Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1	a	i	$\lambda = \frac{ln2}{T_{1/2}} = \frac{ln2}{6.01 \times 3600}$ (= 3.20 x 10^{-5} s^{-1}) $(A = \lambda N)$ 900 x 10^{6} = 3.20 x 10^{-5} x N N = 2.8 x 10^{13}	C1 C1 A1	Correct to at least 2sf (2.81) **Special case:** Calculation of decay constant in hour^{-1} gives 0.115 leading to N = 7.8 × 10^{9} maximum 1 mark Calculation of decay constant in min^{-1} gives 1.9 × 10^{-3} leading to N = 4.7 × 10^{11} maximum 1 mark **<u>Examiner's Comments</u>** It was very encouraging to see that nearly two thirds of candidates were able to score all 3 marks on this question. Logarithms can challenge candidates but it was clear that many understood how to carry this out and were able to effectively. There were relatively few who were confused by the time units, but credit could be given even when the unit was used incorrectly.
		ii	(Correct use of $A = A_0 e^{\lambda t}$) 0.03 = $e^{-3.2 \times 10-5t}$ ln(0.03)= - 3.2 × 10^{-5} t t = 109 500 s = 30 hours	C1 C1 A1	Or use of λ as 0.115 hour^{-1} ecf for λ from (b)(i) ln(0.03)= − 0.115t **Allow** final answer that rounds to 30 or 31 hours **Special case:** if fall of 3% (A = $0.97A_0$) calculated, leading to 0.26 hours then max 1 **<u>Examiner's Comments</u>** This calculation was also carried out very well, with many gaining full marks. There are several different ways to obtain the correct answer and part credit can be given for any method which will use the decay equation correctly. Most candidates calculated what 35 of the initial

					activity would be, putting both A and A_0 into the calculation, rather than just using 0.03 as the ratio.
	b		Activity is low compared to background	B1	**Allow** activity is very low **Allow** decays very slowly / very little decay for low activity **Allow** rate of emission for activity **Ignore** references to long half life **Examiner's Comments** The required response here was to do with the activity of the remaining Tc. It needed to be clear that the activity was very low, or that it was low compared to any background count. Using the half-life alone as the response would not be worth any credit. A noticeable number of candidates misinterpreted the question and answered why the presence of the Tc does continue to cause a risk. Many also gave responses relating to the beta emission, stating that it was safe or wouldn't affect bones.
	c		**Level 3 (5–6 marks)** Clear description **and** full correct calculation *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)** Clear description **or** full correct calculation **OR** Some description **and** some calculation *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 calculation *There is an attempt at a logical structure with a line of reasoning. The*	B1×6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** Expect to see appropriate safety precaution for clear description **Description:** • Take background count • Over (at least) 3 minutes • Take count due to source • Over the same time • Measured using a stopwatch • Calculate the corrected count • Calculate the corrected count per minute • Use a Geiger-Muller tube and counter • Hold source at arms length when transferring • Keep in lead lined box at other times • Use tongs to hold source **Calculation**

			information is in the most part relevant. **0 mark** *No response or no response worthy of credit*		• $C = C_0e^{\lambda t}$ • $lnC = lnC_0 - \lambda t$ • e.g 7.51 = 7.81 - $\lambda \times 6$) • λ around 0.05 $hour^{-1}$ • $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ • $T_{\frac{1}{2}}$ = 13.9 hours(allow any answer that round to 14 hours) • $T_{\frac{1}{2}}$ = 830 minutes or 49 900 seconds (allow some tolerance for slight graph reading discrepancies) • Or by a graphical method **<u>Examiner's Comments</u>** This is the second Level of Response (LoR) question in this paper, and was designed to assess nuclear and particle physics, specifically sections 6.4.3e of the specification. In particular, there are two parts (description and calculation) relating to a method and graphical data. As previous, there are no specific marking points and examiners use a 'best-fit' approach to the marking. Indicative scientific points are given in the mark scheme as a guidance what to expect, but not all need to be satisfied to be given full marks. Incorrect physics can be expected to be penalised, however. Candidates should always be encouraged to structure their answers carefully and in calculations aim to give explanation of each stage rather than just producing a number. The two separate sections can be separated into a description of the method for obtaining the data, and a calculation using the graph to determine the half-life. The key points in the description that examiners were looking for were: - named apparatus - measurement of background radiation - calculation of corrected count rate - safety requirements. The key points in the calculation that examiners were looking for were: - arrangement of decay equation having taken logs -

