1. Radioactive sources are used in hospitals.

Radioactive tracers allow the doctor to investigate organs in a patient's body without surgery.

The patient has a radioactive tracer injected into a vein.

The hospital has four radioactive sources, **A**, **B**, **C** and **D**.

Radioactive source	Radiation emitted	Activity (counts per minute)		
		At start	After 1 hour	After 2 hours
A	?	2000	140	8
B	?	1000	490	240
C	?	2000	950	485
D	?	1000	75	5

The doctor wants to use a tracer with a half-life of about 1 hour.

Which radioactive source should the doctor use as the tracer?

Justify your choice using the data in the table.

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[3]

2. Most of the energy produced in the Sun is from the fusion of hydrogen into helium by the proton-proton chain.

The proton-proton chain involves three stages.

$$_1^1\mathrm{H} + {}_1^1\mathrm{H} \rightarrow {}_1^2\mathrm{H} + \mathrm{e}^+$$
$$_1^2\mathrm{H} + {}_1^1\mathrm{H} \rightarrow {}_2^3\mathrm{He}$$
$$_2^3\mathrm{He} + {}_2^3\mathrm{He} \rightarrow {}_2^4\mathrm{He} + {}_1^1\mathrm{H} + {}_1^1\mathrm{H}$$

(i) How many positrons (e^+) are emitted to produce a stable ^{4}He nucleus?

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[1]

(ii) Why is a positron emitted in the first stage and not an electron?

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[1]

3(a). Read the following article.

Some cancers are treated with a form of radiation therapy called permanent brachytherapy. A small radioactive source is placed inside a tumour. The source then decays over time, releasing ionising radiation that breaks down the tumour.

(i) Link each **phrase** from the article to its correct **meaning.**

phrase	**meaning**
	particles or waves that can break apart atoms
radioactive source	a substance that produces alpha, beta or gamma radiation
ionising radiation	the time taken for half of a radioactive substance to turn into another substance
decay	the particles in a sample naturally change from one element to another
	energy is released by a chain reaction

[3]

(ii) The radioactive source in the tumour gives out one type of ionising radiation.

A small amount of the radiation can be detected outside the body.

This shows that one type of radiation is definitely **not** produced by the source.

Put a (ring) around the correct choice to complete each sentence.

The source does not produce **alpha / beta / gamma** radiation.

This is the least **penetrating / evaporating / decaying** type of radiation,

so it **would / would not** pass out of the body.

[2]

(b). For brachytherapy to be effective, the source implanted into the tumour must have an activity that is high enough to kill the tumour, but drops to background levels soon after.

A doctor has a choice of four different sources to treat a tumour.

- Each source produces the same type of radiation.
- He knows that the source he chooses must have an activity of not more than 4 decays per second at the end of the treatment.
- The treatment lasts one year.
- Each source starts with an activity of 32 decays per second.

source	A	B	C	D
half life	2 months	3 months	6 months	2 years

Which source should the doctor use to treat this tumour?

Justify your answer.

source _____

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[3]

4(a). There are many arguments for and against nuclear power.

Some people are worried about the materials left over as waste from nuclear power stations.

Three of the materials left over are caesium-134, technetium-99 and zirconium-93.

They have very different half-lives.

(i) What is meant by half-life?

---

[1]

(ii) The longer the half-life, the less active the radioactive isotope, for the same number of atoms.

Caesium-134 has a half-life of about 2 years.

Technetium-99 has a half-life of about 200 000 years.

Zirconium-93 has a half-life of about 1.5 million years.

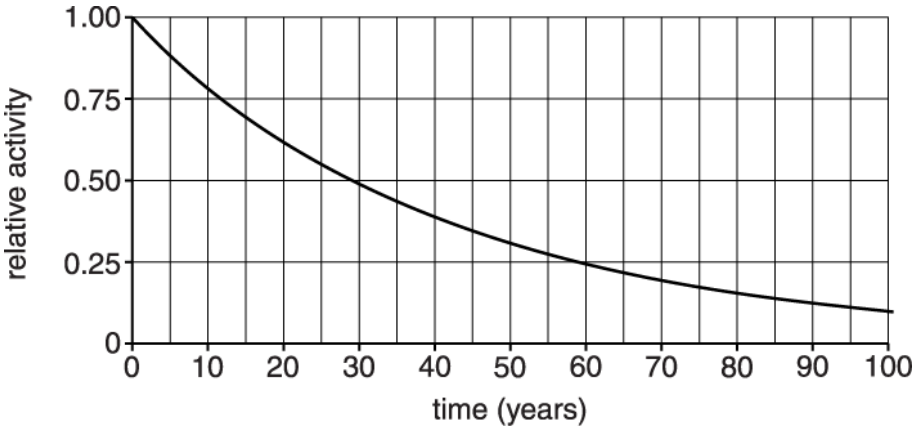
Using this information, draw lines from each **material** to its **activity** and from each **activity** to its **time taken to be considered safe**. Assume each material starts with the same number of atoms.

