Question number	Answer	Mark
5(c)	Correctly identifies data points from the graph to calculate areas (1) Calculates area under AB (1) 240 m Calculates area under CD (1) 135 m distance travelled at constant speed = 240 m is greater than distance travelled when slowing down = 135 m (1)	**(4)**

Question number	Answer	Mark
6(a)	B	**(1)**

Question number	Answer	Additional guidance	Mark
6(b)(i)	The time taken for the activity of a radioactive nuclide to halve (1)	accept for nuclide: isotope sample	**(1)**

Question number	Answer	Additional guidance	Mark
6(b)(ii)	Determines number of half-lives and rounds (1) 263/87.7 = 3 Determines that 3 half-lives is 1/2 × 1/2 × 1/2 = 1/8 (1) Determines mass of Pu-238 after 3 half-lives (1) 925/8 = 115.625 (g) Determines average energy released per second (1) 115.625 × 0.54 = 62.4 (J)	 allow repeated division by 2 allow ecf from step 2 for 1 mark (mass of Pu-238 after1 half-life 925/2 = 462.5 (g)) allow ecf from 1 half-life or from step 3	**(4)**

Question number	Answer	Mark
6(c)(i)	An answer that combines the following points of application of knowledge and understanding to provide a logical description: • proton number/atomic number decreases by 1 (1) • nucleon number/mass number remains unchanged (as p and n have same mass and mass of electron is (assumed) negligible) (1)	(2)

Question number	Answer	Mark
6(c)(ii)	C	(1)

Question number	Answer	Additional guidance	Mark
7(a)	An answer that combines the following points of understanding to provide a logical description: • measurement of time between(or at) two positions using suitable timing equipment (1) • measurement of suitable distance along the runway with metre rule (1) • measurement of vertical height to starting position (1) • repeats AND averages AND use of a correct equation (1)	allow stopwatch, light gates minimum is 0.5 m metal tape measure average speed = distance/time OR average speed = (speed at A − speed at B)/2	(4)

Question number	Answer	Additional guidance	Mark
9(c)	Substitution into $v = \frac{s}{t}$ to find v (1) $v = \frac{1.5\times10^{11}}{500}$ Substitution into $v = f \times \lambda$ and unit conversion (1) $v = \frac{1.5\times10^{11}}{500} = f \times 670 \times 10^{-9}$ Transposition (1) Rearrangement (1) $f = \frac{\left(1.50\times10^{11}\right)}{500\times\left(670\times10^{-9}\right)}$ Answer (1) 4.5 x 10^{14} (Hz)	*s* is distance award full marks for correct numerical answer without working maximum 3 marks if λ in nm 4.4776 x 10^{14} (Hz)	**(4)**

Question number	Answer	Additional guidance	Mark
10(a)(i)	An explanation that combines identification – knowledge (1 mark) and reasoning/justification – knowledge (3 marks): • causes 2 or 3 neutrons to be released (1) • (and) one or more of these (released) neutrons are absorbed by other (U) nuclei (1) • which cause further fission of U nuclei (1) • and release further neutrons that can be absorbed, causing a chain reaction (1)	ignore U nucleus 'splits up'/eq	**(4)**

Question number	Answer	Mark
10(a)(ii)	Idea that to get a chain reaction the particle that impacts the nucleus must be the same as the one released (1)	**(1)**

Question number	Answer	Additional guidance	Mark
10(b)	An explanation that combines identification – knowledge (1 mark) and reasoning/justification – knowledge (2 marks): • reaction will slow down (1) • because there are fewer fissions (1) • because fission more likely with slow neutrons (1)	allow reactor shuts down/eq fission requires slow neutrons thermal neutrons for slow neutrons	**(3)**

Question number	Answer	Mark
10(c)	An answer that combines the following points of understanding to provide a logical description: • the reactor is surrounded by a coolant (1) • the thermal energy release from the chain reaction heats the coolant (1) • the hot coolant is used to generate steam which is used to drive the turbine (1)	**(3)**

