| **Question Number** | **Answer** | | **Mark** |
|---|---|---|---|
| **1 (a)(i)** | $\mathrm{N} + \alpha \rightarrow {}^{17}_{8}\mathrm{O} + {}_{1}\mathrm{p}$<br>All values correct | **(1)** | **1** |
| **1(a)(ii)** | In nuclear fission a chain reaction can be set up<br>**Or** in a chain reaction the (total) energy released can be very large<br>**Or** heavier/larger nuclei release much more energy<br>**Or** a very high reaction rate releases much more energy | **(1)** | **1** |
| **1 (b)** | Attempt at mass deficit calculation<br>Use of $\Delta E = c^2 \Delta m$ (Allow use of 1 u = $1.66 \times 10^{-27}$ kg)<br>Use of 1 MeV = $1.6 \times 10^{-13}$ J (Allow use of 1u = 931.5 MeV/$c^2$)<br>$\Delta E$ = 174 MeV<br><br><u>Example of calculation</u><br>$\Delta m = (390.29989 - 233.99404 - 152.64708 - (2 \times 1.67493)) \times 10^{-27}\,\mathrm{kg}$<br>$\Delta m = 3.0891 \times 10^{-28}\,\mathrm{kg}$<br>$\Delta E = (3.00 \times 10^{8}\,\mathrm{m\,s^{-1}})^2 \times 3.0891 \times 10^{-28}\,\mathrm{kg} = 2.780 \times 10^{-11}\,\mathrm{J}$<br>$\Delta E = \dfrac{2.780 \times 10^{-11}\,\mathrm{J}}{1.60 \times 10^{-13}\,\mathrm{J\,MeV^{-1}}} = 173.8\,\mathrm{MeV}$ | **(1)**<br>**(1)**<br>**(1)**<br>**(1)** | **4** |
| **1 (c)(i)** | Same number of protons [do not accept atomic/proton number],<br>Different numbers of neutrons [do not accept mass/nucleon/neutron number] | **(1)**<br>**(1)** | **2** |
| **1(c)(ii)** | Correct calculation for ω [see 6283 or 2000π or $\frac{60\,000 \times 2\pi}{60}$ ]<br>a = (-) $5.9 \times 10^{6}\,\mathrm{m\,s^{-2}}$<br><br><u>Example of calculation</u><br>$a = -\left(\dfrac{60000 \times 2\pi}{60\,\mathrm{s}}\right)^2 \times 15 \times 10^{-2}\,\mathrm{m} = 5.92 \times 10^{6}\,\mathrm{m\,s^{-2}}$ | **(1)**<br>**(1)** | **2** |
| **1(c)(iii)** | **2**<br>Stiff/stiffness<br>Strong/strength<br>Low density | **(1)**<br>**(1)**<br>**(1)** | **2** |
| **1(d)** | Use of $\Delta E = mc\Delta\theta$<br>Rate at which energy is removed = $3.1 \times 10^{9}$ (W)<br>Use of the efficiency equation [must have $2.2 \times 10^{9}$ (W) on top line]<br>Efficiency = 42% [accept 0.42]<br><br><u>Example of calculation</u><br>$\Delta E = 70000\,\mathrm{kg} \times 3990\,\mathrm{J\,kg^{-1}\,K^{-1}} \times 11\,\mathrm{K} = 3.07 \times 10^{9}\,\mathrm{J}$<br>$\%\,\mathrm{efficiency} = \dfrac{\mathrm{useful\ power\ output}}{\mathrm{total\ power\ input}} \times 100 = \dfrac{2.2 \times 10^{9}\,\mathrm{W}}{(2.2 + 3.1) \times 10^{9}\,\mathrm{W}} \times 100 = 41.5\%$ | **(1)**<br>**(1)**<br>**(1)**<br>**(1)** | **4** |
| | **Total for question** | | **16** |