material	activity	time taken to be considered safe
caesium-134	least active	will take the shortest time to be considered safe
technetium-99	moderate activity	will take moderately long to be considered safe
zirconium-93	most active	will take the longest time to be considered safe

[2]

(iii) A scientist took a sample from a nuclear waste site and measured its activity.

From his data, he generated this graph.



Use the graph to decide whether the sample could be one of the three isotopes given in part **(ii)**, or a different isotope. Explain your decision.

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[2]

(b). Caesium-134 decays by beta (β) decay.

Complete the nuclear equation for its decay.

$$^{134}_{55}\text{Cs} \longrightarrow \begin{matrix}\cdots\\\cdots\end{matrix}\text{Ba} + \begin{matrix}\cdots\\\cdots\end{matrix}\beta$$

[2]

5. Nuclear power stations produce waste. Some of the waste is radioactive.

Some of these waste products are plutonium-238 (Pu-238) and caesium-135 (Cs-135).

Pu-238 decays to uranium (U) by emitting an alpha particle (α); Cs-135 decays to barium (Ba) by emitting a beta particle (β).

Complete these nuclear decay equations:

$$^{238}_{94}\text{Pu} \longrightarrow \text{.....} + \text{.....}\ \alpha + \ ^{\text{.....}}_{\text{.....}}\text{U}$$

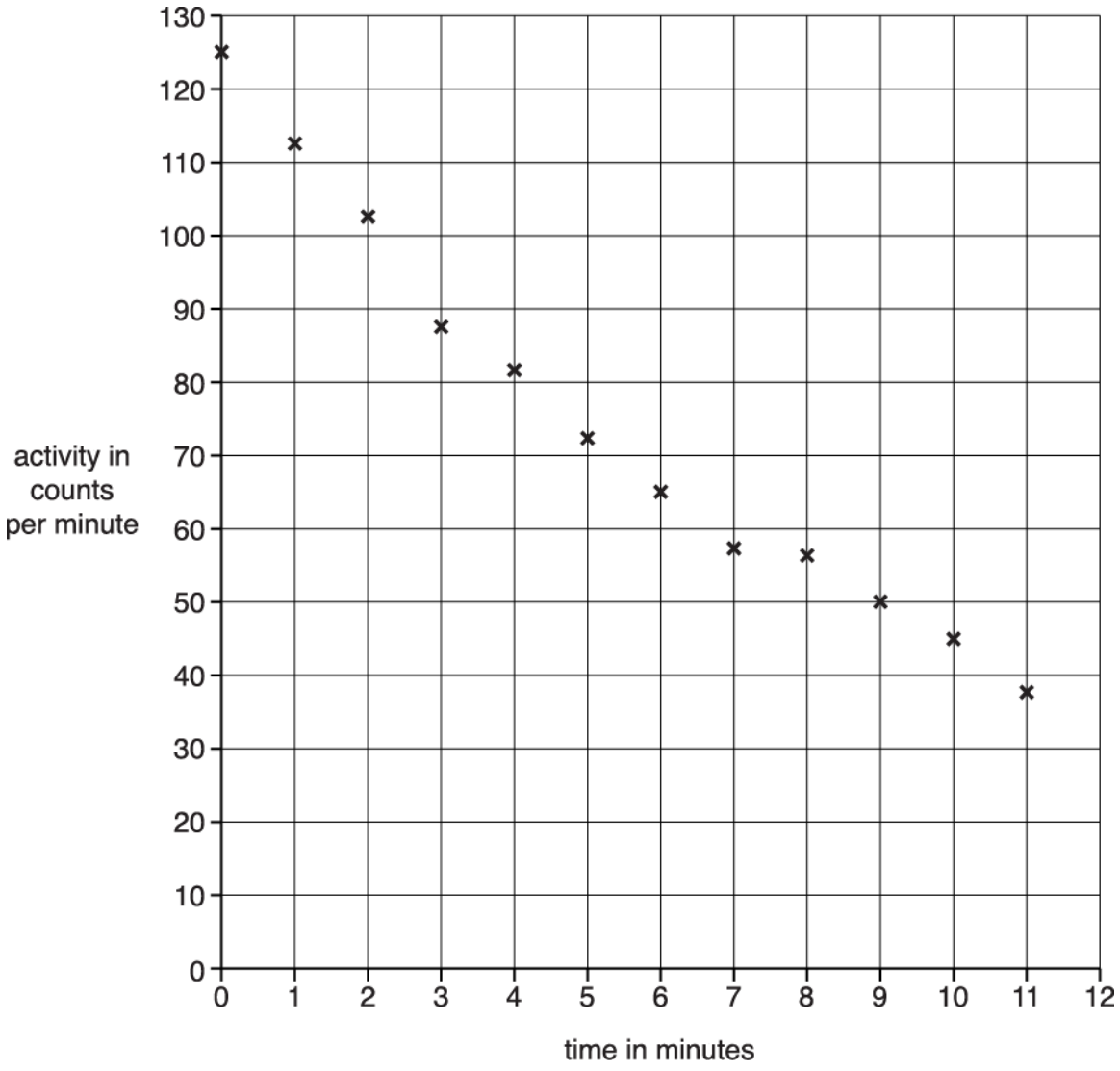
$$^{135}_{55}\text{Cs} \longrightarrow \text{.....} + \text{.....}\ \beta + \ ^{\text{.....}}_{\text{.....}}\text{Ba}$$

