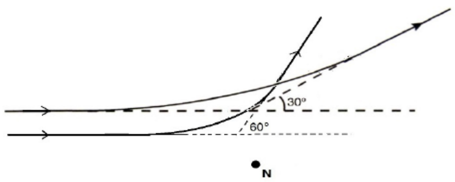
Mark scheme – Nuclear and Particles Physics

Question			Answer/Indicative content	Marks	Guidance
1			C	1	
			Total	**1**	
2			B	1	
			Total	**1**	
3			The decay constant is the probability of decay of a nucleus per unit time.	B1	**Allow**: the decay constant is the fraction of nuclei decaying per unit time. **Allow**: decay constant = activity ÷ number of nuclei left in a sample.
			Total	**1**	
4			D	1	
			Total	**1**	
5			**B**	1	
			Total	**1**	
6			**A**	**1**	**<u>Examiner's Comments</u>** The majority of the candidates did get the correct answer **A**. A significant number of candidates opted for **C**, confusing contrast material with medical tracers.
			Total	**1**	
7			**B**	1	
			Total	**1**	
8			**C**	**1**	
			Total	**1**	
9			**B**	1	
			Total	**1**	
10			A	1	
			Total	**1**	
11			B	1	
			Total	**1**	

12			**A**	**1**	
			Total	**1**	
13			C	1	
			Total	**1**	
14			**C**	**1**	
			Total	**1**	
15			B	1	
			Total	**1**	
16			D	1	
			Total	**1**	
17			C	1	**Examiner's Comments** The correct response is **C**. The responses are terms used frequently when studying data, but as around only one half of the candidates were able to get the correct response, it is clear that they are not fully understood. A little perplexingly, the most common incorrect response was **B**, as it is difficult to see how this data could be considered linear. This does show how easy it is to assume that candidates are confident in their use of terminology, just because they are frequently used.
			Total	**1**	
18			A	1	**Examiner's Comments** The correct response is **A**. Around half of candidates were able to select the correct response. Although it would seem appropriate to write out some simple decay sequence, many candidates showed little working here. Some were able to get the correct response (probably through mental arithmetic) but incorrect responses may simply have been down to a lack of knowledge of nuclear changes, most likely in the beta decay. Incorrect responses were spread fairly evenly among the distractors, again suggesting that this topic was not well understood.
			Total	**1**	
19			D	1	
			Total	**1**	

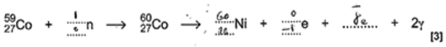
20			The splitting of a (uranium) nucleus as a neutron is absorbed (into two fragment nuclei and neutrons).	B1	
			Total	**1**	
21			d → u + ${}^{0}_{-1}e$	B1	**Allow** ${}^{0}_{-1}\beta^{(-)}$ for the electron
			+ $\bar{\nu}_{(e)}$	B1	
			Total	**2**	
22				B1 B1	Path is initially horizontal **and** further up the page than original Path <u>ends</u> at 30^0 to horizontal (angle must be labelled) in the direction shown **<u>Examiner's Comments</u>** The common errors here were: • not realising that, for the particle to be deflected through a smaller angle, it needed to be travelling further away from N • not labelling the final angle of 30° • not adding arrows to show the direction of travel • drawing a path that continued bending beyond the stated 30° (usually ending up parallel to the original path).
			Total	**2**	
23			number decaying in 1st second = 2000 × 0.10 = 200	C1	
			number decaying in the 2nd second = 1800 × 0.10 = 180 number left = 1800 – 180 = 1620	A1	
			Total	**2**	
24		i	Too many *N* / neutrons	B1	**Allow** 'neutron-rich' **or** (for stability) neutron changes to proton **or** (for stability) charge increases / *Z* changes to 8 **Allow** too few protons / 'proton-poor' **<u>Examiner's Comments</u>** This question required analysis of the information provided in **Fig. 21**. Most candidates scored a mark for either recognising that the isotope had too many neutrons or a neutron had to decay into a proton in order to provide stability.
		ii	Too few *N* / neutrons	B1	**Allow** 'neutron-poor' **or** (for stability) proton changes to neutron **or** (for stability) charge decreases / Z changes to 6

					Allow too many protons / 'proton-rich' **Examiner's Comments** A range of answers were allowed in this question requiring analysis of **Fig. 21**. Most candidates scored a mark for either recognising that the isotope had too few neutrons or a proton had to decay into a neutron in order to provide stability.
			Total	**2**	
25	a		${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + ...$ ${}^{4}_{2}He$ or ${}^{4}_{2}\alpha$	**B1** **B1**	**allow** proton and / or nucleon number to the right of symbol **allow** γ-photon; zero for any other extra particle **Examiner's Comments** Most candidates made a good start to the paper writing a correct equation for the nuclear decay.
	b		$mv = (4.00 - 0.0665) \times 10^{-25} \times 2.40 \times 10^5$ $= 9.44 \times 10^{-20}$ $v = 9.44 \times 10^{-20} / 6.65 \times 10^{-27} = 1.42 \times 10^7$ k.e. $= ½ \times 6.65 \times 10^{-27} \times (1.42 \times 10^7)^2$ $= 6.70 \times 10^{-13}$ (J) $6.70 \times 10^{-13} / 1.60 \times 10^{-13} = 4.19$ (MeV)	**C1** **C1** **A1** **B1**	**allow** 0.07×10^{-25} for α-particle mass **max** 3 if use 4.00 instead of 3.93 in momentum eq'n **allow** ratio of masses 234 and 4 **or** calculations using 234u and 4u **allow** $p^2/2m$ calculation for k.e. **accept** 4.0 to 4.2; **ecf** (calculated value of k.e. in J)/e **N.B.** the correct answer automatically gains all 4 marks **Examiner's Comments** One mark in this question was reserved for converting units from joule into mega electronvolt. This was the only mark awarded to half of the candidates. Few recognised this to be an isolated system, applying the conservation of momentum to solve the problem. Few appeared to realise that the mass of an alpha particle is given in the Data, Formulae, and Relationships Booklet, calculating it instead by summing the masses of neutrons and protons. The most common incorrect approach was to use the formula $E = mc^2$ or to equate the kinetic energies of the thorium nucleus and alpha particle.
	c		$\Delta A = 32 = 4n_\alpha$ so $n_\alpha = 8$ $\Delta Z = 10 = 2n_\alpha - n_\beta$ so $n_\beta = 6$ argument / reasoning given for both n_α and n_β	**B1** **B1** **B1**	**allow** 8 (decays), i.e no mention of α particles **allow** 10 − 16 = −6; **NOT** 14 − 8 = 6; **must state** β(−) particles e.g. change in mass number caused by α decay,change in proton number combination of α and β **Examiner's Comments** A significant number had no idea where to start and left the page blank. Of the rest most managed to decide on 8 alpha particles. A minority worked initially with the proton number rather than the nucleon number incorrectly choosing 5. The explanations about the choice of 6 beta particles were often just restricted to equating the numbers correctly rather than giving any description of the transformation of neutrons into protons.
			Total	**9**	

