3	**C is the only correct answer,** as the mass-energy equivalent is calculated by converting the mass to kg and then using $\Delta E = c^2 \Delta m$	(1)

7	**The only correct answer is C (0.13 I_0)** A is not correct because the absorption calculation assumes a linear absorption B is not correct because this would be the intensity with 5 cm of absorber D is not correct because this would be the intensity with 10 cm of absorber	1

Question Number	Answer	Mark
1	**A is the only correct answer** B is not the correct answer, as temperature must be high for fusion C is not the correct answer, as density must be high for fusion D is not the correct answer, as temperature and density must be high for fusion	(1)

4	**B is the correct answer (P is the least stable and Q is the most stable)** A is not correct because Q is more stable than R C is not correct because Q is the most stable and P the least stable D is not correct because P is less stable than Q	1

3	**The only correct answer is D (B.E. / nucleon increases in fission and fusion)** A is not correct because B.E. / nucleon increases for both fusion and fission B is not correct because B.E. / nucleon increases for fusion C is not correct because B.E. / nucleon increases for fission	1

7	**C is the correct answer** A is not correct, as the longer the count time the larger the count B is not correct, as background count rate varies from place to place D is not correct, as different detectors have different sensitivities	(1)

6	**The only correct answer is B** $\left(\left(\frac{54-22}{4}\right)+22\right)$ A is not correct because inverse square law has not been applied correctly C is not correct because neither inverse square law nor correction for background has not been applied correctly D is not correct because correction for background has not been applied correctly	1

3	**D is the only correct answer** A is not the correct answer, as B.E./nucleon has a maximum for ^{56}Fe B is not the correct answer, as B.E./nucleon has a maximum for ^{56}Fe C is not the correct answer, as B.E./nucleon has a maximum for ^{56}Fe	(1)

Question Number	Answer	Mark
1	**A is the only correct answer** B is not the correct answer, as alpha radiation is the least penetrating C is not the correct answer, as beta radiation is only moderately ionising D is not the correct answer, as gamma radiation is the most penetrating	1

8	**B is the only correct answer** A is not the correct answer, as penetration is high C is not the correct answer, as ionising power is low and penetration is high D is not the correct answer, as ionising power is low	(1)

Question Number	Answer		Mark
21(a)(i)	The paper will absorb some of the beta radiation **Or** beta radiation will pass through the paper	**(1)**	
	(So) the count rate will vary as the thickness of the paper varies	**(1)**	**2**

21(a)(ii)	Top line correct	**(1)**	
	Bottom line correct	**(1)**	**2**
	<u>Example of equation</u> $^{147}_{61}\mathrm{Pm} \rightarrow {}^{147}_{62}\mathrm{Sm} + {}^{0}_{-1}\beta^{-} + {}^{0}_{0}\bar{\nu}_e$		

21(a)(iii)	Use of $\lambda = \frac{\ln 2}{t_{1/2}}$	**(1)**	
	Use of 0.75%	**(1)**	
	Use of $A = A_0 e^{-\lambda t}$	**(1)**	
	t = 18.5 year [5.83 × 108 s]	**(1)**	**4**
	<u>Example of calculation</u> $\lambda = \frac{\ln 2}{2.62\ \text{year}} = 0.265\ \text{year}^{-1}$ $\frac{0.75}{100} = e^{-0.262\ \text{year}^{-1}\ t}$ $t = \frac{\ln(7.5 \times 10^{-3})}{-0.265\ \text{year}^{-1}} = 18.46\ \text{year}$		

21(b)	Use of 1 u = 1.66×10^{-27} kg [to convert mass of nucleus or mass of neutrons]	**(1)**	
	Use of $\Delta E = c^2 \Delta m$ [must substitute a mass difference]	**(1)**	
	Conversion from J to (M)eV	**(1)**	
	B.E./nucleon = 7.6 MeV	**(1)**	**4**
	<u>Example of calculation</u> mass defect = $(61 \times 1.67 \times 10^{-27}\ \text{kg}) + (84 \times 1.00867 \times 1.66 \times 10^{-27}\ \text{kg})) - (144.913 \times 1.66 \times 10^{-27}\ \text{kg})$ $\therefore$ mass defect = 1.963×10^{-27} kg B.E. = $1.963 \times 10^{-27}\ \text{kg} \times (3.00 \times 10^{8}\ \text{m s}^{-1})^2 = 1.767 \times 10^{-10}$ J $\therefore$ B.E. = $\frac{1.767 \times 10^{-10}\ \text{J}}{1.60 \times 10^{-19}\ \text{J eV}^{-1}} = 1.10 \times 10^{9}$ eV $\therefore$ B.E./nucleon = $\frac{1.10 \times 10^{3}\ \text{MeV}}{145} = 7.617$ MeV		
	Total for question 21		**12**