[3]

6(a). A teacher sets up a demonstration experiment. She uses a radioactive source to measure how its activity changes during a lesson.

The students record the activity of the radioactive source every minute.

They plotted this graph:



(i) Complete the graph by drawing a curve of best fit to show how the source decays.

[1]

(ii) Use the graph to estimate the value for the half-life of the source.

half-life = _____ minutes **[1]**

(b). Radioactive sources are considered safe when their activity becomes the same as background radiation.

(i) What is background radiation?

_____

_____ [1]

(ii) The background radiation in the laboratory is 20 counts per minute.

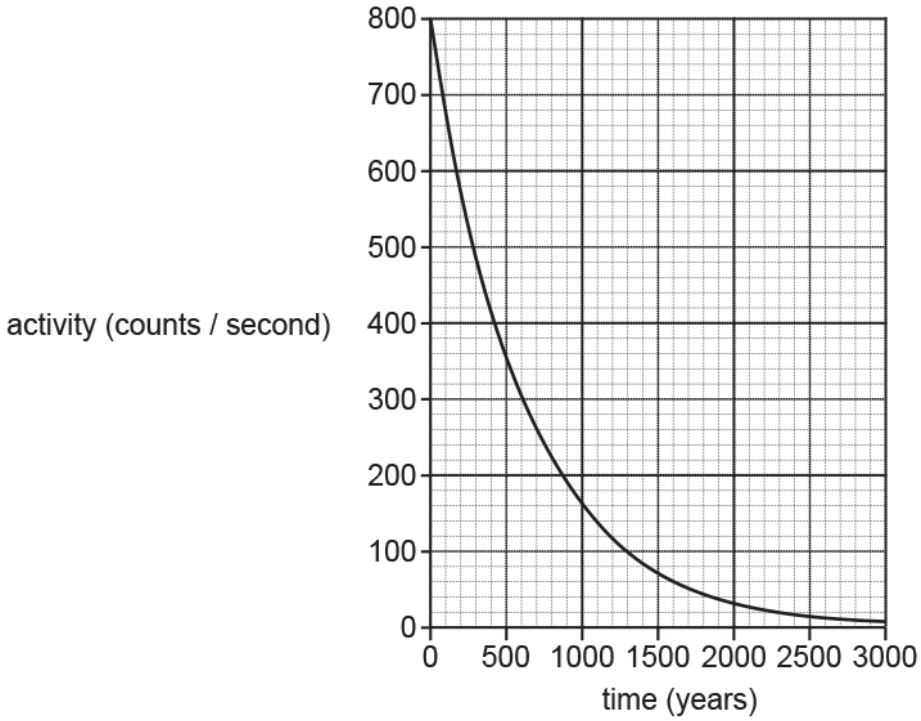
After how many half-lives could this source be considered safe?

