Binding Energy - Answers

1.

a	**(i)**	mass of uranium is greater than (the sum of) the mass of the products $E = \Delta mc^2$ OR binding energy of the products is greater than that of uranium energy available is the difference between the binding energies of uranium and the sum of the products	**M1** **A1** **M1** **A1**	
	(ii)	kinetic energy	**B1**	
b	**(i)**	the neutron is a single nucleon / cannot be split further / no binding has occurred	**B1**	The neutron is not bound to anything
	(ii)	binding energy of uranium = 235 x 7.6 =1786 binding energy of products = 141 x 8.3 + 92 x 8.7 = 1170.3 + 800.4 energy available = 184.7 (MeV)	**C1** **A1**	An answer of 9.4 (not using the number of nucleons) scores zero Allow ≥ 2 sf (180, 185, 184.7) Penalise 184 as an AE

2.

(a)		(Minimum) energy to separate (all) nucleons / protons and neutrons (of a nucleus)	M1 A1	**Alternative**: B.E. = mass defect × c^2 M1 mass defect = mass of nucleons – mass of nucleus A1
(b)	(i)	BE of ^{2}H = 2 × 1.8 × 10^{-13} (J) or BE of ^{4}He = 4 × 1.1 × 10^{-12} (J) energy = (4 × 1.1 × 10^{-12}) – 2 × (2 × 1.8 × 10^{-13}) energy = 3.68 × 10^{-12} (J) / 3.7 × 10^{-12} (J)	C1 C1 A0	**Note**: Ignore signs
	(ii)1	total surface area = 4π × $(1.5 \times 10^{11})^2$ power = 1400 × (2.83× 10^{23}) power = 3.96 × 10^{26} (W) / 4.0 × 10^{26} (W)	C1 C1 A0	
	(ii)2	number = 4.0 × 10^{26}/3.7 × 10^{-12} number = 1.1 × 10^{38} (s^{-1}) or 1.08 × 10^{38} (s^{-1})	C1 A1	**Allow**: 10^{38} (s^{-1}) because the question is about an estimate

3.

(a)		Impossible to predict when a nucleus will decay or impossible to predict which nucleus will decay	B1	
(b)		$N = N_0 e^{-\lambda t}$ (λ =) 0.693/7.1 ×10^8 $\lambda = 9.76 \times 10^{-10}$ y^{-1} $0.011 = e^{-(9.76\times 10^{-10}\times t)}$ (age =) $\dfrac{\ln(0.011)}{-9.76\times 10^{-10}}$ age = 4.6 × 10^9 (y)	C1 C1 A1	**Alternatives:** $N = N_0 e^{-\lambda t}$ (λ =) 0.693/[7.1 ×10^8 × 3.16 × 10^7] C1 λ =3.089 × 10^{-17} s^{-1} $0.011 = e^{-(3.089\times 10^{-17}\times t)}$ C1 (age =) $\dfrac{\ln(0.011)}{-3.089\times 10^{-17}}$ age = 1.46... × 10^{17} (s) age = 4.6 × 10^9 (y) A1 Or $0.011 = \dfrac{1}{2^n}$ C1 $n = -\dfrac{\ln(0.011)}{\ln 2}$ or $n = 6.5$ C1 age = 6.5 × 7.1 × 10^8 (y) age = 4.6 × 10^9 (y) A1
(c)	**(i)**	number in the range 50 to 70	B1	
	(ii)	Correct reference to binding energy. Eg: The BE per nucleon will decrease for fusion (which is impossible unless external energy is supplied) (AW)	B1	

	(iii)	(mass of nucleons =) $4 \times 1.673 \times 10^{-27}$ + $4 \times 1.675 \times 10^{-27}$	C1	**Allow**, due to misinterpretation of Data, Formulae and Relationship Booklet, the following (though incorrect): (nucleon mass =) $8 \times 1.661 \times 10^{-27}$ (kg) C1 (Δm =) $[8 \times 1.661 \times 10^{-27}] - 1.329 \times 10^{-26}$ (kg) C1 (BE =) (-) $2.0 \times 10^{-30} \times (3.0 \times 10^{8})^{2}$ (= 1.8×10^{-13} J) C1 (BE per nucleon =) $1.8 \times 10^{-13}/8$ BE per nucleon = 2.25×10^{-14} (J) A1
		(Δm =) $[4 \times 1.673 \times 10^{-27} + 4 \times 1.675 \times 10^{-27}] - 1.329 \times 10^{-26}$	C1	
		(mass defect =) 1.020×10^{-28} (kg)		
		BE = mass defect × c^2		
		(BE =) $1.020 \times 10^{-28} \times (3.0 \times 10^{8})^{2}$ (= 9.180×10^{-12} J)	C1	
		(BE per nucleon) = $9.180 \times 10^{-12}/8$		
		BE per nucleon = 1.148×10^{-12} (J)	A1	**Allow** 2 sf or 3 sf answer

4.

