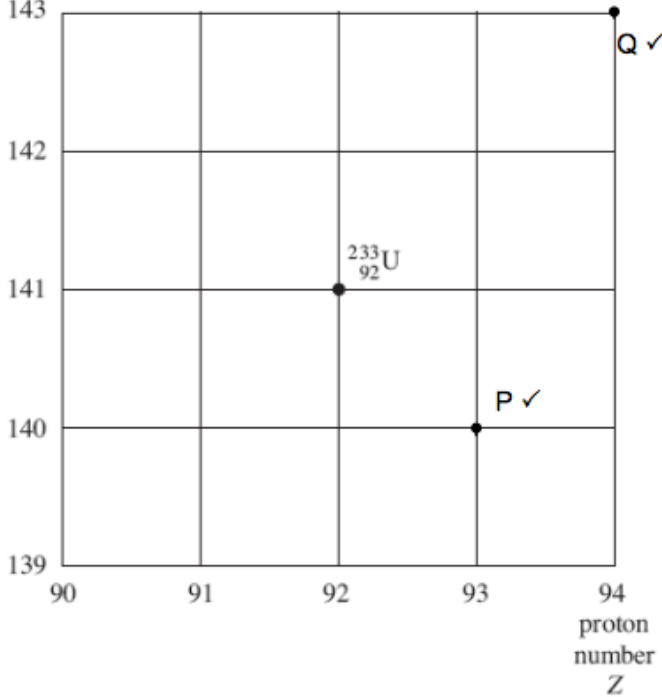
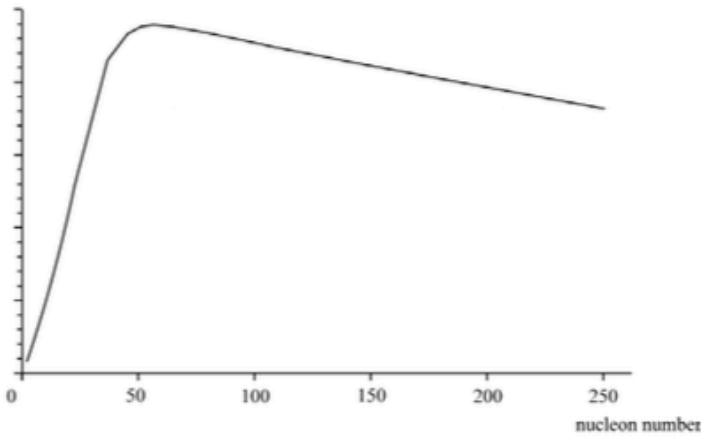


1)

a	${}_{91}^{233}\text{Pa}$ ✓ anti (electron) neutrino ✓	2	
b	neutron number N 	2	
c	i	$x = 4$ ✓	1
c	ii	mass defect = $[(232.98915 + 1.00867) - (90.90368 + 138.87810 + 4 \times 1.00867)] \text{ u}$ ✓ $= 0.18136 \text{ u}$ ✓ energy released $(= 0.18136 \times 931) = 169 \text{ (MeV)}$ ✓	3
Total			8

2)

<p>a</p>	 <p>binding energy per nucleon</p> <p>0 50 100 150 200 250</p> <p>nucleon number</p> <p>peak 8.7 (accept 8.0 – 9.2) ✓ in MeV ✓ (or peak 1.4×10^{-12} accept $1.3 - 1.5 \times 10^{-12}$ ✓ in J ✓) at nucleon number 50 – 60 ✓ accept 50 – 75 sharp rise from origin and moderate fall not below 2/3 of peak height ✓</p>	<p>4</p>
<p>b</p>	<p>energy is released/made available when binding energy per nucleon is increased ✓</p> <p>in fission a (large) nucleus splits and in fusion (small) nuclei join ✓</p> <p>the most stable nuclei are at a peak ✓</p> <p>fusion occurs to the left of peak and fission to the right ✓</p>	<p>max 3</p>
<p style="text-align: right;">Total</p>		<p>7</p>

3)

