Question	Evidence	1–4 marks	5–6 marks	7–8 marks
1 (a)	Nuclear power allows us to convert small amounts of mass into quite large and useful amounts of energy without much production of greenhouse gases. The mass of the reactants is slightly more than the mass of the products – the difference in mass is equivalent to a large amount of energy as can be calculated using $E = \Delta mc^2$.	Thorough understanding of these applications of physics in the real world OR Partially correct mathematical solution to the given problems AND / OR Partial understanding of these applications of physics in the real world.	(Partially) Correct mathematical solution to the given problems AND / OR Partial understanding of these applications of physics in the real world.	Correct mathematical solution to the given problems AND Thorough understanding of these applications of physics in the real world.
(b)	Mass of reactants = $398.60428 \times 10^{-27}$ Mass of products = $398.29518 \times 10^{-27}$ Mass loss = 0.30910×10^{-27} kg Energy released = $mc^2 = 0.30910 \times 10^{-27} \times (3 \times 10^8)^2$ $=2.7819 \times 10^{-11}$J In 1 kg the number of Pu atoms will be $1 / 396.92935 \times 10^{-27}$ $=2.519 \times 10^{24}$ Pu atoms / kg Energy total = $2.519 \times 10^{24} \times 2.7819 \times 10^{-11} = 7.009 \times 10^{13}$J = 70000 GJ 1 tonne of coal is 30 GJ that is means that 1 kg of Pu is equivalent to 2300 tonnes of coal.			

Question	Evidence	1-4 marks	5-6 marks	7-8 marks
2 (a)	$\Delta u = 226.025410 - 226.020181 = 0.005229$ u $\Delta m = 0.005229 \times 1.66 \times 10^{-27} = 0.00868014 \times 10^{-27}$ kg $E = \Delta mc^2 = 8.68014 \times 10^{-30} \times 9 \times 10^{16} = 7.812 \times 10^{-13}$ J $\text{E} = \frac{7.812 \times 10^{-13}}{1.60 \times 10^{-19}} = 4.88$ MeV	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(b)	Conservation of momentum results in the alpha particle having velocity of $\frac{M_{\text{Rn}}}{M_{\text{alpha}}} V_{\text{Rn}}$ $\frac{222.017578}{4.002603} = 55.4682985 \times V_{\text{Rn}}$ Conservation of Energy gives $\Delta E = KE_{\text{Rn}} + KE_{\text{alpha}} = ½ M_{\text{Rn}} V_{\text{Rn}}^2 + ½ M_{\text{alpha}} V_{\text{alpha}}^2$ $\Delta E = \frac{1}{2} M_{\text{Rn}} V_{\text{Rn}}^2 + \frac{1}{2} M_{\text{alpha}} \left(\frac{M_{\text{Rn}}}{M_{\text{alpha}}} V_{\text{Rn}} \right)^2$ $\Delta E = \frac{1}{2} M_{\text{Rn}} V_{\text{Rn}}^2 \left(1 + \frac{M_{\text{Rn}}}{M_{\text{alpha}}} \right)$ $\frac{1}{2} M_{\text{Rn}} V_{\text{Rn}}^2 = KE_{\text{Rn}} = \frac{\Delta E}{56.4682985} = 0.08646584$ MeV $KE_{\text{alpha}} = \Delta E - KE_{\text{Rn}} = 4.88257875 - 0.08646584$ $= 4.79611291$ MeV The lighter particle carries most of the KE because it has the higher velocity after the decay and the velocity term in KE is squared, therefore more than making up for the lower mass component.			
(c)	Every decay should liberate the exact same amount of energy, which should be carried away as the kinetic energy of the reaction products, shared in a similar way to the calculation in part (a) (if there were no neutrino then for beta decay you would expect the electron, being the lighter particle, to carry almost all of the energy). The fact that there is a distribution in beta energy implies that some other particle has the missing energy.			
(d)	The deuteron requires an input of energy to separate the proton and neutron. This added energy manifests itself as an increase in mass. The rocket uses internal energy to eject some mass at high speed in order to gain gravitational potential energy and kinetic energy for the remaining part of the rocket. Considering the Earth and the rocket as a single system, energy is conserved.			

