Question			Answer	Marks	Guidance
1	(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) Causes ionisation	B1 B1	**Allow**: '*Nuclear waste can have long* half *life'*
			Total	**12**	

Question			Expected Answers	Marks	Additional guidance
2	(a)		Any <u>four</u> from 1 to 5: 1. Most of the alpha particles went straight through (some deviated through small angles) 2. Hence most of the atom is empty space 3. Some / a very small number of alpha particles were scattered / repelled through large angles / angles more than 90° 4. This showed the existence of (a tiny) positive nucleus 5. The size of the nucleus is about 10^{-14} <u>m</u> ✍ QWC: Award a mark for one conclusion correctly linked to an observation	B1×4 B1	**Must use ticks on Scoris to show where the marks are awarded** **Allow**: 10^{-15} <u>m</u>
	(b)		Any <u>five</u> from: Gravitational (force) This force is attractive **AND** is long-ranged / obeys '$1/r^2$ relationship' <u>Strong</u> (nuclear force/interaction) This force is attractive (at larger distances) or repulsive at short distances **AND** is short-ranged / ~ 10^{-14} m Electrostatic / electrical (force) / coulomb (force) This force is repulsive between protons / zero between neutrons / zero between protons and neutrons **AND** is long-ranged / obeys '$1/r^2$ relationship'	M1 A1 M1 A1 M1 A1	**Allow:** gravity **Note**: Do not allow 'inverse square law'; allow 'inverse square law with distance' **Allow:** Electromagnetic (interaction/force)

Question			Expected Answers	Marks	Additional guidance
	(c)	**(i)**	mass = $235 \times 1.7 \times 10^{-27}$ ($= 3.995 \times 10^{-25}$ kg)	C1	**Allow:** 1.66×10^{-27} kg for mass of nucleon
			volume = $\frac{4}{3}\pi \times (8.8 \times 10^{-15})^3$ ($= 2.855 \times 10^{-42}$ m^3)	C1	
			density = mass/volume		
			density = 1.4×10^{17} (kg m^{-3})	A1	**Allow:** 10^{17} (kg m^{-3}) for this estimation question **Note:** Omitting 235 gives 6.0×10^{14} (kg m^{-3}), allow 2 mark **Allow:** 1 mark if 92 or 143 is used to determine the mass of the nucleus; this gives a density value of 5.5×10^{16} (kg m^{-3}) and 8.5×10^{16} (kg m^{-3}) respectively
		(ii)	The nucleons / neutrons and protons are packed together with little or no empty space (AW)	B1	
			Total	14	

Question			Expected Answers	Marks	Additional guidance
3	(a)		A neutron is absorbed by a (massive / uranium) nucleus The nucleus splits into two (smaller/daughter) nuclei and (one or more) neutrons	B1 B1	
	(b)		In a fission reaction there is a decreases in the mass (According to $\Delta E = \Delta mc^2$) mass is converted into energy Or The (total) binding energy of the products / smaller nuclei is greater than the binding energy of the original nucleus The difference in the binding energies is released as energy	M1 A1 M1 A1	**Allow:** The 'BE increases (in the reaction)'
	(c)		Moderator: water / graphite / carbon It slows down the (fast-moving) neutrons / reduces the (kinetic) energy of neutrons Slow-moving neutrons have greater chance of causing fission (than fast-moving neutrons)	B1 B1 B1	**Note**: If boron is mentioned, then do not award this B1 mark **Allow**: They become thermal neutrons
			Total	**7**	

Question			Expected Answers	Marks	Additional Guidance
4	a	(i)	$A = \lambda N_0 = 4.5 \times 10^{23} \times 0.693 / (12 \times 3600)$ $= 7.22 \times 10^{18}$ (s^{-1})	C1 A1	allow one mark if the 12 hours is not converted into seconds. Answer is 2.6×10^{22} Allow one mark if the 12 hours is converted into minutes Answer 4.33×10^{20}
		(ii)	3 half lives $N = 5.6 \times 10^{22}$	A1	
		(iii)	$N = N_0 e^{-\lambda t}$ $= 4.5 \times 10^{23} \times e^{-(0.693 \times 50/12)}$ or use of 2^n $= 2.5 \times 10^{22}$	C1 A1	use of 2^n 50/12 half lives
	b		material with large λ / short half life have initial high activity hence precautions needed <u>for initial period</u> of disposal OR material with small λ / long half life activity will last for a long period hence need for long term disposal MAX 2	(B1) (B1) (B1) (B1) B2	
			Total	[7]	

Question			Expected Answers	Marks	Additional Guidance
5	**a**	**(i)**	e: 0 and –1 N: 15 and 7 + (antineutrino)	**B1**	
		(ii)	e: 0 and +1 Si: 30 and 14 + (neutrino) correct 'neutrino' <u>in each case</u>	**B1** **B1**	Allow 1 for +1 Correct symbols required for the neutrinos: ν and (Allow ν_e and (e
	b	**(i)**	uud $\rightarrow$ udd	**B1**	Allow u $\rightarrow$ d
		(ii)	udd $\rightarrow$ uud	**B1**	Allow d $\rightarrow$ u
	c		weak(nuclear force)	**B1**	
			Total	**[6]**	