					demonstration that the gradient is the decay constant - calculation of the gradient - use of the gradient to determine the half-life. The descriptions of the method varied significantly. Some were extensive and detailed and others a very limited response despite being a procedure that candidates are likely to have come across. Most candidates gave a simple safety precaution, such as holding at arm's length, but there were plenty of vague responses such as wearing coats. Not all candidates could explain how, or why, the background was taken and a fair number missed this out completely. Quite a few candidates gave extensive detail about storing the source, which although is relevant, is not the key point to the question. The analysis was done better and in general well-structured and clear. The working was set out well for the most part and it was simple to follow the candidates working. Not all gave a clear reason for how they were obtaining the half-life, but this was not fully necessary as long as the answer was correct. One common error was to take logs of the data on the y-axis rather than appreciating that they are already log values. There were not many misreads, but the nature of the data meant that any could have a significant impact on their answer and would likely be penalised. Some candidates got into difficulties with time units and attempted to convert the decay constant to s^{-1} without success.
			Total	**13**	
2	a		(Minimum) energy required to separate the nucleons (to infinity)	B1	**Allow** protons and neutrons for nucleons **Allow** energy released when the nucleus forms from the nucleons **Do not allow** mathematical descriptions such as (mass defect × c^2)

					Examiner's Comments A little less than half gave a suitable explanation for the binding energy; many incorrect responses were based on the idea that it was the energy holding the nucleus together. Several responses correctly stated the relationship between binding energy and mass defect although this did not answer the question.
	b		H-1 is a single proton / nucleon AND there is no binding energy / it is not bound to anything	B1	**Examiner's Comments** Around half of candidates gave a clear suggestion why hydrogen was not included. Many appreciated that the single nucleon had no binding energy although not all made a link. Several candidates described a hydrogen atom instead of the nucleus causing confusion over electron binding energy.
	c	i	The product has a higher binding energy (per nucleon)	B1	**Allow** the fusion of low Z number nuclei will result in a nucleus higher up the curve making it more stable **Ignore** statements regarding electrostatic repulsion **Examiner's Comments** This question was quite poorly answered with few candidates appreciating the idea that an increase in binding energy per nucleon would result in energy given out. Many candidates simply restated the question, by saying low mass would join to give higher mass or stated that iron was the most stable isotope.
		ii	Energy before = $(1.1 \times 2) + (2.8 \times 3)$ (= 10.6 MeV) Energy after = 7.1 x 4 (= 28.4 MeV) Energy released = 28.4 -10.6 = 17.8 MeV $= 17.8 \times 10^{6} \times 1.6 \times 10^{-19} = 2.8 \times 10^{-12}$ (J)	C1 C1 A1	**Allow** ± 0.1 MeV tolerance on binding energy values from graph Answer to at least 2sf (2.848) MAX value of energy within tolerances $= 2.99 \times 10^{-12}$ MIN value of energy within tolerances $= 2.70 \times 10^{-12}$ **Examiner's Comments**

					As always with a 'show that' question, it is vital to include as many steps as possible, the key to this question involved reading from the graph and then including the number of nucleons in the calculation. A fair number of candidates correctly read the point but did not multiply this with the nucleon number. There were relatively few misreads from the graph and the tolerance allowed some variation. Many simple (and incorrect) methods would give a value fairly close to 3 x 10^{-12} and so candidates would feel that they had correctly answered the question. Very few candidates struggled with the conversion from MeV to joules, although this may have been supported by having the power of ten given to them. It is also important to make sure that any value is given to a greater number of significant figures than that asked for, if appropriate. Around a third of candidates were able to obtain all 3 marks on what a potentially challenging calculation is.
		iii	Energy released per second = $4.3 \times 10^9 \times (3 \times 10^8)^2 = 3.87 \times 10^{26}$ (J) No of reactions = $3.87 \times 10^{26} / 2.85 \times 10^{-12} = 1.4 \times 10^{38}$ (s^{-1})	C1 A1	Alternative method: Mass per reaction = $2.85 \times 10^{-12} / (3 \times 10^8)^2 = 3.2 \times 10^{-29}$ (kg) No of reactions = $4.3 \times 10^9 / 3.2 \times 10^{-29} = 1.4 \times 10^{38}$ (s^{-1}) **Allow** use of 3×10^{-12} to give 1.29×10^{38} **Allow** use of (c)(ii) tolerance range for energy released value from to final answer in range 1.29 − 1.43 ($\times 10^{38}$) Correct to at least 2sf **<u>Examiner's Comments</u>** There are several routes to obtain the correct answer and credit is always given to any correct method. Neatly two thirds of candidates scored both marks on this question, even if they had not completed the previous part by using the 'show that' value. Candidates should always be aware that a 'show that' value is likely to be used in subsequent calculations.

