Question Number	Answer	Mark
1 (a)	A radioactive isotope has an unstable nucleus **(1)** (Which decays and) emits radiation **Or** α/β/γ (radiation) specified **(1)**	**2**
1 (b)	**Max 2** We can't know when an individual nucleus will decay **(1)** We can't know which nucleus will decay next **(1)** (In a given time interval) each nucleus has a fixed probability of decay **Or** (In a given time interval) a fixed fraction of nuclei undergo decay **(1)** [accept atom for nucleus, but there is a one mark penalty for using particle, molecule or isotope]	**2**
1 (c)	Identify half life = 5730 years **(1)** Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ **(1)** Decay constant = 1.21×10^{-4} (yr^{-1}) [3.84×10^{-12} (s^{-1})] **(1)** N/N_0=0.60 **(1)** Use of $N = N_0 e^{-\lambda t}$ **(1)** Age = 4220 yr [1.34×10^{11} s] **(1)** Example of calculation $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{5730} = 1.21 \times 10^{-4}\ \text{yr}^{-1}$ $\frac{N}{N_0} = 0.6 = e^{-1\ 21 \times 10^{-4}\ t}$ $\therefore \ln(0.6) = -1.21 \times 10^{-4}\ t$ $\therefore t = \frac{\ln(0.6)}{-1.21 \times 10^{-4}} = 4220\ \text{yr}$	**6**
1(d)	Ratio of C-14 to C-12 (in living material) was greater in the past **(1)** Appreciation that we are not comparing 'like with like' e.g. ratio used is from current matter **(1)** (Hence) the age of Stonehenge has been underestimated **(1)**	**3**
	Total for question	**13**

Question Number	Answer	Mark
2(a)(i)	Alpha particles ionise the air **Or** alpha particles strip electrons from air molecules **(1)** The ions/electrons move (in the electric field between the plates) **(1)**	**2**
2(a)(ii)	Smoke particles capture electrons (and reduce the free charge able to move) **Or** alpha particles collide with smoke particles and reduce amount of ionisation **(1)**	**1**
2(b)(i)	Random means we cannot identify which atom/nucleus will be the next to decay **Or** we cannot identify when an individual atom/nucleus will decay **Or** we cannot state exactly how many atoms/nuclei will decay in a set time **Or** we can only estimate the fraction that will decay in the next time interval **(1)** Spontaneous means that the decay cannot be influenced by any (external) factors. **(1)**	**2**
2(b)(ii)	${}_{95}\text{Am} \rightarrow {}^{237}\text{Np} + {}^{4}_{2}\alpha$ Top line correct **(1)** Bottom line correct **(1)**	**2**
	Total for question	**7**

Question Number	Answer	Mark
3(a)	Activity is the rate of <u>decay</u> (of radioactive nuclei) **Or** the number of <u>decays</u> in a second **(1)**	**1**
3(b)	Use of $\lambda\, t_{1/2} = 0.693$ **(1)** Use of A = -λ N **(1)** $N = 1.9 \times 10^{12}$ **(1)** <u>Example of calculation:</u> $\lambda = \dfrac{0.693}{3.89 \times 10^{8}\ \text{s}} = 1.78 \times 10^{-9}\ \text{s}^{-1}$ $N = \dfrac{3450\ \text{s}^{-1}}{1.78 \times 10^{-9}\ \text{s}^{-1}} = 1.94 \times 10^{12}$	**3**
3(c)(i)	Use of $A = A_0 e^{-\lambda t}$ **(1)** Conversion between seconds and years **(1)** t = 41 (years) **(1)** <u>Example of calculation:</u> $0.1 = e^{-(1\ 78 \times 10^{-9}\ s^{-1})t}$ $t = 1.29 \times 10^{9}$ s $t = 1.29 \times 10^{9}$ s /(365×24×3600 s y^{-1}) = 41 y	**3**
3(c)(ii)	This is a very long time and so: The sample's activity will stay approx. constant for the procedure (1) **Or** tritium may be in the body long enough for damage to be caused (1) **Or** the sample can be prepared well in advance of the procedure (1)	**1**
	Total for question	**8**

<table>
<tr><th>Question Number</th><th>Answer</th><th></th><th>Mark</th></tr>
<tr><td>4(a)</td><td>Similarity: Same number of protons Or same magnitude of charge Or both have 1 proton

Difference: Different number of neutrons / nucleons Or different mass Or D has 1 neutrons and T has 2 neutrons</td><td>(1)