(a)	(i)	1/12 the mass of an (atom) of $^{12}_6\text{C}$ / carbon-12 / C12 ✓	1	a reference to a nucleus loses the mark
(a)	(ii)	separated nucleons have a greater mass ✓ (than when inside a nucleus) because of the (binding) energy <u>added</u> to <u>separate</u> the nucleons or energy is <u>released</u> when a nucleus is <u>formed</u> (owtte) ✓	2	an answer starting with 'its' implies the nucleus marks are independent direction of energy flow or work done must be explicit
(b)		nuclei need to be <u>close together</u> (owtte) for the Strong Nuclear Force to be involved or for fusion to take place ✓ but the electrostatic/electromagnetic force is repulsive (and tries to prevent this) ✓ (if the temperature is high then) the nuclei have (high) kinetic energy/speed (to overcome the repulsion) ✓	3	e.g. first mark – within the range of the SNF 3 rd mark is for a simple link between temperature and speed/KE
(c)	(i)	15 ✓ e^+ ✓ (or β^+ , $^0_1\beta$, 0_1e) 12 ✓	3	give the middle mark easily for any e or β with a + in any position
(c)	(ii)	$\Delta\text{mass} = 4 \times 1.00728 - 4.00150 - (2 \times 9.11 \times 10^{-31} / 1.661 \times 10^{-27})$ or $\Delta\text{mass} = \{4 \times 1.00728 - 4.00150 - 2 \times 0.00055\}(u)$ ✓ $\Delta\text{mass} = 0.02652(u)$ ✓ $\Delta\text{binding energy} (= 0.02652 \times 931.5)$ {allow 931.3} $\Delta\text{binding energy} = 24.7 \text{ MeV}$ ✓	3	($4 \times 1.00728 = 4.02912$) 1 st mark – correct subtractions in any consistent unit. use of $m_p = 1.67 \times 10^{-27} \text{ kg}$ will gain this mark but will not gain the 2 nd as it will not produce an accurate enough result 2 nd mark – for calculated value 0.02652u $4.405 \times 10^{-29} \text{ kg}$ $3.364 \times 10^{-12} \text{ J}$ 3 rd mark – conversion to Mev conversion mark stands alone award 3 marks for answer provided some working shown – no working gets 2 marks (2sf expected)

4)

(a)		insert control rods (further) into the nuclear core/reactor ✓ which will absorb (more) neutrons (reducing further fission reactions) ✓	2	a change must be implied for 2 marks marks by use of (further) or (more) allow answers that discuss shut down as well as power reduction If a statement is made that is wrong but not asked for limit the score to 1 mark (e.g. wrong reference to moderator)
(b)		fission fragments/daughter products or <u>spent/used</u> fuel/uranium rods (allow) plutonium (produced from U-238) ✓	1	not uranium on its own
(c)	(i)	γ (electromagnetic radiation is emitted) ✓ as the energy gaps are large (in a nucleus) as the nucleus de-excites down discrete energy levels to allow the nucleus to get to the ground level/state ✓ mark for reason	2	A reference to α or β loses this first mark 2 nd mark must imply energy levels or states
(c)	(ii)	momentum/ <u>kinetic energy</u> is transferred (to the moderator atoms) or a neutron slows down/loses <u>kinetic energy</u> (with each collision) ✓ (eventually) reaching speeds associated with thermal random motion or reaches speeds which can cause fission (owtte) ✓	2	

5)

(a)	<p>the amount of energy required to separate a nucleus ✓ into its separate neutrons and protons/nucleons ✓ (or energy released on formation of a nucleus ✓ from its separate neutrons and protons/constituents ✓)</p>	<p>1st mark is for correct energy flow direction 2nd mark is for binding or separating nucleons (nucleus is in the question but a reference to an atom will lose the mark) ignore discussion of SNF etc both marks are independent</p>	2
(b)(i)	$2\text{}^1_0\text{n}$ or $\text{}^1_0\text{n} + \text{}^1_0\text{n}$ ✓	must see subscript and superscripts	1
(b)(ii)	<p>binding energy of U $= 235 \times 7.59$ ✓ (= 1784 (MeV)) binding energy of Tc and In $= 112 \times 8.36 + 122 \times 8.51$ ✓ (= 1975 (MeV)) energy released (=1975 – 1784) = 191 (MeV) ✓ (allow 190 MeV)</p>	<p>1st mark is for 235×7.59 seen anywhere 2nd mark for $112 \times 8.36 + 122 \times 8.51$ or 1975 is only given if there are no other terms or conversions added to the equation (ignore which way round the subtraction is positioned) Correct final answer can score 3 marks</p>	3
(b)(iii)	<p>energy released $= 191 \times 1.60 \times 10^{-13}$ ✓ (= 3.06×10^{-11} J)</p>	Allow CE from (b)(ii) working must be shown for a CE otherwise full marks can be given	2