Question Number	Answer	Acceptable answers	Mark
4(a)	A description including the following points • steam {drives/turns} turbine (1) • (which){drives/turns/powers} generator (1)	transfers ke to electrical energy rotates a magnet in coils or coils in magnet accept dynamo for generator	**(2)**

Question Number	Answer	Acceptable answers	Mark
4(b)	A description including the following points • neutron {hits / splits / is absorbed by} uranium (nucleus) (1) • producing more neutrons (1) • at least one neutron can {hit / split / be absorbed by} other uranium (nuclei) (1)	full marks may be scored on a labelled diagram fired at other U (nuclei) or "process repeats"	**(3)**

Question Number	Answer	Acceptable answers	Mark
4(c)	**A** krypton-91		**(1)**

Question Number	Answer	Acceptable answers	Mark
4(d)	An explanation linking the following points • removes electrons (1) • from atoms (1)	collides with atoms ignore references to β decay process (nucleus losing an electron)	**(2)**

Question Number	Answer	Acceptable answers	Mark
4(e)	An explanation linking the following points • nuclei are positively charged (1) • need enough energy to overcome repulsion (1)	ignore references to high temp and pressure accept same charge accept protons for nuclei accept atoms and will repel each other	**(2)**

Question Number	Answer	Acceptable answers	Mark
5(a)	**A**		**(1)**

Question Number	Answer	Acceptable answers	Mark
5(b)	distance travelled = area under graph (1) substitution (1) ½ x 20 x 2 evaluation (1) 20 (m)	distance = average speed x time = 10 × 2 20 (m) allow (distance) = speed × time or 20 x 2 for 1 mark give full marks for correct answer, no working	**(3)**

Question Number	Answer	Acceptable answers	Mark
6(a)	An explanation linking the following points • small percentage / amount of material (1) • activity level low / less than background (1)	radiation/radioactivity for activity within safe limits	**(2)**

Question Number	Answer	Acceptable answers	Mark
6(b)(i)	**B** 50 days		**(1)**

Question Number	Answer	Acceptable answers	Mark
6(b)(ii)	12.5	10 - 15	**(1)**

Question Number	Answer	Acceptable answers	Mark
6(c)	An explanation linking the following points • time for halving (1) • clear as to what is halving (1)	**Allow** for atoms: isotope / element / nuclei / (radioactive) substance /particles/(radioactive) material/radiation/count rate/Bq/activity/radioactivity time for half of the atoms to decay (2) time for the activity/count rate to drop to half (of original value) (2) time for ½ of it to decay (1)	**(2)**

Question Number		Indicative Content	Mark
QWC	***6(d)**	A discussion including some of the following points Model components related to actual machine • lamp – radioactive source (β- source) • sensor (LDR) – Geiger counter arrangement • card – liquid in bottle Interaction of components related to working of machine • rising of card - more liquid in bottle • rising of card – less light – higher resistance – smaller current / reading – circuit switches on if too much light • greater absorption gives less radiation to detect • machine discards bottle if too little liquid, model does not	**(6)**
Level	**0**	No rewardable content	
1	**1 - 2**	• a limited discussion comparing some of the indicative content. E.g. two of the lamp, sensor and card are related to the source (Geiger) counter and liquid respectively. • the answer communicates ideas using simple language and uses limited scientific terminology • spelling, punctuation and grammar are used with limited accuracy	
2	**3 - 4**	• a simple discussion comparing parts of the process. E.g. Two of the lamp, sensor and card are related to the source Geiger counter and liquid respectively. The rising of the card gives more liquid in the bottle. • the answer communicates ideas showing some evidence of clarity and organisation and uses scientific terminology appropriately • spelling, punctuation and grammar are used with some accuracy	
3	**5 - 6**	• a detailed discussion of the whole process. E.g. the lamp, sensor and card are related to the source Geiger counter and liquid respectively. The rising of the card gives more liquid in bottle. Too much light/ radiation getting through starts the alarm. • the answer communicates ideas clearly and coherently uses a range of scientific terminology accurately • spelling, punctuation and grammar are used with few errors	