Show your working.

number of half-lives _____ [2]

7(a). This question is about the radioactive isotope americium-241, which is found in smoke detectors.

The graph shows how the activity of a sample of americium-241, with an initial activity of 800 counts per second, would change with time.



Use the graph to obtain an estimate of the half-life of americium-241.
Show your working on the graph.

Half-life = ---------- years **[3]**

(b). In schools, the decay of radioactive isotopes such as americium-241 can be modelled by a game rolling many dice. Each dice has 1 chance in 6 of showing a 'six' each time.

In a typical game, 100 dice are rolled onto a table.

The number showing six spots on the top are removed and counted.

The remaining dice are rolled again, and the process continued.

The results are put into a table. The following is an example for one game.

Roll number	1	2	3	4	5	6	7
Number of sixes	18	13	12	9	6	7	5
Number of dice remaining	82	69	57	48	42	35	30

Each 'roll number' stands for an equal interval of time.

(i) What does the number of dice remaining at any roll stand for?

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[1]

(ii) What does the number of sixes taken out in any roll stand for?

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[1]

(iii) Explain why the data in this table suggest that the half-life is about 4 'rolls' but that it's not possible to be exact.

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[3]

8(a). Table 8.1 shows data for four radioactive isotopes.

Isotope	Half life	Type of decay
molybdenum-98	stable	
molybdenum-99	66 hours	beta
technetium-99m	6 hours	gamma
thallium-201	73 hours	gamma

Table 8.1

Technetium-99m is used in hospitals.

Technetium-99m is produced when molybdenum-99 emits beta radiation.

One method of producing molybdenum-99 is by firing neutrons at molybdenum-98.

Complete these nuclear equations to show the production of technetium-99m.

$$^{98}_{42}\text{Mo} + ^{\cdots\cdots}_{\cdots\cdots}\text{n} \rightarrow ^{99}_{42}\text{Mo}$$

$$^{99}_{42}\text{Mo} \rightarrow ^{99}_{43}\text{Tc} + ^{\cdots\cdots}_{\cdots\cdots}\text{e}$$

[2]

(b). Molybdenum-99 is produced in nuclear reactors and then transported to hospitals. It may take several days for the molybdenum-99 to be transported.

In the hospital molybdenum-99 decays and the technetium-99m is produced as shown in part (a).

Using information from Table 8.1, explain why technetium-99m is not transported directly to hospitals.

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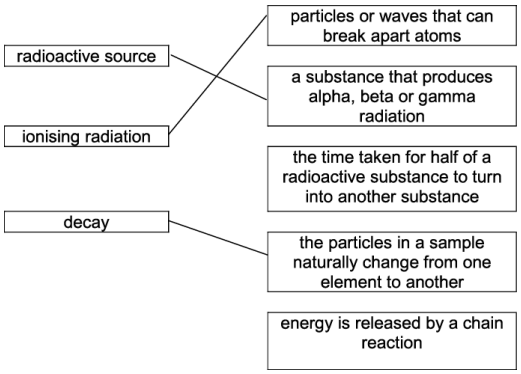
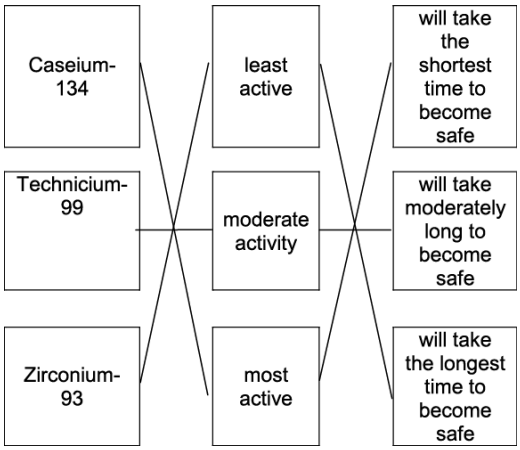
[2]

