1)

Question			Answer	Marks	Guidance
	(a)		They are not fundamental particles because they consist of quarks	B1	**Not**: They can be sub-divided
	(b)		Any two from: electron / positron / neutrino / antineutrino	B1	**Allow**: muon / tau
	(c)	(i)	$^{40}_{20}$Ca $^{0}_{-1}$e + $\bar{\nu}_{(e)}$ or electron + (electron) antineutrino	B1 B1	**Allow**: $^{0}_{-1}\beta$ but not β^- or e^- for the electron
		(ii)	There is a decrease in mass Energy (released) given by $(\Delta)E = (\Delta)mc^2$ **or** Binding energy increases Energy (released) is the difference between the binding energies (of Ca and K nuclei)	M1 A1 M1 A1	**Ignore** Δm being referred to as the 'mass defect' **Allow**: binding energy per nucleon increases
		(iii)	$\lambda = \frac{0.693}{4.2\times10^{16}}$ / $N = \frac{0.012}{100}\times\frac{4.5\times10^{-4}}{0.040}\times6.02\times10^{23}$ $A = 1.65\times10^{-17}\times8.127\times10^{17}$ activity = 13 (Bq)	C1 C1 A1	**Allow**: 1 mark for either $\lambda = 1.65\times10^{-17}$ s^{-1} or $N = 8.127\times10^{17}$ **Note**: Answer to 3 sf is 13.4 (Bq) **Note**: 1.3×10^3 (Bq) scores 2 marks; division by 100 omitted
			Total	**9**	

2)

Question			Answer	Marks	Guidance
	(a)		Observations: 1. Most of the alpha particles went straight / un-deflected through (the atom(s) / foil) (AW) 2. (Some of the) alpha particles were scattered / repelled / deflected through large angles (AW) Conclusions (QWC mark): • 1 showed that most of the atom is empty space **and** • 2 showed the existence of small / dense / positive nucleus	M1 M1 A1	**Not** 'reflected' **Allow**: The QWC mark even if 'alpha reflected at large angles' is mentioned in 2
	(b)	(i)	The aluminium nucleus has velocity / accelerates / moves to the right There is a repulsive force on the (aluminium) nucleus (to the right) / According to conservation of momentum the (aluminium) nucleus must move (to the right)	B1 B1	**Allow**: Moves away from the alpha particle
		(ii)	$8.0\times10^6\times1.6\times10^{-19} = \frac{1}{2}\times6.6\times10^{-27}\times v^2$ (Any subject) speed = 2.0×10^7 (m s^{-1})	C1 A1	**Note**: Answer to 3 sf is 1.97×10^7 (m s^{-1}) **Allow** 1 sf answer 2×10^7 (m s^{-1})
		(iii)	$Q = 13e$ or $q = 2e$ or $F = \frac{Qq}{4\pi\varepsilon_0 r^2}$ $270 = \frac{13\times1.6\times10^{-19}\times2\times1.6\times10^{-19}}{4\pi\times8.85\times10^{-12}\times r^2}$ (Any subject) distance = 4.7×10^{-15} (m)	C1 C1 A1	**Allow**: $F = k\frac{Qq}{r^2}$, where $k = 9\times10^9$ **Note**: No credit for using Q and q as 13 and 2

Question			Answer	Marks	Guidance
		(iv)	The strong force is attractive Correct explanation of size / direction of resultant force	M1 A1	**Allow**: The strong force is repulsive M1 Correct explanation of size / direction of resultant force A1
			Total	**12**	

3)