(a)		The neutrons interact with other uranium (nuclei) / the neutrons cause further (fission) reactions	B1	**Not**: neutrons interact with uranium <u>atoms</u> / <u>molecules</u> / <u>particles</u>
(b)				**Show annotation on Scoris**
		Fuel rod: Contain the <u>uranium</u> (nuclei) / fissile material	B1	**Not** 'contains fuel'
		Control rods: Absorb (some of the) neutrons	B1	
		Controlled chain reaction: The control rods are inserted into the reactor so as to allow (on average) one neutron from previous reaction to cause subsequent fission (AW)	B1	**QWC mark**
		Moderator: Slows down the (fast-moving) neutrons / lowers the KE of (fast moving) neutrons / makes the (fast moving) neutrons into thermal neutrons	B1	
		Slow moving neutrons have a greater chance of causing fission / of being absorbed (by U-235) / sustaining chain reaction	B1	**Allow**: Fast moving neutrons are captured (easily) by uranium-238 (nuclei leaving insufficient number of nuclei for fission / chain reaction) for the last B1 mark

(c)	(i)	power = $3.0 \times 10^9/0.22$ power = 1.36×10^{10} (W) or 1.4×10^{10} (W)	B1	
	(ii)	energy = $1.36 \times 10^{10} \times 8.64 \times 10^4$ energy = 1.18×10^{15} (J) or 1.2×10^{15} (J)	B1	Possible ecf from **(c)(i)**
	(iii)	(number of reactions per day) = $\frac{1.18\times10^{15}}{3.2\times10^{-11}}$	C1	Possible ecf from **(c)(ii)**
		mass = $\frac{1.18\times10^{15}}{3.2\times10^{-11}}\times3.9\times10^{-25}$ mass = 14.4 (kg) or 14 (kg)	A1	**Note**: Using 1.2×10^{15} (J) gives an answer of 14.6 (kg); allow 15 (kg)
(d)		Nuclear waste is (radio)active for a long time (AW)	B1	**Allow**: *'Nuclear waste can have long* half *life'*
		Causes ionisation	B1	

5.

(a)	**(i)**	momentum / mass-energy / charge / proton number / baryon number / nucleon number	B1	**Not**: 'energy' on its own
	(ii)	Some basic labelling of neutron(s), Xe and Sr	B1	
		Correct extension of diagram showing at least one of the neutrons interacting with U-235 nucleus and producing neutron(s) and 'fragments'	B1	
(b)	**(i)**	initial $m = 6.686 \times 10^{-27}$ (kg) or final $m = 6.681 \times 10^{-27}$ (kg) or $\Delta m = 0.005\times10^{-27}$ (kg)	C1	
		$\Delta E = 0.005\times10^{-27}\times(3.0\times10^{8})^{2}$	C1	
		energy = 4.5×10^{-13} (J)	A1	
	(ii)	kinetic (energy)	B1	**Not**: heat / sound **Allow**: (gamma) photons / EM radiation

	(iii)	KE = $\frac{3}{2}kT$ KE = $\frac{3}{2}\times1.38\times10^{-23}\times10^{9}$ KE = 2.1×10^{-14} (J)	C1 A1	**Allow**: 1 sf answer or 10^{-14} (J) because the temperature is given as 10^{9} K
	(iv)	Some nuclei will have KE greater than the mean KE (and hence cause fusion) (AW)	B1	

6.

(i)	binding energies per nucleus: $^{235}_{92}$U 7.6 × 235 (= 1786 MeV) $^{141}_{56}$Ba 8.4 × 141 (= 1184 MeV) $^{92}_{36}$Kr 8.6 × 92 (= 791 MeV)	1	
	so energy released = (1184 + 791) - 1786	1	
	= 189 MeV	1	[3]
	fails to multiply by nucleon number: 8.4+8.6-7.6 = 9.4 gets (0,1,0) = 1/3		
(ii)	number of U-235 atoms in 1.00 kg = 1.00 / ($235\times1.67\times10^{-27}$) = 2.55×10^{24} *or* 6.02×10^{23} / (0.235) = 2.56×10^{24}	1	
	so energy released by fission of 1.00 kg of U-235	1	
	= $2.55\times10^{24}\times200\times1.6\times10^{-19}\times10^{6}$ = 8.2×10^{13} J accept 8×10^{13}	1	[3]
	or $2.55\times10^{24}\times189\times1.6\times10^{-19}\times10^{6}$ = 7.7×10^{13} J		