Question Number	Acceptable Answer		Additional Guidance	Mark
20(a)	Top line correct	**(1)**	<u>Example of calculation</u> $^{238}_{94}\mathrm{Pu} \rightarrow {}^{234}_{92}\mathrm{U} + {}^{4}_{2}\alpha$	
	Bottom line correct	**(1)**		**2**

20(b)(i)	Calculation of mass difference (1) Use of $\Delta E = c^2 \Delta m$ (1) Conversion from J to eV (1) $\Delta E = 5.68$ (MeV) (1)	Number of plutonium atoms in 1 kg may be calculated by using 3.9516×10^{-25} kg from (a) Example of calculation $\Delta m = (3.8851 \times 10^{-25} + 6.6399 \times 10^{-27} - 3.9516 \times 10^{-25})$ kg $\Delta m = (-)1.01 \times 10^{-29}$ kg $\Delta E = (3.0 \times 10^{8}\ \mathrm{m\ s^{-1}})^2 \times 1.01 \times 10^{-29}$ kg $= 9.09 \times 10^{-13}$ J $\Delta E = \frac{9.09 \times 10^{-13}\ \mathrm{J}}{1.6 \times 10^{-19}\ \mathrm{J\ eV^{-1}}} = 5.68 \times 10^{6}\ \mathrm{eV} = 5.68\ \mathrm{MeV}$	4

20(b)(ii)	**EITHER** Calculation of number of plutonium atoms (1) Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ (1) Use of $A = \lambda N$ (1) Rate of energy release = 575 W [ecf from (b)(i)] (1) 575 W ≈ 550 W, so website statement is accurate **Or** Calculated value compared with value in question and consistent conclusion (1) **OR** Calculation of activity using power of plutonium decay (1) Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ (1) Use of $A = \lambda N$ to calculate N (1) Mass of plutonium = 0.96 kg [ecf from (b)(i)] (1) 0.96 kg ≈ 1.00 kg so website statement is accurate **Or** Calculated value compared with value in question and consistent conclusion (1)	Example of calculation $N = \frac{1.000\ \mathrm{kg}}{0.238\ \mathrm{kg}} \times 6.00 \times 10^{23} = 2.52 \times 10^{24}$ $\lambda = \frac{\ln 2}{(87.7 \times 3.15 \times 10^{7})\ \mathrm{s}} = 2.51 \times 10^{-10}\ \mathrm{s^{-1}}$ $A = 2.51 \times 10^{-10}\ \mathrm{s^{-1}} \times 2.52 \times 10^{24} = 6.33 \times 10^{14}\ \mathrm{s^{-1}}$ $P = 6.33 \times 10^{14}\ \mathrm{s^{-1}} \times 9.09 \times 10^{-13}\ \mathrm{J} = 575\ \mathrm{W}$	5

20(b)(iii)	Use of $A = A_0 e^{-\lambda t}$ **Or** Use of $N = N_0 e^{-\lambda t}$ (1) $P = 550$ W [ecf from (b)(ii)] (1)	Power can be substituted instead of activity, but must be calculating final not initial values Example of calculation $P = (575\ \mathrm{W}) e^{-2.51 \times 10^{-10}\ \mathrm{s^{-1}} \times 74 \times 2.63 \times 10^{6}\ \mathrm{s}} = 548\ \mathrm{W}$ Use of 550 W leads to value of 525 W	2

20(c)	Intensity obeys an inverse square law **Or** Intensity is given by $I = \frac{L}{4\pi d^2}$ (1) (So) the power/intensity (incident on the solar cells) would be too small **Or** power/intensity would be much less (than for Mars probe) **Or** (output) power from solar cells would be too small **Or** solar panels would need to be too large (1)	[MP2 dependent upon MP1]	2

Question Number	Answer	Mark
11(a)	Top line correct (1) Bottom line correct (1) Example of calculation $^{187}_{75}\mathrm{Re} \rightarrow {}^{187}_{76}\mathrm{Os} + {}^{0}_{-1}\beta^{-} + {}^{0}_{0}\bar{\nu}$	2

