8 The large amount of energy released in a nuclear fission reaction, together with the emission of more than one neutron, makes it possible for neutron-induced fission to be used as a source of useful energy for the shipping industry. An example of a nuclear-powered cargo ship is Sevmorput, which has a mass of 3.40×10^{7} kg and a maximum speed of 20.8 knots (1 knot = 0.514 m s^{-1}). Sevmorput is powered by a nuclear fission reactor that produces thermal power for a steam turbine. A single propeller is mechanically coupled to the steam turbine which has a maximum output of 29400 kW. The propeller turns at 115 rounds per minute.

In a nuclear fission reactor, a neutron is captured by a Uranium-235 nucleus, and this causes the nucleus to fission. On average, 2.5 neutrons are emitted in these fission reactions. This is illustrated in Fig. 8.1.

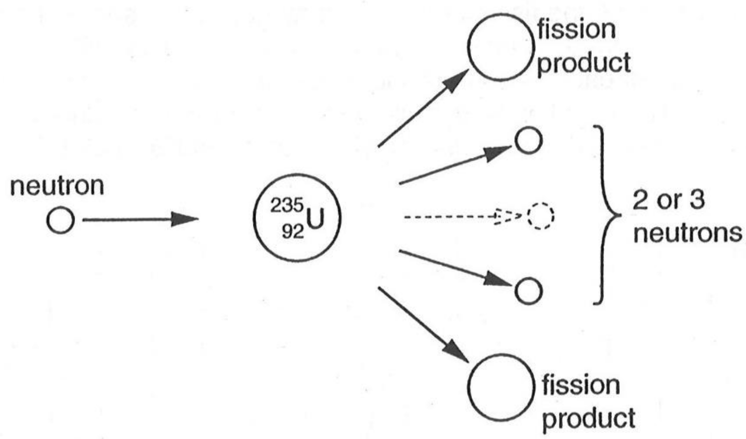

Fig. 8.1

When the conditions are suitable, a chain reaction can occur. If this chain reaction is not controlled, an explosion is likely. However, if the chain reaction is controlled, as in a nuclear fission reactor, a source of continuous power may be created.

The induced fission reaction of Uranium-235 may be represented by a nuclear equation of the form

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{a}_{b}\text{P} + {}^{c}_{d}\text{Q} + (2 \text{ or } 3)\,{}^{1}_{0}\text{n} + 198 \text{ MeV}.$$

The fission products P and Q have approximately equal masses. However, when any two nuclei are fissioned, the fission products may not be the same. If a large sample of Uranium-235 is fissioned, many different fission products will be produced. The percentage amount of each fission product in the fissioned material is referred to as percentage yield.

The variation with nucleon number of the percentage yield of different fission products is referred to as a 'fission yield curve' and is illustrated in Fig. 8.2.