END OF QUESTION PAPER

Question			Answer/Indicative content	Marks	Guidance
1			gamma can exit / be detected outside the body / alpha cannot exit body (1); use of data for sources B or C to show their half-life is 1 hour (1) C (1);	3	**not just** gamma is more penetrating eg. 950 is about half of 2000 look at table for indication of calculation outcomes **not just** 'it goes from 2000 to 950 and then to 485' **do not allow** incorrect statements such as 'half-life is 500' **Examiner's Comments** Half the candidates scored at least one mark for this question. Many candidates did not show an understanding of how an injected tracer works and failed to read the information in the question carefully enough. Some ignored the statement that the source needed to have a half-life of one hour and instead looked for the one with least activity, to prevent causing cancer, or most activity, to get a good reading. Many thought that alpha is less damaging to humans than gamma and few appreciated that it needed to be gamma in order to exit the body. Many failed to get a mark for correct ideas about the meaning of half-life as they did not follow the instructions in the question to justify their answer using the data in the table. The terms half-life and activity were often interchanged such as in the incorrect statement 'the half-life of C is 500'.
			Total	**3**	
2		i	2	1	**Examiner's Comments** Many candidates appeared to confuse 'protons' and 'positrons'.
		ii	idea of conserving charge	1	**Examiner's Comments** Many candidates recognised that charge was involved but were unable to express the idea of charge conservation clearly.

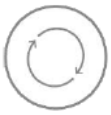
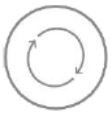
Question			Answer/Indicative content	Marks	Guidance
			Total	2	

Question			Answer/Indicative content	Marks	Guidance
3	a	i		3	1 mark per correct line <u>Examiner's Comments</u> This objective style question was well answered, although weaker candidates seemed unsure of the meaning of the term 'ionising radiation'.
		ii	alpha (1) both penetrating **and** would not (1)	2	<u>Examiner's Comments</u> Most candidates could identify alpha as the source, and therefore that it is least penetrating and that it would not pass out of the body. Candidates who failed to identify the source correctly for the first mark usually failed to score the second mark too, although the mark scheme did treat these as independent marking points.
	b		Source B (1) **2 max from the following:** some evidence of an attempt at half life calculation how long it takes for the activity of the source to reach 4 / activity of their source after 1 year source remains sufficiently active for the majority of the year owtte source becomes inactive shortly after 1 year	3	no marks if source D chosen attempted calculation e.g. 32, 16, 8 etc **allow** discussion of safety of source after treatment last 2 points can only be awarded if Source B chosen <u>Examiner's Comments</u> This question proved difficult for most candidates, with only a minority attempting to use the data regarding half-life to calculate the activity after one year. Significant numbers of candidates over-counted the number of half-lives to go from an activity of 32 to 4 e.g. 4 half-lives instead of 3. They seemed to count the values rather than the number of times halved i.e. 32, 16, 8, 4 giving 4 half-lives was a common response. These candidates could gain partial credit for the idea of repeatedly halving the activity, although they would get the incorrect value for the half life after 12 months.

Question			Answer/Indicative content	Marks	Guidance
			Total	8	
4	a	i	the time taken for half of a radioactive sample to decay / time taken for activity to drop to ½	1	not radioactivity in place of activity **allow** count rate in place of activity **Examiner's Comments** This question was themed around the topic of radioactive waste. More able candidates produced good descriptions of half-life and this had clearly been well covered in schools.
		ii		2	one mark for the left, one for the right **Examiner's Comments** The calculation of half-life from a graph was done well.
		iii	measurement of half life off graph (28 years) so not the same as any of the other isotopes	2	**allow** 27?31 / half life may be marked on graph second mark dependent on first mark being awarded must be a comparison – not just “no”
	b		$^{134}_{55}Cs \rightarrow {}^{134}_{56}Ba + {}^{0}_{-1}\beta$	2	barium correct = 1 mark beta correct = 1 mark **allow** 1 mark for any numbers which balance left and right of equation **Examiner's Comments** The most able could produce the correct nuclear equation and those that could not usually ensured that the equation balanced and therefore received some credit.
			Total	7	

Question			Answer/Indicative content	Marks	Guidance
5			? 4 and 2 (1) ? 0 and ?1 (1) U 234, 92 **and** Ba 135, 56 (1)	3	both needed; correct answers only   (= 3 marks) **Examiner's Comments** The representation of alpha and beta particles was not known by most candidates. Those who did know went on to correctly balance the equations. The nuclear representation of alpha was better known than beta.
			Total	3	