26	a		$^{2}_{1}H$ has two nucleons binding energy per nucleon = 1.1 MeV (per nucleon)	B1 B1	**Allow** 1.76×10^{-13} J (per nucleon) **Examiner's Comment** About half of the candidates scored one or two marks. Some of the answers were concise with just *'1.1 MeV per nucleon because $^{2}_{1}H$ has two nucleons'* but some were simply incorrect with an attempt to answer the question using $\Delta E = \Delta mc^2$ and the rest masses of the proton and neutron. Weaker candidates misunderstood the terms 'binding energy' and 'binding energy per nucleon'.
	b		The protons / nuclei repel each other (At high temperature) particles have more KE **and** hence can get close (enough to fuse)	B1 B1	**Not** atoms / particles **Allow** 'enough KE to get close' **Not** atoms or ions **Examiner's Comment** Fusion is possible in stars because the higher temperatures ensure that nuclei have large enough kinetic energy for the most energetic ones to get close enough for the attractive strong nuclear force to trigger the reactions. Many candidates did realise that higher temperatures meant greater **kinetic** energy but some answers were spoilt for either stating that **atoms** were fusing or mentioning that *'nuclei overcame electrical forces'* without any further explanation. The superficiality of many answers prevented candidates from picking up marks.
	c		$E = hc/\lambda$ **and** $E = me^2$ or $E = 2 \times mc^2$ $\lambda = \frac{6.63\times10^{-34}}{\mathbf{2}\times9.11\times10^{-31}\times3.0\times10^{8}}$ maximum wavelength = 1.2×10^{-12} (m)	C1 C1 A1	**Allow** $hc/\lambda = 2mc^2$ with or without the factor of 2 **Note:** The mass must be $2m_e$ to score this and the next mark **Not** de Broglie equation $\lambda = h / mv$ with speed of c; which gives 2.4×10^{-12} (m) **Allow** 2 marks for 6.6×10^{-16} (m); mass of neutron or proton used instead **Allow** the following marks for 1.02 MeV recalled: $E = 1.63 \times 10^{-13}$ (J) C1 $\lambda = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{1.63\times10^{-13}}$ C1 maximum wavelength $=1.2 \times 10^{-12}$ (m) A1 **Examiner's Comment** This was another question that favoured the top-end candidates. The answers from them showed excellent understanding of pair production. A small number of candidates correctly recalled the 1.02 MeV energy required to produce an electron-positron pair. Full credit was given if this led to the correct answer of 1.2×10^{-12} m for the gamma photon. A disappointing number of candidates used 2.2 MeV

					from **(a)** and the equation $\lambda = hc/E$ to calculate the maximum wavelength. There was no credit for this incorrect approach.
			Total	**7**	
27	a		Any <u>two</u> from: It acts between quarks / nucleons / hadrons 'Short-range' force Repulsive below (about) 0.5 fm Attractive up to (about) 3 fm	**B1×2**	**Allow** any correctly named particle **Allow** any value between 0.5 fm and 5 fm **Examiner's Comment** Most candidates scored two marks and knew a great deal about the strong nuclear force.
	b	i	proton = u u d or neutron = u d d	**B1**	**Examiner's Comment** The modal score here was one mark. The answers were brief with either proton as uud or the neutron as udd. The up ↑ and down ↓ arrows were allowed as acceptable notation for the up and down quarks respectively.
		ii	$d \rightarrow u + {}^{0}_{-1}e$ $+ \bar{\nu}_{(e)}$	**M1** **A1**	**Allow** the equation expressed in words **Allow** $udd \rightarrow uud + {}^{0}_{-1}e$ **Allow** ${}^{0}_{-1}\beta$ **Not** e^- for electron **Allow** this mark if electron written as e^- or p^- **Examiner's Comment** A variety of answers for the decay equations were accepted with most candidates picking up marks. No credit could be given for showing the decay of a neutron into a proton because of the absence of the quarks. Some of missed opportunities were: • Representing the electron as e^- rather than ${}^{0}_{-1}e$. • Confusing the positron and the electron. • Assuming the decay was u → d rather than d → u.
	c		mass (of nucleus) ∝ *A* volume (of nucleus) ∝ radius^3 ∝ *A* **and** clears steps using $\rho = m / V$ to show density is (about) the same	**B1** **B1**	**Allow** mass = Am, mass =*Au,* etc. **Allow** *r* or *R* for radius **Allow** any sensible constant in front of the r^3 **Examiner's Comment** This proved challenging for most candidates with answers lacking clarity. Some candidates secured a mark for suggesting the $mass_{nucleus}$ ∝ A. Only the very top-end candidates managed to show how the density equation and volume ∝ *A* led to the expected conclusion. Too many scripts had vague answers such as *'neutrons and protons are the same, so their density is the same'* and *'protons and neutrons have negligible mass so density is unaffected'.*
			Total	**7**	

28		i	Material **X** because of the shorter half-life	B1	Must be comparative **Allow** explanation in terms of decay constant **<u>Examiner's Comments</u>** This question expects the candidates to appreciate that the activity is related to the half-life. The majority of candidates were able to successfully answer this question although a number did not make it comparative and simply said that X had a short half-life.
		ii	(Alpha particles are stopped by the glass but) the beta-particles are not (AW)	B1	**Allow** symbols **<u>Examiner's Comments</u>** Not many candidates recognised that the penetrating powers of the radiations through glass were required for the response; most referred to the ionising (and so harmful to health) properties of both sources.
			Total	**2**	
29			Downward curved path Same *x*	B1 B1	**Ignore** any line outside of the plates **Expect** same x by eye **<u>Examiner's Comments</u>** Nearly all candidates appreciated that the path should be downwards, but many did not take the care needed for it to be clear that the deflection at the end of the plate should be the same. Some candidates drew an 'x' on their sketch, which was helpful in determining if the intention to draw it the same had been made.
			Total	**2**	
30			Control rods: absorb the <u>neutrons</u> (without further fission) Moderator: Slow down the <u>neutrons</u> / decrease KE of <u>neutrons</u>	B1 B1	**Not** collide for absorb **<u>Examiner's Comments</u>** For this question, the candidates need to explain the role of these components in terms of their interactions with neutrons and those who did not mention neutrons at all in their responses could not score any marks. Many candidates went beyond what was required and explained what effect this has on the reactor, such as controlling the rate of reaction. In general, this question was not answered well. **Misconception** Many candidates gave vague statements regarding the function of these components rather than an explanation.
			Total	**2**	