	d	i	0 / neutral	B1	Unit not necessary, but penalise incorrect unit **<u>Examiner's Comments</u>** Most candidates were able to identify the charge. Most who gave incorrect responses answered a charge of −1, presumably due to the β^+.
		ii	(electron) neutrino	B1	Do **not allow** antineutrino **Ignore** symbols If answer line is blank, then the name in the missing space in the equation can be taken as the answer **<u>Examiner's Comments</u>** Most candidates appreciated that this was a neutrino, with some giving the symbol in the equation too. There were relatively few antineutrino responses with electron being the most common incorrect answer. There seemed to be little connection between this and the previous question for several candidates who correctly gave the charge in (d)(i) but then named a charged particle here, or vice versa.
		iii	4	B1	**<u>Examiner's Comments</u>** Most candidates were able to determine the correct number of quarks; the most common incorrect response was six, being the total number of quarks.
	e		$d \rightarrow u$ $+ {}^{0}_{-1}e^{-} + \bar{\nu}$	B1 B1	Correct change of quark **Allow** udd to uud Correct symbols for other two particles **Allow** e^- or ${}^{0}_{-1}e$ for electron **Allow** beta symbol for electron Numbers for the neutrino do not need to be present, but must be correct if given ${}^{0}_{0}\bar{\nu}$ **<u>Examiner's Comments</u>**

					Candidates needed to show the quark change for a single mark, being a down quark to an up quark. This could be done in a number of ways, as long as there was one fewer d and one more u on the right hand side of the equation. This was done fairly well but the other particles were less clear. A neutrino was often given instead of an antineutrino and even though a beta-minus was given in the question, this was often written as a beta plus. A significant number of candidates gave no response to this question. This did not seem to be an issue of time.
			Total	**13**	
3			B	1	**<u>Examiner's Comments</u>** A little under half of the candidates were able to correctly identify the correct statements. A helpful approach to this type of question is to 'tick' the statements which the candidate is certain of, which then reduces the options available.
			Total	**1**	
4			C	1	**<u>Examiner's Comments</u>** Most candidates were able to correctly calculate the radius and it was clear that most knew how to correctly apply the formula
			Total	**1**	
5			D	1	**<u>Examiner's Comments</u>** This relatively simple question was correctly answered by of the vast majority of candidates. The most common distractor was **B** which was presumably due to a lack of certainty of quark charges.
			Total	**1**	
6			D	1	**<u>Examiner's Comments</u>** Most candidates were able to correctly identify the classification and force. To

					reduce their options, many candidates circled the correct force.
			Total	**1**	
7			C	1	<u>**Examiner's Comments**</u> This question was correctly answered by most of the candidates and demonstrated a good knowledge of ionising radiations in medical applications.
			Total	**1**	
8			$\rho = \frac{m}{V}$ **and** $V = \frac{4}{3}\pi r^3$ ($\approx 4\ r^3$) density of neutron star ≈ **5 × 10^{17}** kg m^{-3} density of nucleus ≈ **4 × 10^{17}** kg m^{-3}	C1 A1 A1	Formulae may be inferred from either calculation **Allow** m/r^3 = constant **Ignore** number of s.f. in answer Volume of neutron star 4 × 10^{12} m^3 **Ignore** number of s.f. in answer Volume of nucleon ≈ 4 × 10^{-45} m^3 $m_{nucleon}$ ≈ u = 1.66 × 10^{-27} kg to 3 sf (**allow** 1.67 × 10^{-27} kg) If the calculation of separate densities is not shown explicitly then the two **A1** marks may be scored for either: • ratio of densities ≈ 0.8 **or** 1.2 • m/r^3 = 2.0 × 10^{18} (kg/m^3) for star **and** 1.7 × 10^{18} (kg/m^3) for nucleon • r^3/m = 5.0 × 10^{-19} (kg/m^3) for star **and** 6.0 × 10^{-19}(kg/m^3) for nucleon <u>**Examiner's Comments**</u> Most candidates were able to apply the correct formulae for density and for volume of a sphere. The calculation for the density of a neutron star was performed easily. However, rather than calculating the density of a single nucleon (whose radius had been given), many candidates tried to calculate the density of a different nucleus (such as deuteron or helium) whose radius had not been given. Some candidates lost marks through not stating the units in which their calculated densities were measured.

			Total	**3**	
9			(mass defect in u =) (2.014102 + 3.016049 − 4.002603 − 1.008665) u (= 0.018883 u) (mass defect in kg =) $0.018883 \times 1.661 \times 10^{-27}$ ($= 3.1365 \times 10^{-29}$) (energy per fusion reaction in J = mc^2 =) $3.1365 \times 10^{-29} \times (3.00 \times 10^8)^2$ ($= 2.82 \times 10^{-12}$) (number of fusion reactions = $\frac{\text{energy needed}}{\text{energy per fusion reaction}}$ = $400 \times 10^6 / 2.82 \times 10^{-12}$ =) **1.4×10^{20}**	C1 C1 C1 A1	**Allow** ECF for mass defect throughout unless **XP** Mark is for correct working leading to the answer. Answer does not need to be calculated but 0.018883 u (not just 0.018883) implies C1 **Allow** negative answer Mark is for substituting u = 1.661×10^{-27} (kg), seen anywhere in the working **Allow** 1.66×10^{-27} or 1.67×10^{-27} for 1.661×10^{-27} Answer need not be calculated but 3.1365×10^{-29} implies first two C1 marks Mark is for multiplying mass defect by $(3.00 \times 10^8)^2$, seen anywhere in the working Answer need not be calculated but 2.82×10^{-12} implies all three C1 marks **Ignore** unit if given **Allow** ECF (a)(i) or (b) for incorrect POT in 400GW Note for markers: calculation in kg 3.34542 + 5.00966 − 6.64832 − 1.67539 ($\times 10^{-27}$) = (8.35508 − 8.32372) $\times 10^{-27}$(= 3.136 $\times 10^{-29}$ kg) Note for markers: calculation in J 3.01088 + 4.50869 − 5.98349 − 1.50785 ($\times 10^{-10}$) = (7.51957 − 7.49134) $\times 10^{-10}$ (= 2.82 $\times 10^{-12}$J) <u>**Examiner's Comments**</u> Most candidates seemed to have a very good understanding of this question, suggesting good preparation by centres. Those who dropped marks often made arithmetical errors in calculating mass defect or forgot to convert atomic mass units into kilograms. A lack of clarity in setting out mathematical procedures made

