1. (a) (i) proportion of U-235 is greater than in natural uranium **(1)**

(ii) induced fission more probable with U-235 than with U-238 **(1)** 2

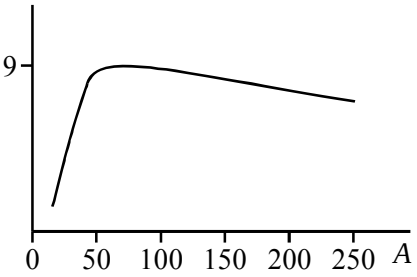
(b) (i) for steady rate of fission, one neutron per fission required to go on to produce further fission **(1)**
each fission produces two or three neutrons on average **(1)**
some neutrons escape [or some absorbed by U-238 without fission] **(1)**
control rods absorb sufficient neutrons (to maintain steady rate of fission) **(1)**

(ii) neutrons need to pass through a moderator **(1)**
to slow them (in order to cause further fissions or prevent U-238 absorbing them) **(1)**
neutrons that leave the fuel rod (and pass through the moderator)
are unlikely to re-enter the same fuel rod **(1)**
makes it easier to replace the fuel in stages **(1)** max 5

[7]

2. (a) (i) binding energy is the work done on nucleons to separate nucleons completely
[or the energy **released** by nucleons when nucleus is formed from separated nucleons] **(1)**

(ii) average
binding energy
per nucleon



curve: correct shape, maximum at A between 40 – 60 **(1)**
sharp rise from <50 $(\text{binding energy})_{max}$ **(1)**
gradual fall to > 60% $(\text{binding energy})_{max}$

scales: binding energy per nucleon to 8 – 10 MeV **(1)**
A to > 220 **(1)** max 5

(b) uranium splits into two fragments **(1)**
binding energy **per nucleon** rises (causing energy release) **(1)** 2

(c) number of neutrons escaping is proportional to surface area **(1)**
as mass increases a smaller fraction escapes **(1)**
because surface/volume ratio decreases **(1)**
hence fraction producing fission increases as mass increases **(1)** max 3

[10]

3. (a) (i) amount of (fissionable) uranium (235) in fuel decreases **(1)**
fission fragments absorb neutrons **(1)**

(ii) fission fragments are radioactive or unstable **(1)**

emitting β^- and γ radiation **(1)**
some fission fragments have short half-lives or high activities **(1)** Max 3

(b) moved by remote control **(1)**
placed in cooling ponds **(1)**
for several months **(1)**
[or to allow short $T_{1/2}$ isotopes to decay]
transport precautions, e.g. impact resistant flasks **(1)**
separation of uranium from active wastes **(1)**
high level waste stored (as liquid) **(1)**
[**alternative** for last two marks:
rods are buried deep underground
at geologically stable site]
storage precautions, e.g. shielded tanks or monitoring **(1)**
reference to vitrification **(1)** Max 5

[8]