3 1			(energy =) $9.11 \times 10^{-31} \times (3.0 \times 10^8)^2$ (energy =) $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2 / 1.60 \times 10^{-19}$ $\lg 1.0(2) \times 10^6 = 6$ (as on graph) **OR** (energy =) 1.0×10^6 (eV) **or** $\lg 1.0 \times 10^6 = 6$ (from graph) (energy =) 1.6×10^{-13} J **and** evidence of *mc*^{2} $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2 \approx 1.6 \times 10^{-13}$	B1 B1 B1 B1 B1 B1	**Note** this is 8.2×10^{-14} (J) Note this is $1.0(2) \times 10^6$ eV **Note** this can be shown in a variety of ways
			Total	**3**	
3 2			superscripts 1,60,0 subscripts 0,28,-1 $\bar{\nu}_{(e)}$ (nu-bar)	B1 B1 B1	recognisable correct symbol required If superscripts and subscripts included, both must be 0 **<u>Examiner's Comments</u>** The correct symbol for the 'one other particle' in this question was (($\bar{\nu}$,)($\bar{\nu}$ _e) or ((_0^0) $\bar{\nu}$), all being acceptable. **Exemplar 2**  Exemplar 2 illustrates the two most common problems that were encountered in this response. **AfL** Centres should give candidates plenty of practice in balancing equations that involve beta minus decay.
			Total	**3**	
3 3			$\frac{hc}{\lambda} = 2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2$	C1	
			$\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2}$	C1	
			$\lambda = 1.2 \times 10^{-12}$ (m)	A1	**Allow** 2 marks for 2.4×10^{-12} (m); factor of 2 omitted in the first line.
			Total	**3**	

34			energy of <u>two</u> photons = $2 \times mc^2$ or $2\times\frac{hc}{\lambda} = 2\times m$ $\lambda = \frac{h}{mc} = \frac{6.63\times10^{-34}}{9.11\times10^{-31}\times3.0\times10^{8}}$	C1 C1	Correct use of $\frac{hc}{\lambda} = mc^2$
			wavelength = 2.4×10^{-12} (m)	A1	
			Total	**3**	
35	a	i	alpha-particle / ${}^{4}_{2}\text{He}$ / ${}^{4}_{2}\alpha$	**B1**	
		ii	nucleon number for Bi = 209 antineutrino / ${}^{(0)}_{(0)}\bar{\upsilon}_{(e)}$	**B1** **B1**	**Note**: Do not allow incorrect subscript and superscript
	b	i	Aluminium (sheet placed between source and detector) The count (rate) reduces **or** Magnetic / electric field used Electrons identified from correct deflection / motion in field	**M1** **A1** **M1** **A1**	**Allow** count (rate) drop to background / zero **Allow** 2 marks for 'the range in air is a few m' <u>**Examiner's Comments**</u> This turned out to be a low-scoring question from candidates across the ability spectrum. Only a quarter of the candidates gained 2 marks for identifying aluminium as the absorber for the beta-minus radiation (electrons) and providing adequate description in terms of reduction in the count-rate. A small number of candidates opted for charged parallel plates and identified the electrons curving towards the positive plate. There were some baffling descriptions involving pointing the source at *'wires and measuring the current'*. Fluorescent screens and cloud chambers were not allowed as acceptable answers because both can be used to detect the presence of gamma-photons and alpha-particles.
		ii	(λ =) ln2/3.3 (h^{-1}) **or** (λ =) 0.21 (h^{-1}) (A_0 =) $12 \times 10^3/e^{-(0.21\times7.0)}$ **or** (A_0 =) 5.219×10^4 (Bq) (N_0 =) $5.219 \times 10^4/5.835 \times 10^{-5}$	**C1** **C1** **C1**	**Allow** credit for alternative methods **Note** this is the same as $12 \times 10^3 \div (0.5)^{7.0/3.3}$ **Note** 9.0×10^8 can score full marks if numbers are rounded

			number of nuclei = 8.9×10^8 **Or** (λ =) ln2/[3.3 × 3600] (s^{-1}) **or** (λ =) 5.835 × 10^{-5} (s^{-1}) (N =) 1.2 × 10^4/5.835 × 10^{-5} **or** 2.057 × 10^8 (N_0 =) 2.057 × 10^8/$e^{-(0.21 \times 7.0)}$ number of nuclei = 8.9×10^8	**A1** **C1** **C1** **C1** **A1**	Possible ECF for incorrect conversion of time Note this is the same as 2.057 × 10**8** ÷ $(0.5)^{7.0/3.3}$ **<u>Examiner's Comments</u>** The question was multi-stepped calculation, requiring knowledge of radioactive decay equations, half-time and activity. The final stage of the calculation was dependent on the equation $A = \lambda N$ and working consistently in Bq for the activity and in s^{-1} for the decay constant. The number of nuclei N could not be calculated with the activity in Bq and the decay constant in either h^{-1} or min^{-1}. About half of the candidates scored full marks. Those working with inconsistent units invariably ended up with the incorrect value 2.5 × 10^5 nuclei, but this still earned them 2 marks for the preceding steps.
			Total	**9**	
36			λ = ln2/6.0 = 0.116 (h^{-1}) ($A = A_0 e^{-\lambda t}$)	C1	**Allow** λ = ln2/(6.0 × 3600) = 3.21 × 10^{-5} (s^{-1})
			$t = \frac{\ln(630/820)}{0.116}$	C1	**Allow** $\frac{\ln(630/820)}{3.2\times10^{-5}}$ (= 8200 s)
			t = 2.3 (h)	A1	
			Total	**3**	
37			Strong nuclear (force / interaction)	B1	**Allow** 'strong' (force / interaction)
			Attractive at short distances and repulsive at short distances	M1	
			Mention of distances of 3 fm and 0.5 fm	A1	
			Total	**3**	
38	a		The patient is surrounded by (gamma) detectors or Increased activity is where F-18 accumulates (AW)	**B1**	**Allow** 'diametrically opposite detectors'
			The positrons (from the F-18) <u>annihilate</u> electrons (inside the patient)	**B1**	
			Each annihilation produces two gamma photons travelling in <u>opposite</u> directions	**B1**	**Not** gamma rays / radiation
			The arrival times are used to locate position (of increased activity)	**B1**	**Allow** 'delay time'