Question			Answer	Marks	Guidance
	(a)	(i)	Any number in the range: 10^4 to 10^5	B1	
		(ii)1	$10^{-14} = \frac{h}{mv}$ momentum = $\frac{6.63 \times 10^{-34}}{10^{-14}}$ momentum = 6.6×10^{-20} (kg m s^{-1})	C1 A1	**Allow** 1 sf answer of 7×10^{-20} (kg m s^{-1})
		(ii)2	The mass of the electron is greater (than its rest mass / 9.11×10^{-31} kg)	B1	**Allow**: Dividing (momentum) by 9.11×10^{-31} (kg) would give a speed of 7.3×10^{10} (m s^{-1}) which is greater than the speed of light / *c* (this is not possible) (AW)
	(b)	(i)	Different number of neutrons	B1	**Not**: different number of nucleons / different mass number / different A
		(ii)	u u d	B1	
		(iii)	u → d + positron + neutrino	M1 A1	**Allow**: u u d → u d d **Allow**: symbols for positron (e^+ / β^+ / ${}^{0}_{+1}e$) and neutrino (υ) **Allow** full marks for an answer in words **Allow** 1 mark for p → n + e^+ + υ
		(iv)	Any two from: charge or proton number / momentum / mass-energy / nucleon number / lepton number / strangeness / baryon number / spin	B1	**Not**: mass on its own or energy on its own, but **allow** mass and energy
		(v)	β^+ when there are fewer neutrons / β^+ for lighter nuclei or β^- when there are more neutrons / β^- for heavier nuclei	B1	**Allow**: Alternative correct answers in terms of ratio of protons to neutrons
			Total	**10**	

4)

Question			Answer	Marks	Guidance
	(a)		Rate of decay / disintegration of nuclei or Number of γ (photons) emitted per unit time	B1	The question has 500 Bq. Hence **allow** the following: Number of nuclei decaying per second / number of γ (photons) emitted per second **Not**: Rate of decay of atoms / molecules / particles
	(b)		(rate of energy =) $500 \times 10^6 \times 2.2 \times 10^{-14}$ rate of energy emission = 1.1×10^{-5} (J s^{-1})	C1 A1	
	(c)		**Collimator / lead tubes** and ...... gamma (ray photons) travel along the axis of lead tubes (AW) **Scintillator / Sodium Iodide (crystal)** and .... gamma ray / gamma photon produces (many) photons of (visible) light **Photomultiplier (tubes) / photocathode and dynodes** and ...... (electrical) pulse / signal / electrons produced by photon(s) of visible light **Computer** and .... signals / pulses /electrons (from photomultiplier tubes) are used to generate an image QWC: Quality of image improved by narrower / thinner / longer collimators OR longer scanning time	B1 B1 B1 B1 B1	**Not** 'it collimates' **Allow**: parallel rays / uni-directional rays travel along the lead tubes (AW) **Not** 'information / data' in place of signals
			Total	**8**	

5)

Question			Expected Answer	Mark	Additional Guidance
	(a)	(i)	composition for n and p: u d d & u u d charge for n and p: 0 & +1	B1 B1	**Allow**: charge 'e' instead of '+1' or '1'
		(ii)	up +2/3 **(+1/3)** 0 down -1/3 +1/3 **(0)**	B1 B1	**Allow**: charges in terms of 'e'
	(b)	(i)	${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{\nu}$	A2	**Allow**: '→ proton + electron + antineutrino' **Note**: -1 for any omission or error. Score = 0 if more than one error
		(ii)	weak (nuclear)	B1	
		(iii)	lepton(s) and hadron(s) / baryons(s)	B1	**Not**: Neutrons are mesons
			Total	8	

6)

