an angle and is therefore attenuated by the collimator. Scatter reaching the camera is reduced.

How it reduces scatter – 1 mark

(ii)
A pulse height analyser is an electronic component of the camera. It rejects pulses that are reduced in height.

Good explanation of what it is – 1 mark

Lower height pulse are those that are from gamma rays that are lower in energy. These gamma rays are likely to have lost energy during a scatter interaction. Therefore the PHA rejects pulses from scattered x-rays.

How it reduces scatter – 1 mark

(c)
Hot spots
Area on an image where there is an increased number of counts due to an accumulation of radiopharmaceutical.

1/2 mark

This is used to show up areas of increased cell activity on images - e.g. tumours or infection or bone growth

mention tumour, infection, bone growth or something else valid – 1 mark
Cold spot
Area on an image where there is a decreased number of counts compared to the background

1/2 mark
due to a lack of radiopharmaceutical.

1/2 mark
This is used to show areas which have a lack of blood or air flow, or clots - e.g. in the heart or lungs.

mention lack of blood or air flow, or clots or something else valid – 1 mark

(total – 10 marks)
Question 2

(a) \[ ^{133}_{54} \text{Xe} \rightarrow ^{133}_{55} \text{Cs}^* + ^0_\beta + ^0_{\bar{\nu}} \rightarrow ^{133}_{55} \text{Cs} + ^0_\gamma \]

correct and complete - 1 mark

(ii) A metastable nucleus has an excess of energy, so is in an excited state which is long-lived.

1 mark

(iii) Energy spectrum of the $\beta^-$ particles:

\[ \begin{array}{c}
\text{Number of particles} \\
\hline
\text{Energy} \\
\end{array} \]

correct axes - 1/2 mark
essentially correct shape - 1/2 mark

The spectrum is a continuum because the beta particles can have any energy from zero to a maximum energy.

1 mark

This is because an anti-neutrino (saying neutrino is good enough) is given out in the process, which can take off any portion of the energy released by the nucleus.

1 mark

(iv) Also expect to observe gamma rays.

1 mark

These are released from the meta-stable nucleus in order for it to become stable. (not essential)

The spectrum will be a line spectrum, as the energy of the gamma rays depends on the difference in energy levels of the nucleus

1 mark
(b) 

\[ A = A_0 e^{-\lambda t} \]

Hence the decay constant is given by

\[ \lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{30} = 0.0231 \text{ yr}^{-1} \]

Then

\[ t = \frac{\ln \left( \frac{A_0}{A} \right)}{\lambda} = \frac{\ln 10}{0.0231} = 99.68 \text{ yr} \]

1 mark

1 mark

1 mark

(total – 10 marks)
**Question 3**

(a) 
\[ D = \frac{E_{abs}}{m} \]
\[ m = \rho V = 1.00 \times 1.250 = 1.25 \text{ kg} \]
Thus \( D = \frac{0.30}{1.25} = 0.24 \text{ Gy} \) or 24 cGy

correct approach - 1 mark
answer - 1 mark

(b) Using X-rays, therefore \( Q = 1 \) and so \( H_{liver} = 0.24 \text{ Sv} \)

\[ H_{eff} = H_T W_T \]
\[ = 0.24 \times 0.05 \]
\[ = 0.012 \text{ Sv} \] or 12 mSv

answer - 1 mark

(c) 
\[ \frac{1}{T_{1/2 \, (eff)}} = \frac{1}{T_{1/2 \, (phys)}} + \frac{1}{T_{1/2 \, (bio)}} \]
\[ \Rightarrow \frac{1}{T_{1/2 \, (eff)}} - \frac{1}{T_{1/2 \, (phys)}} = \frac{1}{T_{1/2 \, (bio)}} \]

this approach - 1 mark

There is no need to convert to SI units if we remain consistent and use days for all half-lives.

\[ \frac{1}{T_{1/2 \, (bio)}} = \frac{1}{7.6} - \frac{1}{8} = 0.1316 - 0.125 = 6.579 \times 10^{-3} \]

working - 1 mark

Therefore \( T_{1/2 \, (bio)} = 1/6.579 \times 10^{-3} = 152 \text{ d} \)

answer - 1 mark

(d) The correct option is

2) more closely approach the physical half-life of the isotope.

answer - 1 mark

Algebraic explanation:

\[ \frac{1}{T_{1/2 \, (eff)}} = \frac{1}{T_{1/2 \, (phys)}} + \frac{1}{T_{1/2 \, (bio)}} \]

Since \( T_{1/2 \, (bio)} \) is very large, \( \frac{1}{T_{1/2 \, (bio)}} \) approaches zero, therefore

\[ \frac{1}{T_{1/2 \, (eff)}} \rightarrow \frac{1}{T_{1/2 \, (phys)}} \]

Invert both sides; \( T_{1/2 \, (eff)} \rightarrow T_{1/2 \, (phys)} \)

2 marks

OR \[ \rightarrow \] PTO
Alternative, wordy explanation:

If the biological half-life is very, very long, then biological processes are failing to remove the isotope from the body so the only process removing the isotope appreciably, is radioactive decay and the half-life of this process is $T_{1/2}^{(phys)}$ so this becomes the only contribution to the $T_{1/2}^{(eff)}$.

