Problem of the week

Nuclear fission

(a) Distinguish between induced and spontaneous fission.

(b) For the fission reaction ${}^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{142}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + x{}^{1}_{0}\text{n}$,

(i) state the number x of neutrons produced,

(ii) calculate the energy released given the atomic masses

U	235.043930 u
Ba	141.916361 u
Kr	91.926269 u

(iii) state the form of energy that is produced in the fission reaction.

(c) A nuclear power plant produces electrical power of 1.5 GW via the reaction in (b). The overall efficiency of the plant in converting nuclear power to electrical power is 45%.

(i) How many fission reactions take place in one year?

(ii) What mass of uranium is required in a year?

(d) The reactor in (c) is shut down for maintenance. It is observed that even after the shutdown the reactor produces many MW of power. Explain this observation.

(e) Outline the role, in a fission reactor, of

(i) the moderator

(ii) the control rods

(f) Discuss concerns about the use of nuclear fission as a commercial production of electricity.

Answers

(a) In induced fission a neutron initiates the fission by impacting a nucleus. In spontaneous fission the nucleus splits into lighter nuclei without the need for neutrons to trigger the splitting; it is a form of radioactive decay.

(b)

(i) $x = 2$

(ii) $\Delta m = 235.043930 - (141.916361 + 91.926269 + 1.008665) = 0.192635$ u.
Hence $Q = 0.192635 \times 931.5 = 179$ MeV.

(iii) Kinetic energy, mainly of the neutrons produced.

(c)

(i) Power produced by fission is $\frac{1.5}{0.45} = 3.33$ GW. One year has $365 \times 24 \times 60 \times 60 = 3.15 \times 10^7$ s so energy produced by fission is $3.33 \times 10^9 \times 3.15 \times 10^7 = 1.049 \times 10^{17}$ J. Hence number of reactions in a year is $\frac{1.049 \times 10^{17}}{179 \times 10^6 \times 1.6 \times 10^{-19}} = 3.67 \times 10^{27}$.

(ii) Uranium mass in a year is $3.67 \times 10^{27} \times 235 \times 1.66 \times 10^{-27} = 1432 \approx 1400$ kg.

(d) The products of the fission process are radioactive and so energy is still produced through the decay of these products.

(e)

(i) The neutrons produced are too fast to induce further fission events. They need to be slowed down, and this is done by collisions with the moderator atoms.

(ii) The control rods regulate the rate of energy production. When they are lowered into the core they absorb neutrons and so lower the rate of energy production. Thet are removed from the core when the rate is low.

(f) Concerns include the possibility of an accident that may result in the release of radioactive material in the atmosphere and water reserves. The possible diversion of uranium into weapons grade plutonium and therefore a risk of proliferation of nuclear weapons and finally the storage of the waste material of a reactor that is radioactive, often with long half-lives.