Question			Expected Answer	Mark	Additional Guidance
	(a)		**Spontaneous**: the decay cannot be induced / occurs without external influence **Random**: cannot predict when / which (nucleus) will decay next	B1 B1	
	(b)		The probability of decay of a nucleus per unit time	M1 A1	**Allow**: $\lambda = A / N$ (Any subject) C1 A = activity and N = number of nuclei A1
	(c)		Living plants / animals absorb carbon(-14) Once dead, the plant does not take in any more carbon(-14) The fraction of C-14 to C-12 (nuclei) or number of C-14 (nuclei) or activity of C-14 (nuclei) measured in dead and living (sample) $x = x_0 e^{-\lambda t}$ used with data above to estimate the age	B1 B1 M1 A1	
	(d)	(i)1	$\lambda = \ln 2 / T_{1/2}$ decay constant = 1.24×10^{-4} (y^{-1})	B1	
		(i)2	$A = A_0 e^{-\lambda t}$ $0.194 = 0.249 \times e^{-(1.24\times10^{-4}\times t)}$ $\ln(0.194/0.249) = -1.24\times10^{-4} t$ time = 2.0×10^{3} (y)	C1 A1	
		(ii)	The activity is (very) small / decay is random	B1	
		(iii)	Activity so low that it cannot be differentiated from the background	B1	
			Total	13	

7)

Question			Answers	Marks	Guidance
	(a)		Same charge / number of protons	B1	**Not**: 'same chemical property'
	(b)		strong (nuclear force / interaction) gravitational (force)	B1 B1	 **Allow**: 'gravity'
	(c)	(i)	$^{15}_{7}$N	B1	
		(ii)	(u d d) → (u u d)	B1	**Allow**: *One down quark becomes up quark* or d → u (+ electron + antineutrino)
	(d)	(i)	0.16 MeV = 0.16 × 10^6 × 1.6 × 10^{-19} $\frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 = 2.56 \times 10^{-14}$ speed = 2.4 × 10^8 (m s^{-1}) or 2.37 × 10^8 (m s^{-1})	C1 A1	 **Allow**: 1 mark for using 9.8 MeV; answer is equal to 1.86 × 10^9 (m s^{-1})
		(ii)	The mass of the electron increases / greater than 'rest mass'	B1	
	(e)	(i)	$\lambda = 0.693 / T$ $\lambda = 0.693/(5560 \times 3.16 \times 10^7)$ λ = 3.9 × 10^{-12} (s^{-1}) or 3.94 × 10^{-12} (s^{-1})	 C1 A1	 **Allow**: 1 mark for 1.25 × 10^{-4} (if 5560 y used)
		(ii)	number = $\frac{1.0 \times 10^{-3}}{14} \times 6.02 \times 10^{23}$ number = 4.3 × 10^{19}	M1 A0	**Note**: This step must be seen to score 1 mark
		(iii)	activity = λN activity = 3.94 × 10^{-12} × 4.3 × 10^{19} activity = 1.7 × 10^8 (Bq) or 1.69 × 10^8 (Bq)	 C1 A1	 Possible ecf from **(e)(i)** and **(e)(ii)**

Question			Answers	Marks	Guidance
	(f)		Any **three** from: 1. Plants / living things take in carbon(-dioxide) or plants / living things stop taking in carbon after death 2. The ratio of carbon-14 to carbon-12 (nuclei) for the relic sample is determined 3. The current ratio of carbon-14 to carbon-12 nuclei is determined 4. The age of the relic is found using '$x = x_0 e^{-\lambda t}$' Limitation: The ratio of carbon-14 to carbon-12 is assumed to be constant / count(-rate) from relic may be comparable to background count(-rate)	B1×3 B1	**Must use ticks on Scoris to show where the marks are awarded** **Allow**: Any other valid comment for the limitation
			Total	**17**	

8)