2 marks

(total – 10 marks)
Question 4

(a) 
Using the inverse square law formula 

\[ D_1 r_1^2 = D_2 r_2^2 \]

1 mark

\[ D_1 = 90 \; \mu Sv/hr \]

1 mark

\[ D_2 = 10 \; \mu Sv/hr \]

1 mark

\[ r_1 = 1 \; m \]

1 mark

Therefore

\[ r_2 = \sqrt{\frac{D_1 r_1^2}{D_2}} = \sqrt{\frac{90 \times 1}{10}} = 3 \; m \]

1 mark

(b) 
Since this is her profession, she is regarded as a radiation worker.

1 mark

Consequently, she is allowed 20 mSv per annum

1 mark

That means, she is allowed 20/12 = 1.67 mSv per month

1 mark

So she is able to handle the source 1.67/0.1 = 16.7

1 mark

Round down to 16 times a month

1 mark

(total – 10 marks)
Question 5

(a) The dose required to kill 90% of the population is given by

\[ D_{10} = \ln(10) \times D_0 \]

\[ = 2.3 \times 3.04 \text{ Gy} \]

\[ \approx 7 \text{ Gy} \]

The number of decades of cell killing is \(\frac{49}{7} = 7\) \(\text{1 mark}\)

Number of cells remaining = \(5 \times 10^8 \times 10^{-7} = 50\) \(\text{1 mark}\)

(b) Five factors that determine RBE:
- Radiation quality (Linear Energy Transfer)
- radiation dose
- number of dose fractions
- dose rate
- biological system.

For each point up to 5 - \(\frac{1}{2}\) mark each

Bonus for getting all 5 - \(\frac{1}{2}\) mark
(sub-total 3 marks)

(c) Stochastic effects:
A. Arise from chance, and have a probability of occurring. Basically, it means that there is always a risk of an event happening, as function of dose. \(\text{1/2 mark}\)

B. There is no threshold for stochastic effects The greater the dose, the greater the risk of an event occurring. \(\text{1/2 mark}\)

C. Also, once an event has occurred, it doesn’t matter what the initial dose was, the severity is still the same. \(\text{1/2 mark}\)

Example:
The primary example is cancer following mutation of somatic cells, or heritable disease in their offspring owing to mutation of reproductive (germ) cells. There can be important effects on an embryo or fetus. \(\text{1/2 mark}\)

Mark for each valid key point up to 2 marks
-\(\frac{1}{2}\) for any clearly incorrect statement
Deterministic effects:

A. Not considered to be probabilistic \( \frac{1}{2} \text{ mark} \)

B. There is a threshold, below which they don't normally occur. \( \frac{1}{2} \text{ mark} \)

C. The severity of deterministic effects does increase with increased dose. \( \frac{1}{2} \text{ mark} \)

Example:
Deterministic effects are due in large part to the killing/malfunction of cells following high doses. \( \frac{1}{2} \text{ mark} \)

Mark for each valid key point up to 2 marks
-\( \frac{1}{2} \) for any clearly incorrect statement

(total – 10 marks)
Question 6

(a) 
\[ Z = \rho v \]

\[ Z_{\text{fat}} = 920 \times 1450 = 1.334 \times 10^6 \text{ rayl} \approx 1.33 \times 10^6 \text{ rayl} \]

\[ Z_{\text{muscle}} = 1040 \times 1585 = 1.6484 \times 10^6 \text{ rayl} \approx 1.65 \times 10^6 \text{ rayl} \]

(3 or 4 sig. figs is correct, hence 2 to 5 is acceptable)

results 1 mark each – 2 marks

(b) 
\[ \frac{I_r}{I_o} = \frac{\left( Z_{\text{muscle}} - Z_{\text{fat}} \right)^2}{\left( Z_{\text{muscle}} + Z_{\text{fat}} \right)^2} = \frac{\left( 1.6484 \times 10^6 \right)^2 - \left( 1.334 \times 10^6 \right)^2}{\left( 1.6484 \times 10^6 \right)^2 + \left( 1.334 \times 10^6 \right)^2} = 0.011 \]

correct equation - 1 mark

calculation - 1 mark

Hence, only ~1.1% of the energy is reflected at the interface.

result - 1 mark

(c) 
There is only ~1% reflection, but this is relatively large for tissues, because the acoustic impedances show a relatively large difference.

1 mark

(It is, however, much smaller than for interfaces with bone or air)

The interface will be clearly seen in ultrasound images

1 mark

(d) 
The reflected signal (echo) will undergo a frequency shift (two in fact). Frequency will increase if moving towards the transducer and decrease if moving away.

1 mark

The frequency shift is caused by the Doppler effect

1 mark

(total – 10 marks)