					some candidates' thought processes difficult to follow.
			Total	**4**	
10	a		${}^{18}_{9}F \rightarrow {}^{18}_{8}O + {}^{0}_{1}\beta^{+}$ $(+\nu)$	C1 A1	Correct fluorine isotope Correct equation **ALLOW** numbers written to right of symbol **ALLOW** e / e^{+} / $\bar{e}$ / β for positron symbol with correct numbers **IGNORE** gamma in products **ALLOW** ${}^{0}_{0}\nu$ for neutrino **ALLOW** ν_e for neutrino **<u>Examiner's Comments</u>** Most candidates will have gained the first mark for the correct isotope of fluorine. Those who didn't likely reversed the positions of the nucleon and proton number. It was noticeable that a large number of candidates were unable to balance the equation and while they had the correct values for the positron, the oxygen isotope was incorrect.
	b		$E = mc^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2$ $= 8.2 \times 10^{-14}$ (J) $E = hc / \lambda = 8.2 \times 10^{-14} = 6.63 \times 10^{-34} \times 3 \times 10^8 / \lambda$ $\lambda = 3.00 \times 10^8 \div 1.2367 \times 10^{20} =$ **2.4×10^{-12}** (m)	C1 C1 A1	Working leading to evaluation of E **ALLOW** factor of 2 leading to 1.6×10^{-13} (J) **NOT** use of $\lambda = h/mv$ where v is 3×10^8 alone **XP** **ALLOW** use of $\lambda = hc/mc^2$ or $\lambda = h/mc$ **ALLOW** Use of electron mass = 0.511 MeV giving 8.2×10^{-14} (J) Correct to at least 2 significant figures Answer of 4.9×10^{-12} or 1.2×10^{-12} allow 2/3 due to incorrect accounting for factor of 2 **<u>Examiner's Comments</u>** Well over half of the candidates were able to score 2 or more marks on this question. A great deal scored 2 marks due to the inclusion of a factor of two, which was then not removed (or vice versa). Some candidates used the formula for kinetic energy – which by coincidence may give the correct

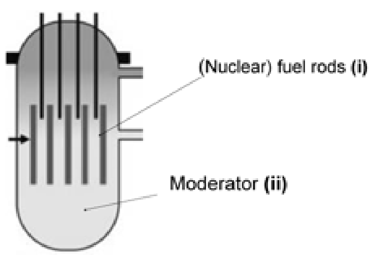
					answer – however this was not credited, nor was the more common use of the de Broglie formula. Examiners sometimes had a difficult decision on this question, whether the response was a physics error or not, and if in doubt a candidate would be awarded the marks.
	c		X-rays formed when <u>electrons</u> (in an atom) de-excite Gamma rays come from the decay of <u>nuclei</u> (in unstable isotopes)	B1 B1	**ALLOW** X-rays may be produced by acceleration / deceleration of (fast moving) electrons / X-rays are produced when (fast moving) electrons are incident on a metal target / X-rays may be produced when electrons lose kinetic energy **ALLOW** gamma rays come from (the decay of) radioactive <u>nuclei</u> / gamma rays come from the <u>nucleus</u> of unstable atoms / gamma rays come from the de-excitation of <u>nuclei</u> / gamma rays come from <u>annihilation</u> of particle-antiparticle (pairs) / **IGNORE** gamma from fission **<u>Examiner's Comments</u>** The main principle behind this question was to distinguish between the X-ray production by electrons and gamma ray production by nuclei. Fairly specific details were required for each, although a wide range of answers were accepted. This question discriminated well among the candidates with roughly equal fractions getting 0, 1 and 2 marks.
	d		The half-life is short Advantage: Exposure of the patient to <u>ionising</u> radiation is kept as low as possible. Disadvantage: (Radiographers have a) short time to scan/diagnose the patient	B1 B1 B1	**ALLOW** activity is high **IGNORE** it decays quickly **ALLOW** F18 has to be manufactured on site before use / high activity means exposure is high during handling **IGNORE** short time to treat the patient **<u>Examiner's Comments</u>** Although apparently a simple set of ideas, the detail required for this question meant that only a small fraction of candidates were able to