Question			Answer	Marks	Guidance
	(a)		no: of neutrons = 142	B1	
	(b)	(i)	(5.6 MeV =) 5.6 × 10^6 × 1.6×10^{-19} energy = 8.96 × 10^{-13} (J)	M1 A0	**Allow**: 5.6 × 1.6×10^{-13}
		(ii)	$\frac{1}{2} \times 6.65 \times 10^{-27} \times v^2 = 8.96 \times 10^{-13}$ $v = \sqrt{\frac{2 \times 8.96 \times 10^{-13}}{6.65 \times 10^{-27}}}$ speed = 1.6 × 10^7 (m s^{-1})	C1 A1	Answer to 3 sf is 1.64 × 10^7 (m s^{-1}) **Note**: The answer is 1.65 × 10^7 (m s^{-1}) if 9 × 10^{-13} (J) is used
	(c)	(i)	activity = $\frac{62}{8.96 \times 10^{-13}}$ activity = 6.92 × 10^{13} (Bq)	C1 A0	**Allow**: activity = $\frac{62}{9 \times 10^{-13}}$ (= 6.89 × 10^{13} Bq) Possible ecf from **(b)(i)**
		(ii)	$\lambda = \frac{0.693}{T}$ $\lambda = \frac{0.693}{88 \times 3.16 \times 10^7}$ decay constant = 2.49 × 10^{-10} (s^{-1}) or 2.5 × 10^{-10} (s^{-1})	C1 A1	**Note**: ln2 = 0.693 **Allow**: 1 mark for using 88 years and getting an answer of 7.9 × 10^{-3}
		(iii)	**1** $A = \lambda N$ $N = \frac{6.92 \times 10^{13}}{2.49 \times 10^{-10}}$ number =2.78 × 10^{23} or 2.8 × 10^{23} **2** mass = $\frac{2.78 \times 10^{23}}{6.02 \times 10^{23}} \times 0.24$ mass = 0.11 (kg)	C1 A1 B1	Possible ecf from **(c)(ii)** **Note**: '7 × 10^{13}/2.5 × 10^{-10} = 2.8 × 10^{23}' Possible ecf for mass from incorrect value for number of nuclei
			Total	**10**	

9)

Question			Answer	Marks	Guidance
	(a)		The neutrons interact with other uranium (nuclei) / the neutrons cause further (fission) reactions	B1	**Not**: neutrons interact with uranium atoms / molecules / particles
	(b)		**Fuel rod**: Contain the uranium (nuclei) / fissile material **Control rods**: Absorb (some of the) neutrons *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) **Moderator**: Slows down the (fast-moving) neutrons / lowers the KE of (fast moving) neutrons / makes the (fast moving) neutrons into thermal neutrons Slow moving neutrons have a greater chance of causing fission / of being absorbed (by U-235) / sustaining chain reaction	B1 B1 B1 B1 B1	**Show annotation on Scoris** **Not** 'contains fuel' **QWC mark** **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 × 10^9/0.22 power = 1.36 × 10^{10} (W) or 1.4 × 10^{10} (W)	B1	
		(ii)	energy = 1.36 × 10^{10} × 8.64 ×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) = $\frac{1.18 \times 10^{15}}{3.2 \times 10^{-11}}$ mass = $\frac{1.18 \times 10^{15}}{3.2 \times 10^{-11}} \times 3.9 \times 10^{-25}$ mass = 14.4 (kg) or 14 (kg)	C1 A1	Possible ecf from **(c)(ii)** **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**	

10)

Question			Expected Answers	Marks	Additional guidance
	(a)		Any four 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} m	B1×4	**Must use ticks on Scoris to show where the marks are awarded** **Allow**: 10^{-15} m
			✎ QWC: Award a mark for one conclusion correctly linked to an observation	B1	
	(b)		Any five from: Gravitational (force) This force is attractive **AND** is long-ranged / obeys '$1/r^2$ relationship'	M1 A1	**Allow:** gravity **Note**: Do not allow 'inverse square law'; allow 'inverse square law with distance'
			Strong (nuclear force/interaction) This force is attractive (at larger distances) or repulsive at short distances **AND** is short-ranged / ~ 10^{-14} m	M1 A1	
			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	**Allow:** Electromagnetic (interaction/force)

Question			Expected Answers	Marks	Additional guidance
	(c)	(i)	mass = 235 × 1.7 × 10^{-27} (= 3.995 × 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 × 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	

11)