| Question Number | Answer | Mark |
|---|---|---|
| **2(a)*** | (QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)<br>Appropriate reference to the following:<br>▪ The penetrating power of beta radiation<br>▪ The ionising effects of the beta radiation<br>▪ The shielding effect that the cylinder might have had<br>▪ The constant activity over the 5 day period<br>Examples of responses:<br>Beta radiation is (moderately) ionising<br>Beta radiation is able to penetrate the body<br>Once inside the body beta radiation may damage / kill / mutate / alter DNA of cells<br>Beta radiation is absorbed by a few mm of aluminium<br>Cylinder may have reduced the radiation to safe levels / absorbed the beta radiation<br>Greater risk of exposure if cylinder damaged or cracked<br>Long half life means that:<br>source stays active for a long time/activity unlikely to lower over 5 days | **max 3** |
| **2(b)** | Top line: $^{137}\text{Ba}\ \ ^{0}\beta^{-}$ (1)<br>Bottom line: $_{56}\text{Ba}\ \ _{-1}\beta^{-}$ (1) | **2** |
| **2(c)(i)** | Cannot identify which atom/nucleus/particle will be the next to decay<br>OR cannot say when a given atom/nucleus/particle will decay<br>OR cannot state exactly how many atoms/nuclei/particles will decay in a set time<br>OR can only estimate the fraction of the total number that will decay in the next time interval (1) | **1** |

| | | |
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| **2(c)(ii)** | Use of $\lambda T_{1/2} = \ln 2$ (1)<br>Decay constant, $\lambda = 7.3 \times 10^{-10}$ ($\text{s}^{-1}$) (1<br><br>Example of calculation<br>$\lambda = \frac{\log_e 2}{T_{\frac{1}{2}}} = \frac{0.693}{30 \times 365 \times 24 \times 3600\,\text{s}} = 7.32 \times 10^{-10}\,\text{s}^{-1}$ | **2** |
| **2(d)** | Use of $\frac{dN}{dt} = \left(\frac{dN}{dt}\right)_0 e^{-\lambda t}$ (1)<br>activity = $3.3 \times 10^{13}$ Bq [$3.3 \times 10^{13}$ Bq if show that value used] (1)<br>Use of d*N*/d*t* = $\lambda N$ (1)<br>$N = 4.5 \times 10^{22}$ [$4.8 \times 10^{22}$ if show that value used] (1)<br><br>OR<br><br>Use of d*N*/d*t* = $\lambda N_o$ (1)<br>$N_o = 7.1 \times 10^{22}$ [$N_o = 7.4 \times 10^{22}$ if show that value used] (1)<br>Use of $N = N_0 e^{-\lambda t}$ (1)<br>$N = 4.5 \times 10^{22}$ [$4.8 \times 10^{22}$ if show that value used] (1)<br>Example of calculation<br>$\frac{\text{dN}}{\text{dt}} = \left(\frac{\text{dN}}{\text{dt}}\right)_0 e^{-\lambda t} = 5.2 \times 10^{13}\,\text{Bq} \times e^{-7.32 \times 10^{-10}\,\text{s}^{-1} \times 20 \times 365 \times 24 \times 3600\,\text{s}}$<br>$= 3.28 \times 10^{13}\,\text{Bq}$<br>$\text{N} = \frac{dN/dt}{\lambda} = \frac{3.28 \times 10^{13}\,\text{s}^{-1}}{7.32 \times 10^{-10}\,\text{s}^{-1}} = 4.48 \times 10^{22}$ | **4** |
| **2(e)(i)** | ${}^{95}_{37}Rb \quad + \quad 4 \times {}^{1}_{0}n$ (1) | **1** |
| **2(e)(ii)** | Idea that at least one neutron needs to be available to be absorbed for a chain reaction to be sustained (1)<br><br>Appreciation of the need to control/limit/restrict the number of neutrons (which can go on to produce another fission) (1) | **2** |
| | **Total for question** | **12** |

| Question Number | Answer | Mark |
|---|---|---|
| **3(a)(i)** | (Small mass) nuclei come very close together<br>**Or** strong (nuclear) force acts on nuclei **(1)**<br>Nuclei join to form a more massive nucleus **(1)** | **2** |
| **3(a)(ii)** | A very/extremely high temperature (plasma) is required **(1)**<br>Plasma must not touch reactor walls, so strong magnetic fields are required<br>**Or** If plasma touches the walls of the reactor its temperature falls (and fusion stops) **(1)** | **2** |
| **3(b)** | Mass of fused nucleus is less than sum of masses of fusing nuclei **(1)**<br>Mass difference/deficit releases energy according to $\Delta E = c^2 \Delta m$<br>**Or** Binding energy per nucleon is greater in the fused nucleus;<br>**Or** Strong (nuclear) force binds the nucleons, lowering total energy of system. **(1)** | **2** |
| | **Total for question** | **6** |