	<p>loss of mass ($= E / c^2$) $= 2.91 \times 10^{-11} / (3.00 \times 10^8)^2$ $= 3.4 \times 10^{-28}$ (kg) ✓ or $= 191/931.5$ u ✓ ($= 0.205$ u) $= 0.205 \times 1.66 \times 10^{-27}$ (kg) $= 3.4 \times 10^{-28}$ (kg) ✓</p>	<p>for correct answer only</p> <p>note for CE answer = (b)(ii) $\times 1.78 \times 10^{-30}$</p> <p>($2.01 \times 10^{-27}$ is a common answer)</p>	
1 (c)(i)	<p>line or band from origin, starting at 45° up to Z approximately = 20 reading Z = 80, N = 110 → 130 ✓</p>	<p>Initial gradient should be about 1 (ie Z=20 ; N = 15 → 25) and overall must show some concave curvature. (ignore slight waviness in the line) If band is shown take middle as the line If line stops at N>70 extrapolate line to N = 80 for marking</p>	1
1 (c)(ii)	<p>Fission fragments are (likely) to be above/to the left of the line of stability ✓ fission fragments are (likely) to have a larger N/Z ratio than stable nuclei or fission fragments are neutron rich and become neutron or β^- emitters ✓</p>	<p>Ignore any reference to α emission. A candidate must make a choice for the first two marks. Stating that there are more neutrons than protons is not enough for a mark. 1st mark reference to graph 2nd mark – high N/Z ratio or neutron rich 3rd mark beta <u>minus</u> Note not just beta.</p>	3

6)

<p>(a)</p>	<p>The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.</p> <p>The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.</p> <p>High Level (Good to excellent): 5 or 6 marks</p> <p>The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.</p> <p>The candidate can explain the role of the moderator and control rods in maintaining a critical condition inside the reactor. The explanation is given in a clear sequence of events and the critical condition is defined in terms of neutrons. To obtain the top mark some other detail must be included. Such as, one of the alternative scattering or absorbing possibilities or appropriate reference to critical mass or detailed description of the feedback to adjust the position of the control rods etc.</p> <p>Intermediate Level (Modest to adequate): 3 or 4 marks</p> <p>The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.</p> <p>The candidate has a clear idea of two of the following: the role of the moderator, the role of the control rods or can explain the critical condition.</p> <p>Low Level (Poor to limited): 1 or 2 marks</p> <p>The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.</p> <p>The candidate explains that a released neutron is absorbed by uranium to cause a further fission. Alternatively the candidate may explain one of the following: the role of the moderator, the role of the control rods or can explain the critical condition.</p> <p>The explanation expected could include the following events that could happen to a released neutron.</p> <p>a neutron is slowed by the moderator taking about 50 collisions to reach thermal speeds then absorbed by uranium-235 to cause a fission event one neutron released goes on to cause a further fission is the critical condition a neutron may leave the reactor core without further interaction a neutron could be absorbed by uranium-238 a neutron could be absorbed by a control rod a neutron could be scattered by uranium-238 a neutron could be scattered by uranium-235</p>	<p>max 6</p>
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7)