(1)</td><td>2</td></tr>
<tr><td>4(b)</td><td>Use of $P = \frac{\Delta E}{\Delta t}$ (do not penalise a power of ten error)
Energy = 7.5×10^6 (J)

<u>Example of calculation</u>
$E = 500 \times 10^{12}\ \text{W} \times 15 \times 10^{-9}\ \text{s} = 7.5 \times 10^6\ \text{J}$</td><td>(1)
(1)</td><td>2</td></tr>
<tr><td>4(c)(i)</td><td>$^{2}_{1}\text{D} + {}^{3}_{1}\text{T} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n}$

<table><tr><td>Top line</td><td>2</td><td>3</td><td>4</td><td>1</td></tr><tr><td>Bottom line</td><td>1</td><td>1</td><td>2</td><td>0</td></tr></table></td><td>(1)
(1)</td><td>2</td></tr>
<tr><td>4(c)(ii)</td><td>Attempt at calculation of mass difference
Energy released = 17.5 (MeV) [17.5 must be clearly identified as an energy]

<u>Example of calculation</u>
Δm= (1875.6 + 2808.9 – 3727.4 – 939.6) MeV/c^2 = 17.5 MeV/c^2
ΔE = 17.5 MeV</td><td>(1)
(1)</td><td>2</td></tr>
<tr><td>4(c)(iii)</td><td>Conversion of energy to consistent units
Number of nuclei = 3×10^{18}

<u>Example of calculation</u>
In each fusion $\Delta E = 17.5 \times 10^6\ \text{eV} \times 1.6 \times 10^{-19}\ \text{J eV}^{-1} = 2.8 \times 10^{-12}\ \text{J}$
$\therefore N = \frac{7.5 \times 10^6\ \text{J}}{2.8 \times 10^{-12}\ \text{J}} = 2.68 \times 10^{18}$
<table><tr><th>Energy MJ (b)</th><th>Energy MeV (c)(ii)</th><th>N × 10^{18}</th></tr><tr><td>7.5</td><td>17.5</td><td>2.7</td></tr><tr><td>7.5</td><td>20</td><td>2.3</td></tr><tr><td>8</td><td>17.</td><td>2.9</td></tr><tr><td>8</td><td>20</td><td>2.5</td></tr></table></td><td>(1)
(1)</td><td>2</td></tr>
</table>

4(c)(iv)	Application of momentum conservation Deduction that $V_N = 4\ V_\alpha$ [$v_N = 3.967\ v_\alpha$] Use of $E_K = \frac{1}{2}mv^2$ (ratio as shown **or** sum = 17.5 MeV) Energy = 14 MeV (ecf (c)(ii), 14.1 MeV, if $v_N = 3.967\ v_\alpha$ 16 MeV if 20 MeV used) **Or** Application of momentum conservation Use of $E_k = p^2/2m$ Deduction that $E_N = 4\ E_\alpha$ Energy = 14 MeV Example of calculation (1st method) $m_N V_N = m_\alpha V_\alpha$ $V_N = \frac{m_\alpha}{m_N} \times V_\alpha = 4V_\alpha$ $\frac{E_N}{E_\alpha} = \frac{\frac{1}{2}m_N V_N^2}{\frac{1}{2}m_\alpha V_\alpha^2} = \frac{1}{4} \times \left(\frac{4}{1}\right)^2 = 4$ $\therefore E_N = \frac{4}{5} \times 17.5\ \text{MeV} = 14\ \text{MeV}$ Example of calculation (2nd method) $p_\alpha = p_N$ $p_\alpha^2 = p_N^2$ $E_\alpha \times 2m_\alpha = E_N \times 2m_N$ $\therefore E_\alpha = E_N \times \frac{m_N}{m_\alpha} = \frac{E_N}{4}$ Also, $E_\alpha + E_N = 17.5\ \text{MeV}$ $\therefore \frac{E_N}{4} + E_N = 17.5\ \text{MeV}$ $\therefore E_N = \frac{4}{5} \times 17.5\ \text{MeV} = 14\ \text{MeV}$	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	4
4(d)	**Max 3** A heavy **nucleus** absorbs a neutron. [accepts “collides with” / “fired into” for “absorbs”] The **nucleus** becomes unstable **and** splits into two (roughly equal sized) fragments [accept “decays” / “breaks up” for “splits”] Idea that a few neutrons are also emitted in the fission process These neutrons cause further fissions **Or** these neutrons cause a chain reaction (if atom is used instead of nucleus **only penalise once**)	**(1)** **(1)** **(1)** **(1)**	3
	Total for question		**17**