					Examiner's Comment Most candidates scored two or more marks for their description of the PET scanner. Most candidates knew that the annihilation of positrons and electrons was central to the scanning technique. A small number of candidates either confused the PET scanning with CAT scanning or assumed that the gamma detectors were monitoring the emission of positrons from the patient.
	b		λ = ln2/110 or 6.3×10^{-3} (min^{-1}) $0.30 = e^{-6.3\times10^{-3}t}$ $t = \frac{\ln(0.30)}{-6.3\times10^{-3}}$ t = 190 (minutes)	**C1** **C1** **A1**	**Allow** 1.05×10^{-4} (s^{-1}) This is the same as $0.30 = e^{-1.05\times10^{-4}t}$ **Note:** This mark is for a **ln** expression (any subject) **Allow** 2 marks for 1.15×10^4 (s) as the final answer **Examiner's Comment** This was not an easy question. It required knowledge and understanding of activity, decay constant and natural logs. It is good to report that most of the candidates produced immaculate answers. The common mistakes made were: • Using either ln(1/3) or ln(0.70) rather than ln(0.30) in the calculations. • Assuming the decay was linear rather than exponential.
	c		Any sensible suggestion, e.g. 'post-code' lottery, some patients may not get the treatment because of where they live, longer waiting lists, etc.	**B1**	**Examiner's Comment** Almost all candidates gave a plausible suggestion in this last question in the paper. It is good to report that physicists are mindful of the impact of science on society.
			Total	**8**	
39			Q = 79e and q = 2e $F = (1/4\pi\varepsilon_0)Qq/r^2$ $= 79 \times 2 \times (1.6 \times 10^{-19})^2 / [4\pi \times 8.85 \times 10^{-12} \times (6.8 \times 10^{-14})^2]$ = 7.9 (N)	C1 C1 C1 A1	**Apply ECF** for wrong charge(s), e.g. Q and / or q = e, or Q = 79 and / or q = 2, etc **<u>Examiner's Comments</u>** The most common error here was to use incorrect values for the charges on the two ions. Even so, most candidates were able to gain most of the marks with ECF.
			Total	**4**	
40			The moderator slows down the fast-moving neutrons.	B1	
			The neutrons lose significant amount of their kinetic energy when colliding with moderator	B1	

			nuclei. or The moderator does not absorb the neutrons.		
			The control rods absorb the neutrons.	B1	
			The rate of fission reactions is less / reduced.	B1	
			Total	**4**	
4 1		i	Electron **and** (electron) antineutrino	B1	**Allow** beta-minus (particle) / β^- ; $\bar{\upsilon}_{(e)}$ **Allow** anti electron neutrino **<u>Examiner's Comments</u>** The majority of the candidates scored a mark for electron and antineutrino as the two leptons. The most common incorrect answers were *neutrino, positron, proton and neutron*. The pairing of electron and positron also appeared on some scripts.
		ii	λ = ln2/49 **or** λ = 0.0141 (billion y^{-1}) 0.95 = $e^{-0.0141t}$ **or** 0.95 = $e^{-4.48\times10^{-19}t}$ (age = - ln(0.95)/0.0141) age = 3.6 (billion years)	C1 C1 A1	**Allow** $\frac{\ln 2}{49\times10^9\times3.16\times10^7}$ **or** 4.48 × 10^{-19} (s^{-1}) **Allow** both C1 marks for ln(0.95) = ln(0.5) × *t*/49 **Allow** 0.05/0.0141 ≈ t (this gives 3.5.. for the final mark) **Note** age in seconds is 1.15 × 10^{17} (s); this will score 2 marks **<u>Examiner's Comments</u>** Many of the top-half candidates demonstrated how the age of the Earth could be calculated in just a few lines. The use of natural logs (ln) was faultless. Most candidates calculated the decay constant and then used the equation 0.95 = $e^{-\lambda t}$, or its equivalent ln0.95 = -λt, to calculate the age *t*. Candidates are reminded not to round numbers in long calculations – it is good practice to keep all the digits on your calculator. A significant number of candidates rounded the decay constant to 2 SF (0.014 billion y^{-1}), and this gave an answer of 3.7 billion years. The correct answer, without rounding ln2/49, was 3.6 billion years. On this occasion, examiners allowed the 3.7 billion years answer. The command term 'estimate' in the question made a small number of candidates to use the equation $\frac{\Delta N}{\Delta t}\approx-\lambda t$. This was allowed, and it gave an estimated age of 3.5 billion years. **Misconception**

					These were some common errors being made in this question, these are summarised below. • Incorrect conversion of billion years into seconds. (Most candidates calculated the decay constant in billion year^{-1}, which easily led to the correct answer in billion years.) • Using ln0.05 instead of ln0.95 when calculating the age of the Earth.
			Total	**4**	
4 2			$\lambda = \frac{\ln 2}{6600} = 1.050 \times 10^{-4}$ (s^{-1})	C1	Correct use of $A = \lambda N$
			$N = \frac{400 \times 10^{6}}{1.050 \times 10^{-4}} = 3.809 \times 10^{12}$	C1	
			mass of FDG = $\frac{3.809 \times 10^{12}}{6.02 \times 10^{23}} \times 0.018 \div 0.099$	C1	
			mass of FDG = 1.15×10^{-12} (kg) or 1.2×10^{-12} (kg)	A1	
			Total	**4**	
4 3		i	(N at 15°/N at 150° =) $10^{5.1} \div 10^{1.5}$ **or** $10^{3.6}$ (≈ 4000)	**B1**	Enter text here.
		ii	Most of the (alpha) particles went through without (much) deflection, hence the atom is mostly empty / space / vacuum Some of the (alpha) particles were scattered (through large angles / greater than 90°), hence there must be a <u>nucleus</u> (at the centre of the atom). Any <u>one</u> from: • The nucleus is very small compared with the atom • Positive charge at the centre / nucleus is positive • Most of the mass (of the atom) is at centre / dense nucleus	**B1** **B1** **B1**	**Allow** Many / Majority / Lots of the alpha particles ….. **Allow** Few(er) / Small(er) number of the alpha particles … **<u>Examiner's Comments</u>** This question provided good discrimination. It is worth 3-marks, so the examiners were broadly looking for three key disparate points. The exemplar below, from a top-end candidate, illustrates a model answer. There is no ambiguity – full marks scored. **Exemplar 12**

					The majority of the alpha particles pass straig through which suggests that the majority of the atom is empty space. The fact that some were scattered suggested there was a nucleus with a positive charge repelling the positive alpha particles away from it. It would be difficult to provide an improved answer. However, it is worth pointing out that the same ideas can also be presented in bullet-point form – three distinct points for the 3 available marks.
			Total	**4**	
44			Electrons and quarks identified as fundamental particles There are 6 electrons, 6 protons and 8 neutrons Composition of proton → u u d Composition of neutron → u d d	B1 B1	**Allow** e for electron, p for proton, and n for neutron throughout **Allow** 6 electrons, 20 u and 22 d **Do not** award this mark if electron has quark-composition **Allow** '2 up and 1 down' **Allow** '2 down and 1 up'
			Total	**4**	
45		i	1	B1	**Examiner's Comments** This question was correctly answered by the vast majority of candidates.
		ii	Either: mass of nucleus 14.000 × 1.66 × 10^{-27} (= 2.324 × 10^{-26} kg) Or: mass of nucleons = 8 × 1.675 ×10^{-27} + 6 × 1.673 × 10^{-27} (= 2.3438 × 10^{-26} kg) (Δm =) 2.3438 × 10-*26* - 2.324 × 10^{-26} = (1.98 × 10^{-28} kg) (ΔE =) 1.98 × 10^{-28} × (3.00 × 10^{8})^2 (BE per nucleon =) 1.782 × 10^{-11}/14 binding energy per nucleon = 1.27 × 10^{-12} (J per nucleon)	C1 C1 C1 A1	Δm = 1.9262 × 10^{-28} kg **Ignore** sign throughout ΔE = 1.782 × 10^{-11} J **Allow** for any mass difference × (3.00 × 10^{8})^2 **Note** A mark for correct answer to 3sf only **Examiner's Comments** This final calculation required some careful structure and several stages. An encouraging number were able to work through the solution to its conclusion. Some rounded intermediate calculations too early and so lost the final 3 significant figures mark. Several candidates also missed the division by the nucleon number, either as a slip or perhaps they did not appreciate that this was what was required. Even the weakest candidates realised the need to apply $E = mc^2$, but would only gain credit here if they had calculated a mass difference. Some candidates also miscalculated the number