:)(i)	<p>uranium (– 235 captures) a <u>neutron</u> (and splits into 2 smaller nuclei/fission fragments) <u>releasing more neutrons</u> ✓</p> <p>(at least one of) <u>these neutrons</u> go on to cause further/more <u>splitting/fissioning</u> (of uranium–235) ✓</p>	<p>first mark for uranium + neutron gives more neutrons</p> <p>Ignore which isotope of uranium is used.</p> <p>second mark for released neutron causes more fission The word 'reaction' may replace 'fission' here provided 'fission/splitting of uranium' is given somewhere in the answer.</p>	2	
(ii) Escalate if clip shows critical mass in the question.				
:)(ii)	<p>the moderator slows down/reduces the kinetic energy of <u>neutrons</u> ✓</p> <p>so neutrons are absorbed/react/fission (efficiently) by the <u>uranium/fuel</u> ✓</p>	<p>owtte</p> <p>Possible escalation</p>	2	
:)(iii)	<p><u>neutrons</u> are absorbed/collide with (by the nuclei in the shielding) ✓</p> <p>converting the nuclei/atoms (of the shielding) into unstable isotopes (owtte) ✓</p>	<p>Second mark is only given if neutrons appear somewhere in the answer.</p> <p>No neutrons = no marks making it neutron rich implies making them unstable.</p>	2	

8)

(a)(i)	<p>Fission occurs at A values above the peak / above A of about 56 <u>and</u> fusion occurs at A values below the peak / below A of about 56 ✓</p> <p>Fission is the splitting of a nucleus (into two smaller ones) <u>and</u> fusion is the joining of two nuclei ✓</p>	<p>First mark uses the graph so 'fission occurs in very large nuclei' does not gain a mark. (allow other interpretations that use the graph eg gradients)</p> <p>2nd Mark splitting into 2 is not required for fission but if the answer implies something different like the separating of all the nucleons the mark may not be given.</p>	2
(a)(ii)	<p>Energy is released when the binding energy (per nucleon) is increased ✓</p> <p>fusion energy is greater as the increase in BE/A for fusion > increase in BE/A for fission (owtte) ✓</p>	<p>The last point can be given for a reference to the larger gradient at small values of A (fusion region) compared to the gradient at large values of A (fission region)</p>	2
(b)(i)	<p>$\Delta m = (8m_p + 8m_n) - M_{\text{oxygen}}$ mark for substituting data into the above equation in any workable consistent units</p> <p>$= 8(1.00867 + 1.00728) - 15.991$ ✓ ($\Delta m = 0.1366$ u $\Delta m = 0.1366 \times 1.661 \times 10^{-27}$) = 2.3×10^{-28} (kg) ✓ (range of answers 2.2 - 2.3×10^{-28} kg)</p>	<p>Substitution may take the following form $8(1.673 \times 10^{-27}) + 8(1.675 \times 10^{-27}) - (15.991 \times 1.661 \times 10^{-27})$ ✓ $= 2.23 \times 10^{-28}$ (kg) ✓</p> <p>Correct answer gains full marks. Look out for a physics error in which u is not taken as 1.661×10^{-27} kg</p>	2
(b)(ii)	<p>$E = m \times c^2 = 2.3 \times 10^{-28} \times (3.00 \times 10^8)^2 = 2.07 \times 10^{-11}$ J $BE = 2.07 \times 10^{-11} / 1.6 \times 10^{-13} = 130$ (MeV) ✓ (129 MeV) Or using using $\Delta m = 0.1366$ u (this must appear in b(i) for this approach) $BE = 0.1366 \times 931.3 = 130$ (MeV) ✓ (127 MeV)</p>	<p>CE is allowed but only if the calculation is shown Note answer = b(i) $\times 5.625 \times 10^{29}$ answer only is acceptable for one mark. (factor may be 931 or 931.5)</p>	1
b)(iii)	<p>read from the graph the BE/A for (${}^{16}_8\text{O}$) and multiply by the number of nucleons (or 16) ✓ Or show the calculation $BE = 8(\text{MeV}) \times 16(\text{nucleons}) = 130$ (MeV) ✓ (128 MeV) ✓</p>	<p>There must be a reference to (${}^{16}_8\text{O}$) position on the graph. with the calculation allow $BE = 8.1(\text{MeV}) \times 16(\text{nucleons}) = 130$ (MeV) A calculation may lead to an answer in joule</p>	1