					gain full marks. It was necessary to state that the half-life was (relatively) short, which many of the stronger candidates did not do. The advantage to the patient requires the use of the term 'ionising' as this is the fundamental issue with the radiation. Similarly, candidates had to make it clear that the disadvantage was due to the short time to carry out the scan rather than just a statement of needing to work quickly.
			Total	**10**	
11	a		Marks may be awarded for the following considerations only: technology, reaction, fuel, waste, safety. Technology: • Fission: technology already established / Fusion: technology not yet established Reaction: • Fission: chain reaction self-sustaining once initiated • Fusion: very high temperatures/pressures /amounts of energy required to initiate and continue reaction / challenges with storage and containment of plasma Fuel: • Fission: finite amount of uranium / needs to be enriched • Fusion: (unlimited) fuel available from (sea) water Waste: • Fission: Produces highly / high level / long half-life / long storage time radioactive waste • Fusion: Produces (effectively) no radioactive waste (products) / only radioactive	4 x B1	ALLOW 1 mark for basic comparison within each consideration if no other marks are awarded. **ALLOW** hydrogen is easier to source (than uranium) for 1 mark **ALLOW** Fission produces radioactive waste and fusion does not for 1 mark. **IGNORE** nuclear for radioactive **<u>Examiner's Comments</u>** This question needed candidates to use appropriate scientific knowledge and understanding to discuss the differences between fission and fusion in terms of the practicalities. Many candidates were able to give good responses to several of the main points with careful comparisons. One of the key features of this question is to avoid social and economic arguments and base the points on ideas from the course. It is not a 'compare and contrast' question, but many of the marking points can be gained that way. A relatively small number of candidates gained full marks on this, as may be expected, however a good fraction gained 2 or more marks. Responses which could not be credited were simple statements like 'safer', 'easier to use', 'no toxic waste' and 'renewable'. Examiners will have

			material in contained in the reactor Safety: • Fission: Possibility of serious accident / leakage of radioactive material / “meltdown” AND/OR Fusion: very unlikely to produce serious accident (due to near instant shut down of reaction) / no leakage of radioactive material		worked strictly to the mark scheme, and so given marks consistently.
	b		**Level 3 (5–6 marks)** Clear description **and** full correct calculation. *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)** Clear description **or** full correct calculation. **or** Some description **and** some calculation *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 calculation *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 mark** *No response or no response worthy of credit.*	6 x B1	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Description** • Absorption of neutron by U-235 • U-235 nuclei become unstable U236 nuclei • U-236 undergoes fission • Resulting in smaller nuclei daughter products and additional fast neutrons • Moderator slows neutrons so that they can be absorbed by U-235 nuclei • Process repeats to form a chain reaction • Rate of chain reaction controlled by raising or lowering control rods • Which absorb excess neutrons • To allow one neutron per fission to cause further fission **Calculation** Use of ${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{92}_{36}Kr + {}^{141}_{56}Ba + 3{}^{1}_{0}n$ Mass of U236 = 235.04395 + 1.00867 = 236.05262u Total mass of fission products = 140.91440 + 91.92617 + (3 x 1.00867)

					= 235.86658u Difference = 0.18604 u Mass defect =0.18604 x 1.661 x 10^{-27} = 3.0901244 x 10^{-28} kg Energy equivalence per fission event = 3.0901244 x 10^{-28} x (3 x 10^{8})^{2} = 2.78111x10^{-11}J Alternative: Energy equivalence per fission in MeV = 174 MeV **<u>Examiner's Comments</u>** This is the second level of response (LoR) question in this paper, and was designed to assess nuclear physics, specifically Sections 6.4.4 (a), (b), (g) and (h). In particular, there are two parts (description and calculation) both of which need to be answered to obtain a Level 3. As previous, there are no specific marking points and examiners use a 'best fit' approach to the marking. Indicative scientific points are given in the mark scheme as a guidance to what to expect, but not all need to be satisfied for full credit, however for full credit for the calculation, the energy released per fission is the minimum end point. Incorrect physics can be expected to be penalised, however. Candidates should always be encouraged to structure their answers carefully and in calculations aim to give explanation of each stage rather than just produce a number. The two separate sections can be separated into a description of the induction and control, and calculation of the energy released. The key points in the description that examiners were looking for were: - idea of induced fission by a thermal neutron– the chain reaction leading to more neutrons released - a description of the role of the moderator – a description of the role of the control rods.