Question Number	Answer	Acceptable answers	Mark
2(a) (i)	B		**(1)**

Question Number	Answer	Acceptable answers	Mark
2(a) (ii)	Any one of the following Rocks Food Radon gas Cosmic rays Own bodies Fall-out Sun/stars (1)	Plausible named food such as coffee, brazil nut, bananas Space Specified medical/industrial use of x-rays Ignore smoke alarms, power stations (in normal use)	**(1)**

Question Number	Answer	Acceptable answers	Mark
2(a) (iii)	An explanation linking • personal circumstances such as geographical location nature of their work lifestyle (1) • the consequences such as radiation from radon gas/particular rocks/fall-out (eg Chernobyl) greater exposure to x-rays greater exposure to cosmic rays (1)		**(2)**

Question Number	Answer	Acceptable answers	Mark
2(a) (iv)	D		**(1)**

Question Number	Answer	Acceptable answers	Mark
2(b) (i)	From the graph Time taken to fall (from 120 to) 60 (1) = 8 days (1)	Any other suitable pair of readings from graph 8.1, 8.2 Full marks for correct answer even if no working is evident	**(2)**

Question Number	Answer	Acceptable answers	Mark
2(b) (ii)	2.2 (days) (1)	between 2.0 and 2.5 2	**(1)**

Question Number	Answer	Acceptable answers	Mark
2(b) (iii)	Any one of the following: • Mutation of dna • Ionisation of cells • (Increases risk of) cancer (1)	damage / mutate cells	**(1)**

Question Number	Answer	Acceptable answers	Mark
3(a)(i)	B		**(1)**

Question Number	Answer	Acceptable answers	Mark
3(a) (ii)	(equivalent to a) helium nucleus	Two protons and two neutrons for 2 marks helium/mass of 4 for 1 mark charge of +2 for 1 mark correct statement of any property for 1 mark	**(2)**

Question Number	Answer	Acceptable answers	Mark
3 (b)	A description to include any four of the following • neutron • is captured by a U-235 nucleus • nucleus (is) unstable • nucleus splits • into 2 daughter nuclei (of similar size) • (2 or more) neutrons are released • energy is released	• collides with /absorbed by (U-235) nucleus • metastable • named isotopes	**(4)**

Question Number	Answer	Acceptable answers	Mark
3 (c)	An explanation linking • moderator slows down (absorbs energy from) neutrons • more likely to be captured /cause fission (if it collides with a U-235 nuclei)	Reverse argument	**(2)**

Question Number	Answer	Acceptable answers	Mark
4(a)	P and M OR M and P OR N and Q OR Q and N	one mark for a pair	**(1)**

Question Number	Answer	Acceptable answers	Mark
4(b)	{atomic /proton} number drops by 2 **and** {mass/nucleon} number by 4 (1) (which is) alpha decay (1)	2 protons **and** 2 neutrons are lost 92 → 90 **and** 238 → 234 helium nucleus given off (which is) alpha particle	**(2)**

Question Number	Answer	Acceptable answers	Mark
4(c)	same {mass/nucleon} number but {atomic/proton} number increases by 1 (1) (negative) beta decay (1)	a neutron changes to a proton ignore GAINS a proton beta particle /electron given off	**(2)**

Question Number	Answer	Acceptable answers	Mark
4(d)(i)	alpha	Alpha ray, alpha particle, α Ignore capital letters	**(1)**

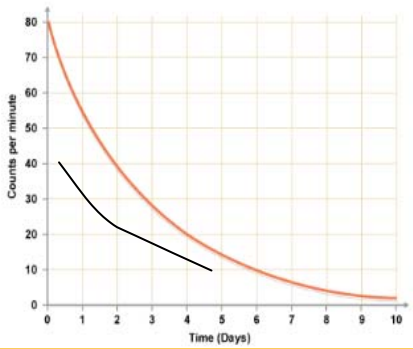
Question Number	Answer	Acceptable answers	Mark
4(d)(ii)	A description including two of one increases as other increases (1) rate of increase is in the range from 1.17 to 1.33 (cm/MeV) (1) range gradually increases more with energy (1)	the particles with higher energy travel further accept values quoted from graph not (quite) linear/not proportional /curves upwards accept values quoted from graph	**(2)**

