Question	Answer	Marks
1	B	1
2 a	Missing particle is ${}^{0}_{+1}\mathrm{e}$, a positron.	1 1
2 b	The positron (an anti-lepton) has a lepton number of –1. The lepton number on the left-hand side of the equation is zero, on the right hand side the lepton number = –1 (positron) +1 (neutrino) = 0.	1
2 c	mass loss per second = $\frac{4\times10^{26}}{9\times10^{16}}$ = 4.4×10^{9} kg s^{-1}	1 1
3 a	Initial binding energy = –1793.6 MeV Final binding energy = –1978.2 MeV Energy released = 184.6 MeV = 2.96×10^{-11} J	1 1 1
3 b i	A chain reaction is one in which the products of one reaction go on to start one or more further reactions.	1
3 b ii	If the mass is insufficient, neutrons will escape from the fissile material before they have interacted with uranium nuclei. Fast neutrons interact more rarely with nuclei than slower (thermal) neutrons. The moderator acts to slow down the neutrons released in the fission.	1 1 1
4	Energy required for dose equivalent of 100 msV = $\frac{100\times10^{-3}\times2.5\times10^{-4}}{10}$ = 2.5×10^{-6} j Number of protons = $\frac{2.5\times10^{-6}}{180\times10^{6}\times1.6\times10^{-19}}$ = 8.7×10^{4}	1 1 1
5 a	4%	1
5 b	X-rays spread out with distance so the intensity of X-rays decrease with distance so exposure is reduced.	1 1 1
6 a	Mass of component nuclei = 4.03188 $\frac{\text{mass of helium nucleus}}{\text{mass of components}}$ = 0.9925, a difference of about 0.75%	1
6 b	Total binding energy = (4.0015 – 4.03188) × 1.66056 × 10^{-27} × $(3 \times 10^{8})^{2}$ = –4.50… × 10^{-12} J Binding energy per nucleus = $\frac{-4.50\ldots\times10^{-12}}{4}$ = -1.14×10^{-12} J	1 1 1
7 a	number of cases = 2000 × 10^{-6} × 60 × 10^{6} × 0.05 = 6000	1 1
7 b	number of cases = 500 × 10^{-6} × 60 × 10^{6} × 0.05 = 1500	1 1
7 c	E.g.: • Average dose would produce around 9 cases a year – much smaller than other sources. • Much lower than other sources, but this represents 9 additional cases. • In some areas the dose will be higher. • Dose could be higher if an accident occurs.	4
8 a	$\lambda = \frac{0.693}{1.3\times10^{9}\times3.2\times10^{7}}$ = 1.66… × 10^{-17} s^{-1} Activity = 3.6 × 10^{20} × 1.66… × 10^{-17} s^{-1} = 6000 s^{-1}	1 1 1

8 b	Assuming constant decay rate and all energy absorbed by body: $\frac{6000\times 3.2\times 10^{7}\times 4\times 10^{-14}\times 1}{65}$ 120 µSv	2 1
8 c	$0.05 \times 120 \times 10^{-6} \times 60 \times 10^{6}$ = 360	2 1
8 d	Any from: • A more massive person will have more potassium-40 so the dose will increase, but the dose equivalent will be the same. • Assumes potassium is evenly spread in all body tissue. • The amount of potassium-40 per kg will be constant and dose equivalent is concerned with energy absorbed per kg. • Larger bodies may have a different proportion of (for example) fat to bone and this may affect the amount of potassium-40 in the body per kg.	3
9 a i	2.0135 + 3.0155 – 4.0015 – 1.0087 = 0.0188 u = 3.12×10^{-29} kg	1 1
9 a ii	energy released = $3.12 \times 10^{-29} \times 9 \times 10^{16}\ \mathrm{m^2\ s^{-2}}$ = 2.81×10^{-12} J	1 1
9 b	work done = $\frac{1.6\times 10^{-19}\times 1.6\times 10^{-19}\times 9\times 10^{9}}{1\times 10^{-14}}$ = 2.3×10^{-14} J	1 1
9 c i	7×10^{8} K	1
9 c ii	Either: • This estimate gives an average kinetic energy/range of energies. • Some of the particles with more than the average energy will have sufficient energy for fusion. Or: • Particles exchange energy in collisions. • Successive energy gains lead to particles with sufficient energy for fusion (‘getting lucky’).	2