					The key points in the calculation that examiners were looking for were: - calculation of the mass before fission – calculation of the mass after the fission – difference between these two masses – calculation of the energy equivalent (hence released) from this mass difference. The descriptions of the induction and control varied hugely both in quality and quantity. Many candidates did not start from U-235 but went straight into the fission. Most candidates were aware that extra neutrons were released in fission and had a good idea of the absorption of the extra neutrons by the control rods, but there was often confusion about the role of the moderator (by explaining that it simply 'controlled the reaction') and a significant number did not appreciate why a slower neutron was needed. However, there were many excellent explanations covering all of the indicative points and going beyond. The calculations were attempted well by many candidates and obtaining the energy equivalence of one fission was a suitable point to stop the calculation. A comment supporting the size of the energy compared to this number of fissions per second helped to confirm the large release of energy. Several candidates took this further and calculated the energy per kg, showing how large this was. The main source of error was in not accounting for the mass of the initial neutron in the reaction and so the energy calculated was one 'neutron mass equivalence' too high. Several candidates ended their calculation with a mass difference, or even attempted to calculate the mass defect in the formation of U-235, but this led nowhere. There was a fair number of candidates who made no attempt on the calculation despite having given a good description and it can be

					assumed that they hadn't fully read what they were asked to do. Similarly there were some excellent calculations but no with no description. Candidates are always encouraged to consider both parts of any LoR question. Exemplar 3  - U-235 + $^{1}_{0}n$ → BA-141 + KR-92 + $3^{1}_{0}n$ (235.04395) (140.91440 + 91.92617 + (3 × 1.00867)) = 235.86658 ∴ M_D = 235.86658 − 235.04395 = 0.82263 0.82263 × 1.661×10^{-27} = 1.367×10^{-27} $\Delta E = mc^2$ E = 1.366×10^{-27} × $(3\times10^{8})^2$ = 1.23×10^{-10} J per reaction - ~~The~~ A fission reaction is induced by a neutron being absorbed by a radioactive nucleus, which is split into two lighter nuclei and more neutrons. - Energy is released. Neutrons are then absorbed by other radioactive nuclei causing a chain reaction - The moderator slows down the fast moving neutrons released in the reactions into thermal neutrons, as they are more likely to continue the reaction - Control rods absorb some of the thermal neutrons leaving on average one left from each reaction so the reaction is controlled. This is an example of a Level 2 response to a LoR question. The candidate has given a clear calculation with a good structure but has forgotten to add the neutron mass to the uranium mass to give the initial mass. The remainder of the calculation is correct, giving a final value for the energy per fission which is incorrect by a value of the neutron mass-energy. The explanation of the induction and control is good, if a little brief and lacking in real detail. On the holistic approach taken to the LoR questions, this is a clear Level 2. The communication is good and the setting out of the response is clear.
	c		 	B1 B1	**ALLOW** any correctly named fuel e.g. uranium (oxide) for **(i)** **ALLOW** any correctly named moderator e.g. (heavy) water for **(ii)** **ALLOW** coolant for **(ii)** **ALLOW** any correctly named coolant (e.g. CO2) for **(ii)** **<u>Examiner's Comments</u>** Many candidates were able to

					demonstrate their knowledge of the internal structure of a fission reactor and correctly label the components or the material they are made from. Simple answers such as ‘reactor core’ or ‘fluid’ are not sufficient at this level.
			Total	**12**	
12			C	1	**<u>Examiner’s Comments</u>** A good proportion of candidates were able to answer this correctly. Good practice in this style of questions is to tick the statements that the candidates are sure is correct and try a ‘best fit’. Most candidates knew statement 3 was correct and so response **B** was fairly uncommon as an incorrect response.
			Total	**1**	
13	a		p → n **or** proton → neutron (p → n +) e^+ + v **or** positron + (electron) neutrino	M1 A1	**Allow** u→d or uud→udd **Ignore** A/Z values for the M1 mark **Allow** $\beta+$ or $^{0}_{1}\beta$ or $\overline{e}$ or $^{0}_{1}e$ (but **not** e) for e^+ **Allow** v_e (but **not** $\overline{v}$) for v **Allow** $^{1}_{1}H$ for $^{1}_{1}p$ Where A/Z values are given then they must be correct i.e. $^{1}_{1}p \rightarrow {^{1}_{0}n} + {^{0}_{1}e^{+}} + {^{0}_{0}v}$ **<u>Examiner’s Comments</u>** The question did not specify what type of equation was needed, and the simple word equation proton → neutron + positron + neutrino was sufficient for full marks. **Common problems in 3(a)** • using the symbol N instead of n for neutron (N is the symbol for nitrogen)