					of protons and neutrons in the carbon nucleus, which meant that they were limited to a maximum of 2 marks.
			Total	**5**	
46		i	(decay constant =) $\frac{\ln 2}{5700}$ decay constant = 1.2(2) × 10^{-4} (y^{-1})	C1 A0	
		ii	0.78 = $e^{-\lambda t}$ ln0.78 = (−) 1.2 × 10^{-4} × t age = 2100 (y)	C1 C1 A1	**Note** 1 = 0.78$e^{-\lambda t}$ is **XP**; answer is negative (− 2100 y) There is no ECF from **(b)(i)** **Note** 1.22 × 10^{-4} gives an answer of 2040 y or 2000 y
		iii	The ratio (of carbon-14 to carbon-12) has remained constant	B1	
			Total	**5**	
47		i	total nucleon number after fusion = 3 + 3 − 4 = 2	M1	**Allow** other correct methods
		i	total proton number after fusion = 1 +1 − 2 = 0	M1	
		i	(Hence it must be 2 neutrons $^{1}_{0}n$ after the fusion reaction)	A0	
		ii	(BE of neutron(s) = 0 and BE of $^{4}_{2}He$ = 28.4 MeV) BE of $^{3}_{1}H$ nucleus = ½ × (28.4 − 11) = 8.7 (MeV)	C1	
		ii	BE per nucleon = 8.7/3 = 2.9 (MeV) BE per nucleon = 2.9 × 10^{6} × 1.60 × 10^{-19}	C1	
		ii	BE per nucleon = 4.6 × 10^{-13} (J)	A1	
			Total	**5**	
48		i	Fission reactors produce radioactive by-products which affect future generations and the environment in terms of possible contamination / exposure to humans and animals.	B1	
		ii	No of particles in 1000 g U = 1000/235 × 6.02 × 10^{23} = 2.56 × 10^{24} No of reactions for U = 2.56 × 10^{24}	B1	Appreciate that the key to the answer is the difference in numbers of atoms / nuclei **or** equal number of nucleons involved scores one mark if nothing else achieved.
		ii	Energy from U = 2.56 × 10^{24} × 200 = 5.12 × 10^{26} MeV	B1	
		ii	No of particles in 1000g H = 6.02 × 10^{26} No of reactions = 6.02 × 10^{26}/4 Energy from H = 6.02 × 10^{26}/4 × 28 = 42.14 × 10^{26} MeV	B1	

		ii	Hence energy 42/5 = 8.2 times higher	B1	
		ii	*second method* 235 g of U and 4 g of H / He contain 1 mole of atoms	or B1	
		ii	there are 4.26 moles of U and 250 moles of He	B1	
		ii	so at least 58 times as many energy releases in fusion ratio of energies is only 7 fold in favour of U	B1	
		ii	therefore 58/7 times as much energy released by 1 kg of H	B1	
		ii	*similar alternative argument,* e.g. For U each nucleon 'provides' 0.85 MeV	B1	
		ii	For H each nucleon 'provides' 7 MeV	B1	
		ii	(Approx) same number of nucleons per kg of U or H	B1	
		ii	so 8.2 times as much energy from H	B1	
			Total	**5**	
49	a	i	$I = I_0/r^2$ or $I = kr^{-2}$	B1	**allow** inverse square law statement
		i	(k = 20) so $I = 20/(0.25)^2 = 20 \times 16 = 320$	B1	
		ii	640	B1	
		iii	$640 = 20/r^2$	C1	**ecf(ii)1**
		iii	so $r = \sqrt{(20/640)} = 0.18$ (m)	A1	**accept** 0.177 (m)
	b		**Level 3 (5–6 marks)** Clear set up and description of chosen experiment(s) **and** clear interpretation of observations *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Limited set up and description of chosen experiment **and** limited interpretation of observations *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.*	B1 × 6	**Indicative scientific points may include:** **1**. range/penetration/absorption/deflection experiment suggested **2**. suitable arrangement and choice of apparatus e.g. on diagram; allow GM tube as detector for all particles **3**. description of range/penetration/absorption experiment: **a**. α place detector very close/ 2cm from source; measure count rate, use paper screen or move back to 10 cm or more, measure count rate, interpret result; contrast to background count level and/or other emissions from same source **b**. β place detector e.g. 10 cm from source measure count rate, add thin sheets of Al until count drops to very low or almost constant value e.g. γ present; interpret result; **c**. γ place detector e.g. 10 cm from source measure count rate, add thin sheets of Pb until count drops to very low/background level; interpret result

			Level 1 (1–2 marks) Very basic description of chosen experiment **and** limited interpretation of observations *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.		**4**. deflection experiment: needs vacuum for α experiment;source for radiation passes through region of E- or B- field; deflection or not of particles detected by detector to distinguish emissions; detail of directions; amount of curvature determines energy of emission; and nature of particle
			Total	**11**	
5 0		i	2	B1	
		ii	Zero	B1	
		iii	Δm = 236.053 − 235.840 = 0.213 u	C1	
		iii	$\Delta E = [0.213 \times 1.661 \times 10^{-27}] \times (3.0 \times 10^{8})^2 = 3.184 \times 10^{-11}$ (J)	C1	
		iii	number of reactions per second = $10^9/3.184 \times 10^{-11}$	C1	
		iii	number of reactions per second = 3.1×10^{19} (s^{-1})	A1	
			Total	**6**	
5 1			* **Level 3 (5–6 marks)** All of B correct. One of S and one of D stated. C fully described. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** B partially given. S and D given but one not clear. C lacks detail. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** B poor and incomplete. Only S or D given. C not mentioned or very inadequate.	B1	**basic description (B)** *1. fission:* neutron is absorbed by the nucleus causing it to split into two (major) fragments and several / two / three neutrons *2. fusion:* two light nuclei (moving rapidly enough) overcome the Coulomb repulsion between them fuse. **similarity (S)** 1. release of energy 2. total (rest) mass decrease 3. ‘increase’ in binding energy 4. conservation of charge / mass-energy. **difference (D)** 1. cold, hot 2. heavy, light nuclei 3. large (200 MeV), small (30 MeV) energy release per reaction. **conditions (C)** 1. fission rate can be varied / controlled by absorbing and or slowing released neutrons in reactor where chain reaction is occurring 2. fusion needs a very hot and sufficiently dense and plentiful