11(b)	Use of 1 eV = 1.6×10^{-19} J [4.16×10^{-16}] Use of $E_k = \frac{1}{2}mv^2$ [Allow use of the mass of an proton] $v = 3.0 \times 10^7$ m s^{-1} Example of calculation $2.6 \times 10^3 \times 1.6 \times 10^{-19}\ \text{J} = \frac{1}{2} \times 9.11 \times 10^{-31}\ \text{kg} \times v^2$ $\therefore v = \sqrt{\frac{2 \times 4.16 \times 10^{-16}\ \text{J}}{9.11 \times 10^{-31}\ \text{kg}}} = 3.02 \times 10^7\ \text{m s}^{-1}$	(1) (1) (1)	3

Question Number	Answer		Mark
19(a)	A large nucleus splits (into two nuclei plus neutrons) The binding energy increases, (so energy is released) [Accept binding energy per nucleon increases] **Or** There is a decrease in (total) mass, (so energy is released)	(1) (1)	2
19(b)	Binding energy per nucleon read from graph for before and after fission Binding energy before and after fission calculated **Or** Binding energy increase calculated Energy released ≈ 240 (MeV) Example of calculation Increase in binding energy per nucleon = (8.5 – 7.5) MeV = 1.0 MeV Increase in binding energy ≈ 238 × 1.0 MeV Energy released ≈ 240 MeV	(1) (1) (1)	3
19(c)(i)	Top line correct Bottom line correct Example of completed equation $^{90}_{38}\text{Sr} \rightarrow {}^{90}_{39}\text{Y} + {}^{0}_{-1}\beta^{-} + {}^{0}_{0}\bar{\nu}_e$	(1) (1)	2
19(c)(ii)	Calculates total energy released Conversion between eV and J P = 110 (W) Example of calculation $P = 1295 \times 10^{12}\ \text{s}^{-1} \times 0.546 \times 10^{6}\text{eV} \times 1.6 \times 10^{-19}\ \text{J eV}^{-1} = 113\ \text{W}$	(1) (1) (1)	3

19(c)(iii)	Use of $\lambda = \frac{\ln 2}{t_{½}}$ Use of $A = A_0 e^{-\lambda t}$ t = 44 (years) ≠ 50 (years), so claim inaccurate **Or** (After 50 years), A = 1.1 × 10[15] (Bq) ≠ 1.295 × 10[15] (Bq) so claim inaccurate **Or** (If A 1.295 × 10[15] Bq), $A_0 = 4.3 \times 10^{15}$ (Bq) ≠ 3.7 × 10[15] (Bq) so claim inaccurate Example of calculation $\lambda = \frac{\ln 2}{28.8} = 0.0241\ \text{years}^{-1}$ $1295\ \text{TBq} = 3700\ \text{TBq} \times e^{-0.0241\ \text{years}^{-1} \times t}$ $t = \frac{\ln\left(1295\ \text{TBq}/3700\ \text{TBq}\right)}{-0.0241\ \text{years}^{-1}} = 43.6\ \text{years}$	(1) (1) (1)	3
	Total for question 19		**13**

Question Number	Answer		Mark
14(a)	The alpha radiation will not penetrate the lead **Or** The lead will absorb the alpha radiation	(1)	**1**
14(b)	**EITHER** Determine the background count (rate) Subtract background count (rate) from the recorded count (rate) to eliminate systematic error **Or** Subtract background count from the recorded count to prevent the count rate being overestimated **OR** Record the count for a longer time interval **Or** Record the count more than once and calculate a mean value This will reduce the effect of random variation on the count rate **Or** this will decrease the percentage uncertainty	 (1) (1) (1) (1)	 **2**

14(c)	**EITHER** One pair of values read from <u>curve</u> Use of $R = 60e^{-\mu x}$ with values read from graph $\mu = 0.30\ \text{cm}^{-1} \rightarrow 0.36\ \text{cm}^{-1}$ **OR** Tangent drawn at $x = 0$ 1/(x-intercept of tangent) determined **Or** gradient of tangent divided by y-intercept (R_0) [MP2 dependent on MP1] $\mu = 0.30\ \text{cm}^{-1} \rightarrow 0.39\ \text{cm}^{-1}$ [Accept μ in m^{-1}] <u>Example of calculation</u> $\ln R = \ln 60 - \mu x$ $\therefore \mu = \dfrac{\ln 60 - \ln R}{x} = \dfrac{4.094 - \ln 43}{1.0} = 0.333\ \text{cm}^{-1}$	 (1) (1) (1) (1) (1) (1)	 3
	Total for question 14		**6**