Question			Answer/Indicative content	Marks	Guidance
6	a	i	best fit curve drawn i.e. single **smooth** curve with roughly equal number of points either side of the line	1	judge by eye **Examiner's Comments** Most answers were not given credit as the curve of best fit either had too many points on one side, or it was not a single line or it was not smooth. Candidates need to take more care when drawing lines on graphs. Very often the three points at the end were either ignored or the line was placed well below them.
		ii	from 5.5 to 7.0 inclusive	1	**Examiner's Comments** Most answers fell within the tolerance given in the mark scheme. A few candidates wrote the time as seen on a stopwatch e.g. 5.30 meaning 5.5, others gave the activity e.g. 62 instead of the time.
	b	i	radiation present in the environment / around us / radiation that is always present	1	**allow** radiation in the atmosphere / air **ignore** named sources or references to natural sources / radiation from the air **Examiner's Comments** Some answers gave sources of background radiation rather than what it is.
		ii	any value in the range from 2 to 3 inclusive **but** if incorrect, for 1 mark, look for working applications of the half-life over at least two halvings, starting at any number	2	e.g. 124?62?31 or 20?10?5 **Examiner's Comments** About half the candidates obtained an answer within the values in the mark scheme. Some of those giving an incorrect answer were able to gain a compensatory mark by showing appropriate working.
			Total	**5**	

Question			Answer/Indicative content	Marks	Guidance
7	a		Graph marking/references show two points of activity ratio 2:1 ✓ 400 years ≤ *T*½ ≤ 450 years ✓	(AO 1.2) 2 (AO 3.1b)	One may be (0, 800) Examiner's Comments The majority of candidates successfully calculated the correct half-life of 241Am., someone in ten candidates did not show any working on the graph, or quote any data taken from the graph and so could not be credited with both marks. AfL  Key: It is important to answer the question that has been asked. Underlining key terms such as use the graph and show your working on the graph can help candidates to check that they are answering the question asked.  AfL Guidance to offer for future teaching and learning practice.
	b	i	Number of radioactive nuclei (remaining) ✓	1 (AO 2.1)	ALLOW atoms for nuclei

Question			Answer/Indicative content	Marks	Guidance
		ii	(Number of) nuclei decaying / (number of) alpha particles emitted AW / activity (of sample) ✓	1 (AO 2.1)	Examiner's Comments This was a very challenging question for the majority of candidates. Many candidates used technical terms such as 'isotope' 'half-life' and 'amount of radiation' in their responses to parts (i) or (ii) but in an arbitrary way that showed poor understanding. Exemplar 21 This straightforward response to Q8(c)(ii) was one of the few which showed a good understanding of the dice rolling simulation. 
		iii	Any three from: 48 is roughly half of 100 ✓ 'Number of sixes' dice should be one-sixth of previous 'number of dice left' ✓ It's random ✓ the sample is very small ✓	3 (AO 2.2 x 3)	Examiner's Comments Many candidates were able to analyse the table and identified that the 'number of remaining nuclei' roughly halved from 100 to 48 in this time, or that the 'activity' dropped from 18 to 9 in about 4 throws (actually 3). Some gained credit for identifying the random nature of rolling dice to explain why the figures were not exact. Interestingly, a number of candidates were able to express very clearly their feeling that the dice model was only a game and not real physics such as measuring radioactive decay using a radioactive source.
			Total	7	

Question			Answer/Indicative content	Marks	Guidance
8	a		correct numbers for neutron (1 over 0) ✓ correct numbers for electron (0 over –1) ✓	2 (AO 1.1 ×2)	Examiner's Comments Most candidates score both marks on this question. A common error was to omit the negative sign for the (0, –1) electron.
	b		Any two from: half-life of Tc-99m is short (compared to transport time) ✓ so (almost) all Tc-99m would have decayed ✓ gamma is more penetrating (than beta) so it would be more difficult to shield as it is transported to the hospital ✓	2 (AO 3.2b ×2)	ALLOW it only has a half-life of 6 hours ALLOW it would have decayed a lot / its activity would be too low Examiner's Comments Most candidates scored at least one mark for this AO3 (making judgements and drawing conclusions) question. However many more candidates could have gained more marks if they had been just a little more precise in their answer. In general candidates recognised that the Tc-99m has a short half-life in comparison to Mo-99. Commonly, candidates go on to explain that the Tc-99m would decay. While this is correct it is insufficient for the idea that so much would decay there would be little left after transportation.
			Total	4	