			The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear. **0 marks** No response or no response worthy of credit.		plasma for random fusion collisions to occur, e.g. inside Sun / star.
			Total	**6**	
5 2			**Level 3 (5–6 marks)** Correct explanation Correct determination of λ and half-life Correct determination of uncertainty (Maximum 6 marks) Any point omitted or incorrect (5 marks). *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Mostly correct explanation Mostly correct determination of λ and half-life Some attempt of determining uncertainty (Maximum 4 marks) Any point omitted or incorrect (3 marks). *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Basic explanation Some attempt to determine λ or half-life No attempt at uncertainty. (Maximum 2 marks) *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1 x 6	**Explanation** 1. $A = A_0e^{-\lambda t}$ 2. $\ln A = \ln A_0 - \lambda t$ 3. A graph of ln$A$ against t will be a straight line with gradient (−) λ 4. half-life = ln2/λ **Determination** 1. Line of best fit drawn 2. Gradient determined using a large triangle 3. decay constant in the range 0.5 to 0.7 min^{-1} 4. half-life in the range 1.0 to 1.4 min **Uncertainty** 1. Worst line of fit drawn 2. Correct attempt to determine uncertainty
			Total	**6**	
5 3			**Level 3 (5 – 6 marks)** Clear expansion of three statements *There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear, relevant and*	B1 x 6	**Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2ˆ for 3 marks, etc.** **Indicative scientific points may include:** **statement 1**

			substantiated. **Level 2 (3 – 4 marks)** Clear expansion of two statements **or** Limited attempt at all three *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** Limited attempt at one or two statements *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*		• fusion reactions are occurring • which change H into He • and mass is lost which releases energy • energy released = $c^2\Delta m$ • Δm per second = luminosity / c^2 **statement 2** • average k.e. of each proton is $\frac{3}{2}kT$ • high T means protons are travelling at high speed • so fast enough to overcome repulsive forces • and get close enough to fuse • p.e. = $e^2/4\pi\varepsilon_0 r$ so T must be high enough for $\frac{3}{2}kT > e^2/4\pi\varepsilon_0 r$ • r is approximately 3fm **statement 3** • k.e. ∝ T so average energy at 10^7 K is only one thousandth of the average energy at 10^{10} K when protons might fuse • but M-B distribution applies so at the high energy end there will be a few p with enough energy • quantum tunnelling across potential barrier is possible • small probability of many favourable collisions to boost energy of p • 4 p must fuse to produce He; it is complicated process making probability of fusion much less • number of p in Sun is so huge that, even with such a small probability, 4 x 10^9 kg of p still interact s^{-1} • a larger probability means lifetime of the Sun would be shorter **<u>Examiner's Comments</u>** This was one of the two LoR questions. It required understanding of fusion, mass-energy equivalence, the Maxwell-Boltzmann distribution, and the relationship between mean kinetic energy and temperature for particles in an ideal gas. Responses to the following questions were being sought: 1. Why is the Sun losing mass? 2. Why is an extremely high temperature needed for fusion in stars? 3. Why does fusion occur in the Sun even though its temperature is 1,000 times less than that required by theory? Two dissimilar responses could score comparable marks if the

					criteria set out in the answer section of the marking scheme were met. Level 3 responses gave a clear answer to all three of the questions, whereas Level 2 responses generally had clear answers to only two. In Level 1, limited answers to only one or two of the above questions were given.
			Total	**6**	
5 4			* **Level 3 (5–6 marks)** For equipment expect both E1 and E2 Descriptions has all the points At least two safety precautions mentioned Both Q1 and Q2 mentioned for the quality of results. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Expect at least E1 for equipment For description expect D1 and D2 and an attempt at either D3 or D4 At least one safety point mentioned Expect either Q1 or Q2 for quality of results. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Expect at least E1 for equipment For description expect D1 and D2 At least one safety point mentioned Statements for quality are not relevant. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1	**Equipment (E)** 1. GM tube, counter or rate-meter and lead plates used 2. Micrometer or vernier calliper (to measure thickness of plates). **Description (D)** 1. Measure counts for a specific time and hence the count-rate for each thickness of lead 2. Vary the thickness of lead and record the count-rates 3. Plot a graph of count-rate against thickness and determine the half thickness of lead 4. Fig. 23.1 is used to determine the photon energy. **Safety (S)** 1. Do not point source at person 2. Keep safe distance between you and source 3. Use tongs to handle source. **Quality of results (Q)** 1. The counts are recorded over a long period of time 2. Background radiation taken into account.
			Total	**6**	
5 5			**Level 3 (5–6 marks)** Some description **and** clear analysis for $r \propto A^{1/3}$ **and** correct calculation of mean density *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.*	B1×6	**Indicative scientific points may include:** **Description** • The density is independent of *A*

			Level 2 (3–4 marks) Some description **and** some analysis for $r \propto A^{1/3}$ **or** some calculation of mean density **OR** Some description **and** clear analysis for $r \propto A^{1/3}$ **OR** Some description **and** correct calculation of mean density **OR** Clear analysis for $r \propto A^{1/3}$ **and** correct calculation of mean density *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Some description **OR** Limited analysis for $r \propto A^{1/3}$ **OR** Limited calculation of mean density *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit		• The density is constant for most of *d* • Nucleus with bigger *A* is larger (*d* / volume / mass) **Analysis for $r \propto A^{1/3}$** • $r \approx 3.6$ (× 10^{-15} m) for Al-27 / $r \approx 5.5$ (× 10^{-15} m) for Mo-96 / $r \approx 7.0$ (× 10^{-15} m) for Hg-200 • $r/A^{1/3}$ = constant (or equivalent) • Evidence for $r \propto A^{1/3}$ with at least 2 nuclei (Note: 3.6 (×10^{-15})/$27^{1/3}$ ≈ 5.5 (×10^{-15})/$96^{1/3}$ ≈ 7.0 (×10^{-15})/$200^{1/3}$ ≈ **1.2** (×10^{-15}) **or** • r^3/A = constant (or equivalent) • Evidence for $r^3 \propto A$ with at least 2 nuclei (Note. 3.6^3 (×10^{-45})/27 ≈ 5.5^3 (×10^{-45})/96 ≈ 7.0^3 (×10^{-45})/200 ≈ **1.7** (×10^{-45}) **Calculation for density** • $\rho = M/V$ • $\rho = Am_n \div \frac{4}{3}\pi r^3$ **or** $\rho \approx Amn \div$ diameter^3 • $m_n \approx 1.7 \times 10^{-27}$ (kg); $\rho = 2.3 \times \mathbf{10}^{-17}$ (kg m^{-3}) for at least one of the nuclei given in the figure or table
			Total	**6**	
56		i	<u>**A =**</u> 470/8.8 × 10^{-13} = 5.3 × 10^{14} (Bq) λ = ln 2/(88 × 3.16 × 10^7) (= 2.5 x 10^{-10} s^{-1}) ($A = \lambda N$); N (= 5.3 x10^{14} / 2.5 x 10^{-10}) = 2.1 x 10^{24}	C1 C1 A1	Mark is for correct calculation of A (in Bq **or** decays per s) Mark is for correct working to give λ in s^{-1}
		ii	$P = P_o \exp(-\lambda t)$ P = 470 exp (− ln 2 x 100 / 88) P = 210 (W)	C1 C1 A1	**Allow** formula in terms of *N* or *A* **Allow** calculation in terms of *N* or *A*; **allow ECF** for *N* or *A*
			Total	**6**	
57			**Level 3 (5–6 marks)** Clear description and clear calculations of energy per kg *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and*	B1×6	**Indicative scientific points may include:** **Description** • Energy is produced in both reactions • More energy produced (per reaction) in fission