Question			Expected Answers	Marks	Additional Guidance
	a	(i)	$A = \lambda N_0$ = 4.5 x 10^{23} x 0.693 / (12 x 3600) = 7.22 x 10^{18} (s^{-1})	C1 A1	allow one mark if the 12 hours is not converted into seconds. Answer is 2.6 x10^{22} Allow one mark if the 12 hours is converted into minutes Answer 4.33 x 10^{20}
		(ii)	3 half lives N = 5.6 x 10^{22}	A1	
		(iii)	$N = N_0 e^{-\lambda t}$ = 4.5 x 10^{23} x $e^{-(0.693 \times 50/12)}$ or use of 2^n = 2.5 x 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 for initial period 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]**	

12)

Question			Expected Answers	Marks	Additional Guidance
	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 → udd	B1	Allow u → d
		(ii)	udd → uud	B1	Allow d → u
	c		weak(nuclear force)	B1	
			Total	**[6]**	

13)

Question			Expected Answers	Marks	Additional Guidance
	a		$F = Q_1Q_2 / 4\pi\varepsilon_0 r^2$ $= (1.6 \times 10^{-19} \times 1.6 \times 10^{-19}) / 4\pi\varepsilon_0 (2 \times 10^{-15})^2$ = 57.5 (N)	C1 A1	Allow use of 9×10^9 instead of $1 / 4\pi\varepsilon_0$ (using this gives 57.6) Allow ≥ 2sf (58) If correct formula quoted and then AE (e.g. not squaring r <u>or</u> not squaring Q) then allow ecf in final answer for 2/3
	b		<u>attractive</u> strong (nuclear force)	B1	Do not it holds them together
	c		as the proton travels towards the stationary proton it experiences a repulsive force that slows it down. (It needs a high velocity) to get close enough (to the proton) / for the (attractive) <u>short range</u> force to have any effect	B1 B1	
			Total	**[5]**	

14)

Question			Answer	Marks	Guidance
	(a)		$\lambda = \dfrac{0.693}{6.6 \times 10^3}$ or $\lambda = \dfrac{\ln 2}{6.6 \times 10^3}$ decay constant = 1.1×10^{-4} (s^{-1})	C1 A1	**Note**: Answer to 3sf is 1.05×10^{-4} (s^{-1})
	(b)		$A = \lambda N$ $N = \dfrac{250 \times 10^6}{1.05 \times 10^{-4}}$ number = 2.38×10^{12} or 2.4×10^{12}	C1 A0	Possible ecf from **(a)** **Allow** full credit for bald 2.4×10^{12}
	(c)		mass of F-18 = $\dfrac{2.38 \times 10^{12}}{6.02 \times 10^{23}} \times 0.018$ (= 7.116×10^{-14} kg) mass of FDG= $7.116 \times 10^{-14} / 0.099$ mass of FDG = 7.2×10^{-13} (kg)	C1 C1 A1	Possible ecf from **(b)** **Allow** full credit for using 2×10^{12}; answer is 6.04×10^{-13} (kg)
	(d)		$A = 250 \times e^{-(1.05 \times 10^{-4} \times 20 \times 60)}$ activity = 220 (MBq)	C1 A1	Possible ecf from **(a)** **Allow**: 1 mark for 249 (MBq); factor of 60 omitted
	(e)		(FDG/positron-emitting substance is injected into the patient) Any <u>three</u> from: 1. Annihilation of electron and positron 2. Positron-electron annihilation produces <u>two</u> gamma photons 3. The gamma photons travels in opposite directions 4. The patient is surrounded by (a ring of) gamma detectors 5. A 3-D image is created (using the detector-signals with the aid of computer software) **QWC**: The arrival times / delay times of the photons (at diametrically opposite detectors) are used to pinpoint areas of increased activity (AW)	B1 × 3 B1	**Allow**: rays / waves instead of photons in 2 and 3
			Total	**12**	