Question Number	Answer	Acceptable answers	Mark
4(e)	chain reaction needs a neutron from one fission to reach another uranium nucleus/atom (at the right speed) (1) (fission of 238) needs {fast/high(er) energy} neutrons (1)	idea of continuous nature of chain reaction the neutrons would be going too slowly /do not have enough energy / lose energy too fast	**(2)**

Question Number	Answer	Acceptable answers	Mark
6(a)	A description to include • name of detector / move detector over the ground (1) • where leak is, there will be an increased rate (1)	(move) until a {leak/high reading} is found	**(2)**

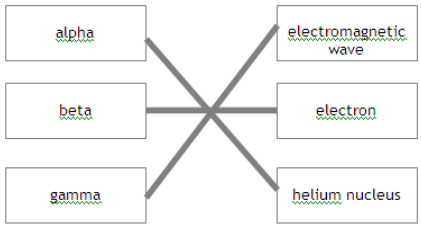
Question Number	Answer	Acceptable answers	Mark
6(b)	D It is the time it takes for half the atoms to decay		**(1)**

Question Number	Answer	Acceptable answers	Mark
6(c)i	1.9-2 (days)		**(1)**

Question Number	Answer	Acceptable answers	Mark
6(c)ii	 plotting (0,40), (2,20) and (4,10) **OR ANY** line which passes through those coordinates (1) smooth curve through those points (1)	Ignore any part of line after 4 days	**(2)**

Question Number		Indicative Content	Mark
QWC	***6(d)**	An explanation including some of the following ideas **Need for measurement (N)** Background radiation • is {always present/all around us} • has (natural) source(s) exemplified by space, living things, rocks, food, nuclear/medical sources etc. • would give false reading in experiment **How and why to measure(H)** Background radiation measurement • is taken at site of experiment **because** it is different in different places • is taken with all apparatus **except** source in place • is taken before and after **because** {it can change with time / they need an average} • {must be worked out for same time as (or longer than) experiment / rate found} **so** analysis is simpler • It is {taken several times/ averaged} **because** it is random **Analysis (A)** Background radiation measurement • must be subtracted from {measurements with source /main count rate}	**(6)**
Level	**0**	No rewardable content	
1	**1 - 2**	• A limited explanation mentioning any **two** from N or **one** from H or A e.g. Background comes from space and rocks.(N) It is there all the time. (N) OR Readings for background must be repeated because they are random. (H) OR Background must be taken away from all other readings (A) • the answer communicates ideas using simple language and uses limited scientific terminology • spelling, punctuation and grammar are used with limited accuracy	
2	**3 - 4**	• A simple explanation ***linking*** aspects of two ideas i.e. **N** + **H** OR **N** + **A** OR **H** + **A** e.g Take readings without source (H) and subtract them from the main readings with source present.(A) OR It should be taken several times because it is random (H)so that the average can be subtracted from the main readings (A) • the answer communicates ideas showing some evidence of clarity and organisation and uses scientific terminology appropriately • spelling, punctuation and grammar are used with some accuracy	

3	**5 - 6**	• A detailed explanation ***linking*** **A** with EITHER N + an idea from **H** OR two or more ideas from **H** e.g. Background radiation is there all the time. (N) You need to take readings at the place where you will do the experiment and with all the apparatus set up except the source because BR changes from place to place.(H) Then you should subtract background readings from the main experimental readings.(A) OR Take several readings of count rate for averaging since the effect is random (H) and make sure that they are taken in the same place.(H) Then subtract from readings in main experiment.(A) • the answer communicates ideas clearly and coherently uses a range of scientific terminology accurately • spelling, punctuation and grammar are used with few errors