			substantiated. **Level 2 (3–4 marks)** Clear description **OR** Clear calculations of energy per kg **OR** Some description **and** some calculations *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **OR** Limited calculations *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit		• The (total) binding energy of 'products' is greater • In fusion, nuclei repel (each other) • Fusion requires high temperatures / high KE • Fission reactions are triggered by (slow-)neutrons • Chain reaction possible in fission **Calculations** • 1 kg of uranium has 4.26 mols / 2.56 × 10^{24} nuclei • 1 kg of deuterium has 500 mol / 3.01 × 10^{26} nuclei / 1.50 × 10^{26} 'reactions' • 200 MeV = 3.2 × 10^{-11} J • 4 MeV = 6.4 × 10^{-13} J • Uranium: ~ 10^{14} (J kg^{-1}) (actual value 8.2 × 10^{13}) • Deuterium: ~ 10^{14} (J kg^{-1}) (actual value 9.6 × 10^{13}) • The energy per kg is roughly the same **Examiner's Comments** This is the second LoR question. This is designed to assess knowledge of the two nuclear energy reactions and to calculate energy release using some given data. The differences between the fission and fusion reactions were generally well answered although many candidates explained differences in design, operation and waste more than the reactions. The similarities were often not as clear however several candidates gave excellent responses in terms of binding energies and mass differences. Candidates were also expected to complete a calculation to show which produces more energy output per kilogram. This is challenging calculation to follow through fully, but most candidates were able to make some attempt, even if it was only converting MeV to J. Only better candidates realised 2 nuclei of deuterium were used for one fusion reaction. While a small number of candidates did correctly calculate the energy per kilogram, they tended to state that fusion produced more energy rather than a feeling that they are basically equivalent. As usual with LoR questions, a holistic approach is taken to the marking and candidates can access higher levels without necessarily reaching all the marking points. Even so, relatively few candidates were able to access Level 3, generally due to poor calculations and/or descriptions.
			Total	**6**	
5 8		i	(force =) $\frac{(1.6\times10^{-19})^2}{4\pi\epsilon_0\times(1.0\times10^{-15})^2}$ (F =) 230 (N) $F^2 = 230^2 + 230^2 - 2\times230\times230\times\cos120°$	C1 C1 C1	**Special case:** $F = \frac{Qq}{4\pi\epsilon_0 r^2} = \frac{2\times1.6\times10^{-19}}{4\pi\epsilon_0\times(1.0\times10^{-15})^2}$ loses this C1 mark, then ECF for the rest of the marks **Not** the first two C1 marks for incorrect charge, then allow ECF for the final C1A1 marks **Note** force to 4 SF is 230.2 N **Allow** sine rule / scale drawing **Allow** this mark for 230cos30° **or** 200 (N)

			or $F = 2 \times 230\cos30°$ $F = 400$ (N)		**Allow** ± 10 (N) if scale drawing used
		ii	F / arrow vertical up the page	B1	**Allow** correct arrow direction anywhere on the figure
		iii	Strong (nuclear) force (acts on the protons) The strong (nuclear) force is attractive	B1 B1	**Ignore** gravitational force **Allow** pulls / holds (the protons) / binds (the protons) for 'attractive'
			Total	**7**	
59		i	Proton is repelled (by nucleus) (High-speed) proton can get close to (oxygen) nucleus	**B1** **B1**	**Allow** 'proton can experience the strong (nuclear) force' **Not** 'collide / hit nucleus'
		ii	$E = [0.25 - (2.24 - 2.20)] \times 10^{-11}$ (J) **or** 0.21×10^{-11} (J) $\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{0.21 \times 10^{-11}}$ (Any subject) $\lambda = 9.5 \times 10^{-14}$ (m)	**C1** **C1** **A1**	**Allow** 2 marks for 6.9×10^{-14}; $E = 0.29 \times 10^{-11}$ used **Allow** 1 mark for a value correctly calculated based on any other incorrect value for E (e.g. 8(.0) × 10^{-14} for $E = 0.25 \times 10^{-11}$ and 5(.0) × 10^{-13} for $E = 0.04 \times 10^{-11}$)
		iii	Used in PET (scans) Any **<u>one</u>** from: Used to diagnose function of organ / brain / body Detection of cancer / tumour Non-invasive / no surgery / no infection 3D (image)	**M1** **A1**	Enter text here.
			Total	**7**	
60		i	More neutrons produced (from each fission reaction) Go on to produce further (fission) reactions / splitting (of nuclei) / energy	B1 B1	**<u>Examiner's Comments</u>** Most candidates scored 1 mark for the general idea of a chain reaction, but the important role played by the neutrons was often omitted in the descriptions. Only a small number of candidates misunderstood fission as a reaction in which the Cs and Rb nuclei themselves were responsible for triggering subsequent reactions of the uranium nuclei.

