Question			Expected Answer	Mark	Additional Guidance
1	(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 + (**+1/3**) 0 down - +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 + <u>anti</u>neutrino' **Note**: -1 for any omission or error. Score = 0 if more than one error
		(ii)	weak (nuclear)	B1	
		(iii)	lepton(s) <u>and</u> hadron(s) / baryons(s)	B1	**Not**: Neutrons are mesons
			Total	8	

Question			Expected Answer	Mark	Additional Guidance
2	(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)	$\lambda = \ln 2 / T_{1/2}$ decay constant = 1.24×10^{-4} (y^{-1})	B1	
		(i)	$A = A_0 e^{-\lambda t}$ $0.194 = 0.249 \times e^{-(1\,24\times10^{-4}\times t)}$ $\ln(0.194/0.249) = -1.24\times10^{-4} t$ 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	

Question			Answer	Marks	Guidance
3	(a)		Rate of decay / disintegration of <u>nuclei</u> or Number of γ (photons) emitted per unit time	B1	The question has 500 Bq. Hence a**llow** the following: Number of <u>nuclei</u> 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** <u>and</u> ..... gamma (ray photons) travel along the axis of lead tubes (AW) **Scintillator / Sodium Iodide (crystal)** <u>and</u> ..... gamma ray / gamma photon produces (many) photon**s** of (visible) light **Photomultiplier (tubes) / photocathode and dynodes** <u>and</u> ..... (electrical) pulse / signal / electron<u>s</u> produced by photon(s) of visible light **Computer** <u>and</u> ..... 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**	

Question			Answer	Marks	Guidance
4	(a)		$\lambda = \frac{0.693}{6.6\times10^{3}}$ or $\lambda = \frac{\ln 2}{6.6\times10^{3}}$ decay constant = 1.1×10^{-4} (s^{-1})	C1 A1	**Note**: Answer to 3sf is 1.05×10^{-4} (s^{-1})
	(b)		$A = \lambda N$ $N = \frac{250\times10^{6}}{1.05\times10^{-4}}$ 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 = $\frac{2.38\times10^{12}}{6.02\times10^{23}}\times0.018$ (= 7.116×10^{-14} kg) mass of FDG= $7.116\times10^{-14} / 0.099$ 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)		$A = 250\times e^{-(1\,05\times10^{-4}\times20\times60)}$ 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**	