Question Number	Answer	Acceptable answers	Mark
1(a)	Three lines as shown:  (2)	Any one line correct only scores 1 mark	**(2)**

Question Number	Answer	Acceptable answers	Mark
1(b)	An explanation linking Absorb (more) neutrons (1) (to) reduce the number of fission reactions (1)	ignore slow down neutrons slow down (the rate of) the reaction/fission	**(2)**

Question Number	Answer	Acceptable answers	Mark
1(c)(i)	**B** electrostatic repulsion of protons		**(1)**

Question Number	Answer	Acceptable answers	Mark
1(c)(ii)	A description to include • (two/or more/smaller) nuclei combine/fuse/join (1) • (to produce) a larger nucleus (1)	{(two or more) hydrogen nuclei/protons OR deuterium and tritium} combine/fuse (forming) helium nucleus ONLY penalise use of atoms instead of nuclei ONCE ignore references to release of energy as this is given earlier in the question.	**(2)**

Total for Question 1 = 7 marks

Question Number	Answer	Acceptable answers	Mark
4 (a)(i)	**B 21**		**(1)**

Question Number	Answer	Acceptable answers	Mark
4 (a)(ii)	**A** $^{39}_{19}K$		**(1)**

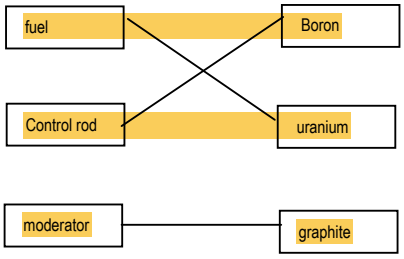
Question Number	Answer	Acceptable answers	Mark
4(a)(iii)	A description to include any two of • (nucleus/isotope is) unstable (1) • (nucleus/isotope is) radioactive (1) • decay is random (1) • long half life (1)		**(2)**

Question Number	Answer	Acceptable answers	Mark
4(b)(i)	1250 (million years) (1)	Between 1200 and 1300 (my) inclusive	**(1)**

Question Number	Answer	Acceptable answers	**Mark**
4(b)(ii)	2 half lives (1) 2500 (million years) (1)	Allow ecf from (bi) Give full marks for answer between 2400 and 2600 with no working.	**(2)**

Question Number	Answer	Acceptable answers	Mark
4(c)	An explanation linking any three from • Radon is radioactive (1) • Radon can escape from rocks and buildings (1) • Radon can be inhaled (1) • Radiation (from radon) can cause cancer (1) • Radon emits alpha (1)	Ignore radiation from rocks themselves Radon enters/gets trapped in buildings/homes / increases background radiation (breathed into) lungs (DNA) mutation / cell damage (Highly) ionising radiation	**(3)**

Total for Question 4 = 10 marks

Question Number	Answer	Acceptable answers	Mark
5 (a) (i)		All three correct for 2 marks One or two only correct for 1 mark Reject any box with more than one line	**(2)**

Question Number	Answer	Acceptable answers	Mark
5(a) (ii)	A suggestion to include Neutrons do not need to be captured (by another nucleus) / do not play a part in the fusion process	Fusion does not use neutrons No chain reaction	**(1)**

Question Number	Answer	Acceptable answers	Mark
5 (b)	A description to include Thermal energy used to create steam / boil water(1) (Steam used to drive) turbine (1) (Turbine used to turn) generator (1)	Ignore detail of fission process.	**(3)**