					• using incorrect A/Z values such as $^{0}_{1}n$ for neutron and/or $^{0}_{-1}e$ for positron • using an incorrect symbol for the neutrino
•	b		***Level 3 (5–6 marks)** Detailed method **and** analysis which clearly distinguishes between gamma, beta-plus and beta-minus *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)** Some method **and** analysis which clearly distinguishes between any two of the sources *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 method **or** limited analysis *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.*	B1 × 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Method** • Measure background count and subtract from source count • Clamp source pointing away from you • Safety precautions (handle source with tongs, limit time etc.) • Record count over fixed time period • Investigate variation of count rate with range • Place aluminium sheets between source and radiation counter • Set up magnetic field at right angles to emission direction in order to investigate deflection of charged particles • Move radiation counter to find direction of deflection **Analysis** • Gamma has longest range in air, beta minus and beta plus have similar range (or β^+ has shortest range due to annihilation in air) • Gamma penetrates aluminium which is (more than a few mm) thick whereas beta does not • Gamma is undeflected by magnet (because neutral) • Beta radiation is deflected by magnet (because charged particles) • Beta plus and beta minus are deflected in opposite directions

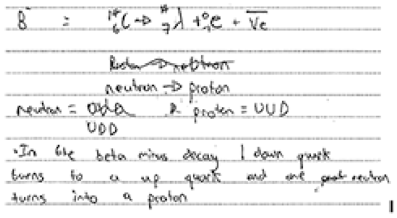
					• because they have opposite charges / beta plus particle is a positron and beta minus particle is an electron • Use Fleming's left-hand rule to determine charge on beta particle through the direction of its deflection • With beta-plus, current is in same direction as motion of particle (opposite for beta-minus) **<u>Examiner's Comments</u>** When marking a LoR question, the examiner first decides the level of response (1, 2 or 3) by considering the quality of the physics. The examiner then decides whether to award the top of the level (for a well-structured and relevant response) or the bottom of the level (for a poorly structured and mostly irrelevant response). In this LoR question, responses in Level 1 often contained insufficient key physics. The experiment described was extremely safe and painstaking but, at the end of the day, the three sources were not clearly distinguishable. Low level responses frequently included instructions on how to test for an alpha source. The magnet was often used either to pick up the sources or to attract/repel charged particles. In a typical top level response, the thickness of aluminium used to block beta (but not gamma) was specified. A perpendicular magnetic field was used to separate the charged particles and the direction of their travel was predicted using an accurate diagram and Fleming's left hand rule. There were three possible approaches: 1. Investigate the range in air. Gamma has the largest range and beta-plus

					the smallest (due to annihilation). (The answer 'both beta-plus and beta-minus have a similar range in air' was also accepted). 2. Investigate the path through a perpendicular magnetic field. Gamma is undeflected; beta-plus and beta-minus would deflect in opposite directions. 3. Investigate the penetrative power. Since the materials and thicknesses available were not specified, it was easiest to keep increasing the thickness and density of the materials until all but one of the sources was blocked, thus identifying the gamma source. Many candidates were unable to distinguish clearly between the two beta sources because they did not understand how beta-plus and beta-minus particles would travel in a magnetic field. Many candidates erroneously thought that a magnet had a positive pole (which would attract beta-minus) and a negative pole (which would attract beta-plus). **Misconceptions** • A bar magnet does not have positive and negative poles – it has north and south poles • A magnet does not attract or repel charges – it exerts a force on charged particles moving at right angles to its magnetic field
			Total	**8**	
14	a		Mark **first two named** forces only Strong (nuclear force) Any one from: short-range / range of about 3 fm / attractive between 0.5 fm to about 3 fm / repulsive below 0.5 fm	M1 A1	**Ignore** any comments on the weak nuclear force **Penalise** any clearly incorrect statements. Implication that strong is always attractive will lose A mark

			Gravitational (force) Any one from: long (infinite) range / attractive / negligible / follows inverse square law	M1 A1	**Allow** 'gravity' **Penalise** any clearly incorrect statements **<u>Examiner's Comments</u>** There were many superb answers to this question, with candidates giving plenty of correct detail in describing these forces. The vast majority appreciated the strong nuclear force was one of the forces and were able to give correct numerical values in terms of attractive and repulsive distances. Some stated that it was a purely attractive force, up to about 3fm, which could not be given the nature/range mark. Those who selected gravitational force as their second force were generally able to score the nature/range mark as this was simpler than that required for the strong force. A number of candidates stated that the electromagnetic force acted on the two hadrons and tried to justify the charge of the neutron in terms of its quarks.
	b		**Level 3 (5–6 marks)** Clear description including at least one correct comment on quarks **and** analysis of density *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)** Some description **and** some analysis of density **or** clear description **or** clear analysis of 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)** Limited description **or** Limited analysis	B1 × 6	**Indicative scientific points may include:** **Description (max L2 if either alpha or beta not described)** • $^{14}_{6}C \rightarrow {}^{0}_{-1}e + {}^{14}_{7}X$ (ignore identification of X) • Before: 6 protons and 8 neutrons • After: 7 protons and 7 neutrons • Neutron → u d d and/or Proton → u u d • Neutron changes into proton (+ electron + antineutrino) • Down quark changes into an up quark (+ electron + antineutrino) • $^{235}_{92}U \rightarrow {}^{4}_{2}\alpha + {}^{231}_{90}Y$ (ignore identification of Y) • Before: 92 protons and 143 neutrons