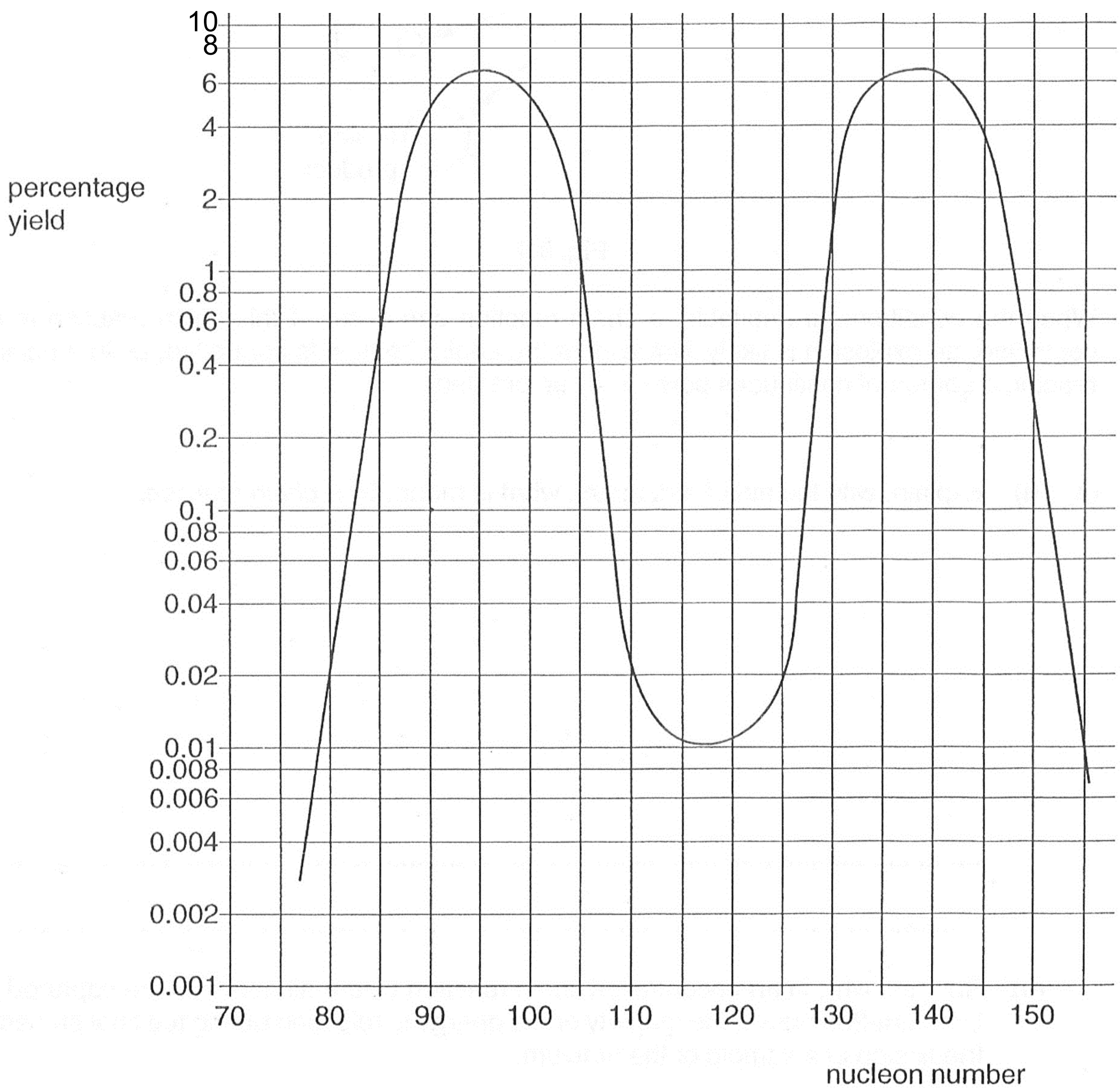

Fig. 8.2

(a) Calculate

(i) the maximum kinetic energy of Sevmorput, kinetic energy = ... J [2]

(ii) the angular speed of the propeller.

angular speed = ... rad s^{-1} [2]

(b) The nuclear fission reactor converts 2.15×10^5 kg of water at 100 °C to steam at 100 °C every hour, to be used by the steam turbine.

Calculate the maximum efficiency of the steam turbine. The specific latent heat of vaporisation of water is 2.26×10^6 J kg^{-1}.

efficiency = ... % [3]

(c) **(i)** Explain what is meant by a *chain reaction*.

....

....

.... [1]

(ii) Suggest why, in an uncontrolled chain reaction where all neutrons are captured by Uranium-235 nuclei, the majority of the energy is released during the final stages of the fission of a sample of the uranium.

....

....

.... [1]

(iii) The energy released in the reaction occurs partly as kinetic energy of the fission products and of the neutrons.

Suggest one other mechanism by which energy is released in the fission reaction.

.... [1]

(d) (i) Use Fig. 8.2 to determine the nucleon numbers of those fission products that have the same percentage yield as the nuclide with a nucleon number of 82.

....

.... [2]

(ii) By reference to the nuclear equation, and your answer in **(i)**, suggest the nucleon number of the nuclide that would be produced in the same fission reaction as the nuclide with nucleon number 82.

nucleon number = ... [1]

(iii) Use Fig. 8.2 to determine the percentage yield of fission products having nucleon numbers of 95 and 139.

percentage yield = ... [1]

(iv) Hence show that the fission products in **(iii)** are about 600 times more likely to be produced than those having masses equal to each other.

[2]

(e) A sample of Molybdenum-99 which decays by the emission of β^--particles is stored in a lead container having walls approximately 5 mm thick.

Explain why, although the lead container provides adequate shielding for the β^--particle emissions, some X-ray radiation may be detected outside the lead container.

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End of paper