Question Number		Indicative Content	Mark
QWC	***5(c)**	An explanation including some of the following points • Description of the problem - Nuclei have positive charge - Repel each other - Reduces possibility of suitable collisions - Rate of fusion too small to be useful • Description of how this can be overcome ○ Very high temperature (of fuel) ○ Very high KE / speed of nuclei ○ High KE can overcome repulsion ○ Very high density / pressure ○ Increases possibility of suitable collisions	**(6)**
Level	**0**	No rewardable content	
1	**1 - 2**	A limited explanation e.g. The fuel has to be at a high temperature to start the reaction/to make particles collide. Or The fuel has to be at a very high temperature and pressure. • the answer communicates ideas using simple language and uses limited scientific terminology • spelling, punctuation and grammar are used with limited accuracy	
2	**3 - 4**	• A simple explanation. e.g. We need to overcome repulsion of nuclei to make them collide. This is achieved by having a high temperature and pressure. • the answer communicates ideas showing some evidence of clarity and organisation and uses scientific terminology appropriately • spelling, punctuation and grammar are used with some accuracy	
3	**5 - 6**	• A detailed explanation • e.g. The nuclei repel each other. To overcome this they need very high kinetic energy which is achieved by generating high temperature and pressure. • the answer communicates ideas clearly and coherently uses a range of scientific terminology accurately • spelling, punctuation and grammar are used with few errors	

(Total for Question 5 = 12 marks)

Question Number	Answer	Acceptable answers	Mark
6 (a)	C - kill microbes in the food		**(1)**

Question Number	Answer	Acceptable answers	Mark
6 (b)(i)	From the graph Time taken to fall (from 8000) to 4000 (1) = 5.3 (years) (1)	Any other suitable pair of readings from the graph. Between 5.1 and 5.5 Full marks for correct answer even if no working is evident	**(2)**

Question Number	Answer	Acceptable answers	Mark
6 (b)(ii)	3 x 5.3 (= 15.9 years)	Allow attempt at extrapolation only if the answer is between 15.5 and 16.5 Allow ecf of 3 half lives from bi.	**(1)**

Question Number	Answer	Acceptable answers	Mark
6 (c)(i)	Comparison including any two from Same number of protons (1) Different number of neutrons (1) Cobalt-60 is unstable (1)	 Same atomic/proton number/charge Different nucleon number/mass number/atomic mass Cobalt 60 is radioactive Ignore reference to electrons	**(2)**

Question Number		Indicative Content	Mark
QWC	***6(c)(ii)**	A discussion which includes description of the hazards (H) and / or possible precautions (P) to reduce risks arising from them such as • In either option. ○ Rods are radioactive (H) ○ Gamma radiation is highly penetrating / ionising (H) ○ Radiation from them can cause cancer / damage to organisms / people / environment (H) ○ Need for shielding (P) ○ Security to prevent public access (P) • Transportation / reprocessing ○ Danger of accident during transport (H) ○ Need to be suitably protected against damage. (P) ○ Danger of interception/high-jacking/terrorists (H) ○ Need security (P) ○ Workers could be exposed to radiation (H) ○ Special facilities required (P) • Disposal ○ Can damage environment if not properly contained (H) ○ Special disposal facilities, not landfill (P) ○ Remain radioactive for some time (H) ○ Need to be kept secure while decaying to safe levels. (P) ○ Relatively short half-life means that very long term storage is not necessary. (P)	**(6)**

Level	0	No rewardable content
1	**1 - 2**	• a limited description of hazards or precautions in one option e.g. The rods are radioactive. Radiation can cause cancer. When the rods are disposed of then they will remain radioactive for some time. • the answer communicates ideas using simple language and uses limited scientific terminology • spelling, punctuation and grammar are used with limited accuracy
2	**3 - 4**	• a simple discussion of hazards for both options or a detailed discussion of one option. • A detail discussion may **either** expand on several descriptive points about the hazard **or** may include suitable precautions. e.g. The gamma radiation from the rods is highly penetrating. If they were simply put into landfill then they could damage the environment and so they would need special storage facilities until they had decayed to a safe level. • the answer communicates ideas showing some evidence of clarity and organisation and uses scientific terminology appropriately • spelling, punctuation and grammar are used with some accuracy
3	**5 - 6**	• a detailed discussion of hazards for both options. e.g. Response as above PLUS if they were transported back to the reactor then they must be in very strong containers so that, if there was an accident, they would not be damaged and allow radioactive material to escape. • the answer communicates ideas clearly and coherently uses a range of scientific terminology accurately • spelling, punctuation and grammar are used with few errors

(Total for Question 6 = 12 marks)