			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.*		• After: 90 protons and 141 neutrons • 2 neutrons and 2 protons removed (by alpha particle) • Has 6 fewer u quarks and 6 fewer d quarks **Density (max L2 if analysis done without use of data)** • masses: 14.0(u) and 235.0(u) • ratios: masses = 16.8; radii = 2.55; volumes = 16.6 • volume ~ 2.9^3 and 7.4^3 (ignore $4/3\pi$ and 10^{-15}) • densities calculated (about 2.3×10^{17} kgm^{-3}) • density shown to be (roughly the) same **<u>Examiner's Comments</u>** This is the second level of response (LoR) question in this paper, and was designed to assess nuclear and particle physics, specifically sections 6.4.1 and 6.4.2 of the specification. In particular, there are two parts (description and analysis) relating to two radioisotopes, and some given data. As previous, there are no specific marking points and examiners use a "best-fit" approach to the marking. Indicative scientific points are given in the mark scheme as a guidance what to expect, but not all need to be satisfied to be given full marks. Incorrect physics can be expected to be penalised however. Candidates should always be encouraged to structure their answers carefully and in calculations aim to give explanation of each stage rather than just producing a number. The two separate sections can be separated into a description of the decays, and an analysis of the data to show the two nuclear densities are the same. The key points in the description that examiners were looking for were:– numbers of protons before and after

					each decay – a description of the change in quark structure during beta decay – correctly balanced equations for alpha and beta-minus decay – the nature of the emissions in each decay. The key points in the analysis that examiners were looking for were: – calculation of volumes of nuclei, using (4/3π) r^3 − correct use of the density formula – numerical evaluation of the densities of the nuclei and a comparison. The descriptions of the decays varied hugely both in quality and quantity. Most candidates were aware that a beta particle is an electron, but several seemed to think it was an orbiting one which had no structural changes on the nucleus. Those who did know it was from a neutron to proton change often mixed up the nucleon numbers afterwards. Alpha decay was generally done better with most candidates knowing the nature of an alpha particle and correctly stating the structure of the remaining nucleus. Attempts were generally made to changes in quark structures (mostly for beta decay) and the structure of a neutron and proton were known, although strangely several candidates stated the change was from an up quark to a down quark. Candidates who did not give any descriptions of the quark structures were limited to Level 2. For the most part, the analysis was done better than the description and candidates were generally able to correctly evaluate the two densities and make a suitable comparison. Units of density were not penalised here, with many candidates using the mass (in u) in the calculation but giving the units of density as kg m^{-3}, although many stating u m^{-3}. However, many did correctly calculate the mass of the nucleus using the correct factor coming out with densities of approximately 2.3×10^{17} kg m^{-3}. Those who took an approach

					to algebraically show that the density of every nucleus is independent of the nucleon number (using a standard method to get to some variation of $3u/4\pi r^3$) alone were unable to reach Level 3 as they had not used the data. The use of r_0 as 1.2×10^{-15} m was commonly seen.  β^- : $^{14}_{6}C \to ^{*}_{7}\lambda + ^{0}_{1}e + \overline{V_e}$ ~~Beta → proton~~ neutron → proton neutron = ~~dda~~ UDD proton = UUD •In the beta minus decay 1 down quark turns to a up quark and one ~~prot~~ neutron turns into a proton A candidate who provides some description and analysis which places it in Level 2, but the confusion over alpha decay and general lack of clarity means it would be at the lower point (3 marks).
			Total	**10**	
15			**D**	1	**<u>Examiner's Comments</u>** This question can correctly be answered by over three quarters of the candidates. Most appeared to be able to evaluate the composition of the nucleus correctly and then work forward from that. A was the most common incorrect response, presumably as less successful responses were able to recognise a variation of $E = mc^2$.
			Total	**1**	
16			**D**	1	**<u>Examiner's Comments</u>** This question proved to be relatively straightforward with most candidates selecting the correct response. By far the most common incorrect response was C, suggesting that the idea of modelling using dice was not known, despite it being specification point 6.4.3f(ii).

			Total	**1**	
17			**A**	1	**Examiner's Comments** This question was answered correctly by approximately half of the candidates. Most showed written working, often as $hf = 2mc^2$ or the equivalent in numerical form. **B** was by far the most common incorrect response, and it is clear from candidates working that the factor of 2 had simply been missed out.
			Total	**1**	
18			**C**	1	**Examiner's Comments** Only around one third of candidates were able to give the correct response of **C**. Many candidates showed a variety of correct working to produce the correct initial number of nuclei as 16 N, however then gave the incorrect response of **D**. This highlights the need to read each question carefully.
			Total	**1**	
19			**C**	1	**Examiner's Comments** Although a little over two thirds of candidates selected the correct response, this question discriminated well between candidates of differing abilities. Potential errors in this question included two unit prefix conversions and the conversion between eV and joules. Incorrect responses were fairly well spread across the other distractors.
			Total	**1**	