		ii	Control rod(s) used These absorb the neutrons (without fission)	B1 B1	**Allow** boron / cadmium / indium / silver **Not** moderator **Not** neutrons slowed down and/or stopped **<u>Examiner's Comments</u>** The mechanism of preventing uncontrolled chain reaction within a nuclear reactor was generally well understood. Having given perfect answers with control rods absorbing the excess neutrons, a significant number of candidates confusing their answers by also mentioning the moderator. It many cases it was impossible for examiners to decide from the candidates response if the control rods, or the moderators, were responsible for preventing chain reactions. Some candidates mentioned 'boron rods', this was an acceptable alternative for the 'control rods'.
		iii	(Δm =) 0.190 × 1.66 × 10^{-27} **or** 3.15 × 10^{-28} (kg) (ΔE =) 0.190 × 1.66 × 10^{-27} × (3.0 × 10^{8})^{2} **or** 2.84 × 10^{-11} (J) $\frac{1.00}{0.235}$ ×6.02×10^{23} **or** 2.56 × 10^{24} (energy = 0.03 × 2.56 × 10^{24} × 2.84 × 10^{-11}) energy = 2.2 × 10^{12} (J)	C1 C1 C1 A1	**Note** the 3.0% can be done at any stage, allow other correct methods **Allow** the use of 1.67 × 10^{-27} **Allow** ECF from 1.66 × 10^{-27} omitted **Note** 7.69 × 10^{22} will score this C1 mark; 3.0% included **Allow** 3 marks for 7.3 × 10^{13} (J); 3.0% omitted **Allow** 3 marks for 1.3 × 10^{39} (J); 1.66 × 10^{-27} omitted **<u>Examiner's Comments</u>** This proved to be an excellent discriminator with top end candidates showing excellent skills to get to the correct answer of 2.2 × 10^{12} J. The majority of the candidates correctly converted the 0.19u into kilograms, and then successfully used Einstein's mass-energy equation to calculate the equivalent energy of 2.8 × 10^{-11} J. The main obstacle in this question was the determination of the number of uranium nuclei in the fuel rods. Avogadro constant, given in the data booklet, was either omitted or the incorrect mass used to determine the number of uranium nuclei. **Misconception** There were some missed opportunities, with some candidates making the following mistakes when determining the number of uranium nuclei in the 1.0 kg fuel rod. • Using 0.235 × N_A. to calculate the number of uranium nuclei. • Using the rest masses of neutrons and protons.

					• Omitting the 3.0%.
			Total	**8**	
6 1		i	Beta radiation would not penetrate/ would be absorbed by the lead	B1	**Not** gamma radiation would be stopped **Ignore** reference to alpha radiation **<u>Examiner's Comments</u>** Most candidates were obviously very familiar with this and gave a clear response. Credit was given for either Gradient of best fit line: • a clear comparison of ln $N = -\mu d + \ln N_0$ with y = mx + c • using log rules to give $\ln(N_0 e^{-\mu d}) = -\mu d + \ln N_0$
		ii	$\ln N = -\mu d + \ln N_0$ compared to y = mx + c (so m = - μ and c = $\ln N_0$)	B1	**or** $\ln N = \ln(N_0 e^{-\mu d}) = \ln N_0 - \mu d$ **<u>Examiner's Comments</u>** Candidates who gained the uncertainty mark mostly used the standard method of finding half the range i.e. (ln340–ln260)/2. However, a very common response was to calculate the fractional uncertainty in N (i.e. 40/300) rather than the absolute uncertainty in lnN. This was not given without mathematical justification e.g. Δ(lnN) ≈ (ΔN)/N.
		iii	5.70 ± 0.14	B1 B1	Both answers must be to 2d.p. **Allow** ± 0.13 not second B1 mark without correct working shown e.g. ln300 – ln260 or (5.83-5.56)/2 **Allow** $\Delta N/N$ (= 40/300) but only if $\Delta(\ln N) \approx \Delta N/N$ is quoted **<u>Examiner's Comments</u>** The majority of candidates had no difficulty in plotting the point (50, 5.70) correctly. Both best and worst fit lines were usually drawn well enough, although some had very thick pencil lines and a surprising number had not been extended to the lnN axis. Almost all candidates gained the mark for using a sufficiently large triangle (Δd > 25mm) for calculating the gradient of their best fit line.
		i v	Point plotted correctly to within ½ small square	B1 B1	**Ignore** accuracy of length of error bar

			Best fit and worst fit line(s) drawn		**ECF (ii)2** for incorrect value(s) in table **ECF (ii)2** for incorrect value(s) in table Best fit line should have an equal scatter of points about the line Worst fit line should be steepest/shallowest possible line that passes through all the error bars (allow ±½ small square tolerance vertically) **Examiner's Comments** Most mathematically able candidates quickly obtained the result $\mu d1/2 = \ln 2$ and then used it with their value of μ. Other candidates used a variety of (usually correct) graphical methods with Fig. 2.2.
		v	gradient of best fit line = (-) μ = (-) 54 (m^{-1}) large triangle used to determine gradient of best fit line calculation of absolute uncertainty using their values in the formula (|wfl gradient – bfl gradient|) uncertainty and value of μ to same number of dp	B1 B1 B1 B1	**Allow** 51 to 56 **Allow** value of μ up to 4 SF **ECF(ii)3** for wrongly plotted point Δd > 25mm (seen from graph or working) **ECF (ii)3** for worst fit line **Ignore** any POT error in gradients **Allow** value of absolute uncertainty up to 3 SF only e.g. 53.4 ± 5.6 or 54 ± 6
		vi	$\mu d_{½} = \ln 2$ (or 0.693) $d_{½}$ = 0.013 (m)	C1 A1	**ECF (ii)4** for ½ Alternative method: $\ln(N_0/2)$ =7.67 (C1) then use of graph to give $d_{½}$ = 0.013±0.001 (m) (A1)
			Total	**12**	
62		i	$-mV_g = ½mv^2$ or $½mv^2 + mV_g = 0$	B1	
		i	$V_g = -GM/R = -gR$	B1	
		i	$v = \sqrt{(2gR)}$	B1	Working must be shown
		ii	$v = \sqrt{(2 \times 9.81 \times 6.4 \times 10^6)} = 11 \times 10^3$ m s^{-1}	B1	allow 11(.2) km s^{-1}
		iii	$½mc^2 = 3/2\ kT$ where $m = (M/N_A) = 6.6 \times 10^{-27}$ kg	B1	**ecf (ii); allow** $m = 4u$ or $4 \times 1.67 \times 10^{-27}$

		iii	$T = 6.6 \times 10^{-27} \times 121 \times 10^{6} / 3 \times 1.38 \times 10^{-23}$	C1	
		iii	$T = 1.9 \times 10^{4}$ (K)	A1	**allow** 2 or 2.0
		iv	1 random motion and elastic collisions of particles	B1	**max** 4 out of 5 marking points where answer is a logical progression
		iv	2 lead to distribution of kinetic energies/velocities among particles	B1 B1	
		iv	3 a very few will have very high velocities at top end of distribution 4 a long way from mean /r.m.s. velocity at 300 K 5 hence some able to escape	B1	
		v	helium nucleus is an α-particle	B1	**max** 2 out of 3 marking points
		v	so helium is generated by radioactive decay helium is found in (natural gas) deposits underground	B1	
			Total	**13**	