Question	Evidence	1-4 marks	5-6 marks	7-8 marks
3 (a)	The fusion of low mass nuclei and the fission of large mass nuclei both produce products that have less mass than the starting mass. The mass loss in both cases is released as energy.	Shows some understanding of the underlying physics. AND / OR (Partially) correct mathematical solution to given problem.	A reasonable understanding of the underlying physics. AND (Partially) correct mathematical solution to given problem.	Thorough understanding of the underlying physics. AND Correct mathematical solution to the given problem.
(b)	Fusion is the joining of low mass nuclei to produce a heavier nucleus. The nuclei are positively charged and have strong electrostatic repulsion. For the strong nuclear force to operate and unite the reactant nuclei, they must approach to within 10^{-15} m. To overcome the force of repulsion at this distance requires very high kinetic energy (temperature), which has proven hard to produce and hard to keep confined without melting the surroundings.			
(c)(i) (ii)	The negative radiation is Beta radiation – electrons resulting from the decay of neutrons $n \rightarrow p + e$. At short range, 10^{-15} m, the strong force of attraction between protons overwhelms the force of electrostatic repulsion. So most small nuclei are stable.			
(d)	Energy released = $4 \times 10^9 .(3 \times 10^8)^2 = 3.6 \times 10^{26}$ J s^{-1} Area spread over = $4 \times \pi .(1.50 \times 10^{11})^2 = 2.83 \times 10^{23}$ m^2 That is 1.3×10^3 W m^{-2} 10^9 W will need $\frac{10^9}{1.3 \times 10^3} = 7.7 \times 10^5$ m^2 (not far short of 1 square km) Some possible assumptions are: a) 100% efficiency b) normal incidence (overhead sun) c) no absorption, reflection from the atmosphere.			

Question	Mark Allocation	Typical evidence
4 (a)	1 mark for adequate BE definition (mass deficit / $E=mc^2$). 1 mark for stability – need to mention Fe. 1 mark for fission / fusion description. 1 mark for graph fine structure description or other comments relating to nuclear forces / Coulomb repulsion etc.	Iron is the most stable nuclei as it has the most binding energy per nucleon. This means that if you formed iron from individual protons and neutrons, the mass of the iron nucleus could be less than the total mass of the individual protons and neutrons required. The 'missing' mass has been converted to energy (Einstein's equation $E = mc^2$). To separate the iron nucleus back to its protons and neutrons, you need to supply this energy so it can be converted back into mass. The binding energy per nucleon is the amount of energy which would need to be supplied to each nucleon to separate the nucleus. Small nuclei (eg H, He, C…) have less BE per nucleon than iron, so when they are combined they form bigger nuclei (closer to iron); mass is released as energy. This is called fusion, and is observed in stars. Very large nuclei (eg U, Pu…) also have less binding energy per nucleon than iron. When they are split up into smaller nuclei, these smaller nuclei are closer to iron, so once again mass is converted to energy. This is called fission, and is observed in nuclear power stations. The 'spikes' represent anomalously stable nuclei. The first 'spike' is helium, the others exist at multiples of four nucleons.
(bi)	1 mark for correct energy expression. 1 mark for correct answer.	$eV = \frac{1}{2}mv^2$ $v = \sqrt{\frac{2eV}{m}}$ $\lambda = \frac{h}{p} = \frac{h}{m\sqrt{\frac{2eV}{m}}} = \frac{h}{\sqrt{2eVm}} = \frac{6.63\times10^{-34}}{\sqrt{2\times9.11\times10^{-31}\times1\times10^{4}\times1.6\times10^{-19}}}$ $\lambda = 1.228\times10^{-11}m$ $n\lambda = \frac{dx}{L}$ $x = \frac{L}{d}\lambda = \frac{1\times1.228\times10^{-11}}{50\times10^{-9}} = 2.46\times10^{-4}m$
(bii)	1 mark for change factor. 1 mark for correct answer.	Electron velocity = $\sqrt{\frac{2eV}{m}} = 5.927\times10^{7}\,ms^{-1}$ Momentum change factor = $\frac{1}{\sqrt{1-\frac{(5.927\times10^{7})^2}{(3\times10^{8})^2}}} = 1.02$ Relativistic correction is 2% so can be ignored.