A2 Questions - Fission - The Markscheme

1. (a) (i) $\Delta m = Zm_p + (A - Z)m_n - M$ **(1)**

(ii) binding energy per nucleon = $\dfrac{(\Delta m)c^2}{A}$ **(1)** 2

(b) (i) A in range 54 → 64 **(1)**
stability increases as binding energy per nucleon increases **(1)**
[or binding energy per nucleon is a measure of stability]
[or large binding energy per nucleon shows nucleus is difficult to break apart] 5

(ii) binding energy per nucleon increases from about 7.6 to 8.5 **(1)**
increase of about 0.9 MeV for 235 nucleons **(1)**
hence 210 MeV (≈ 200 MeV) in total **(1)**

[7]

2. (a) for one reaction ΔE (= $\Delta m\, c^2$) = $3.1 \times 10^{-28} \times (3.00 \text{ x } 10^8)^2$ **(1)**
= $(2.79\times10^{-11}\text{J})$

number of nuclei required = $\dfrac{1}{2.79 \times 10^{-11}}$ = $3.5(8) \times 10^{10}$ **(1)**

[or equivalent credit for any other valid method] 2

(b) output power from reactor = $\dfrac{600}{0.35} = 1700\,(\text{MW})$ **(1)**

(1714 MW)

energy output from fuel rods in one week
= $1.70 \times 10^9 \times 24 \times 7 \times 3600$ **(1)**

(= 1.03×10^{15} J)

$\Delta m\left(=\dfrac{\Delta E}{c^2}\right) = \dfrac{1.03 \times 10^{15}}{(3.0 \times 10^8)^2}$ **(1)**

= 1.14×10^{-2} kg **(1)**

[or equivalent credit for any other valid method] 4

[6]

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]

4. (a) (i) to reduce the average speed (or kinetic energy) of the fission neutrons **(1)**

(ii) mean E_k (or $\frac{1}{2}mv^2$) = $^3/2kT$ **(1)**

gives $v\left(=\left[\frac{3kT}{m}\right]^{1/2}\right) = \left(\frac{3\times1.38\times10^{-23}\times700}{1.67\times10^{-27}}\right)^{1/2}$ **(1)**

$= 4.1(7)\times10^3 \text{m s}^{-1}$ **(1)** 4

(b) (i) mass of carbon 12 nucleus $\left(=\frac{0.012}{6.02\times10^{23}}\right) = 2.0\times10^{-26}$(kg) **(1)**

final momentum of neutron and nucleus = initial momentum of neutron **(1)**

$(1.67\times10^{-21}\times v) + (2.0\times10^{-26}\times6.0\times10^5) = 1.67\times10^{-27}\times3.9\times10^6$ **(1)**

$v = \frac{6\,5\times10^{-21} - 12\times10^{-21}}{1.67\times10^{-27}}$ **(1)** $(= 3.3\times10^6 \text{ m s}^{-1})$

(ii) initial E_k of neutron $(= \frac{1}{2}\times1.67\times10^{-27}\times(3.9\times10^6)^2) = 1.27\times10^{-14}$(J)

final E_k of neutron $(= \frac{1}{2}\times1.67\times10^{-27}\times(3.3\times10^6)^2) = 9.1\times10^{-15}$(J)

E_k of carbon nucleus $(= \frac{1}{2}\times2.0\times10^{-26}\times(6.0\times10^5)^2) = 3.6\times10^{-15}$(J)

(1) for all correct

initial E_k $(= 1.27\times10^{-14}$ J) = final E_k $(= 9.1\times10^{-15}$(J) + 3.6×10^{-15}(J)) **(1)**

(iii) % E_k transferred $\left(=\frac{3.6\times10^{-15}}{1.27\times10^{-14}}\right)\times100 = 28(.3)\%$ **(1)** 7

[11]

5. (a) (i) splitting of nucleus into two smaller nuclei **(1)**
brought about by bombardment **(1)**

(ii) thermal neutrons have low energies or speeds (e.g. 0.03 eV) **(1)**

(iii) fission reaction gives out neutrons **(1)**
neutrons (from fission) cause further fissions **(1)**
self-sustaining when one fission leads to (at least) one further fission **(1)** max 5

(b) (i) neutrons from fission are fast (high energy) neutrons (e.g. 2 MeV) **(1)**
fission most favourable with low energy neutrons **(1)**
moderation involves slowing down neutrons **(1)**
by collision with moderator atoms **(1)**
large number of collisions required (e.g. 50) **(1)**
collisions are elastic/k.e. transferred to atoms **(1)**
suitable moderator material named e.g. graphite, water **(1)**
moderator must not absorb neutrons **(1)**
moderator atoms should have (relatively) low mass **(1)**

QWC 1

(ii) control involves limiting number of neutrons **(1)**
excess neutrons absorbed by control rods **(1)**
suitable control rod material named e.g. boron, cadmium **(1)**
control rods inserted into reactor to slow reaction rate (or vice-versa) **(1)** max 7

[12]

6. (a) (i) a neutron strikes the nucleus **(1)**

nucleus splits into two fragments **(1)**

(ii) some electrostatic Ep converted to E_k of fragments **(1)**

some electrostatic Ep used to overcome strong interaction **(1)**

some electrostatic Ep used to increase surface energy **(1)**

(iii) fission fragments repel and collide with other atoms in fuel rod **(1)**

high energy fission neutrons enter moderator

[or collide with moderator atoms] **(1)**

atoms gain *Ek* due to collisions (and vibrate more) **(1)**

temperature depends on the average E_k of (vibrating) atoms **(1)**

a chain reaction occurs **(1)** max 8

(b) energy from fuel per year at 100% efficiency

$= 1600(\text{MW}) \times 3.2 \times 10^7 \text{ s} \approx 5.0 \times 10^{16}$ (J) **(1)**

energy supplied from fuel per year at 25% efficiency

$\approx 4 \times 5.0 \times 10^{16} \approx 2.0 \times 10^{17}$(J) **(1)**

energy released per kilogram of fuel

$= 200 \times 1.6 \times 10^{-13} \times 6.0 \times 10^{23} \times \frac{1}{0.238}$ **(1)** $\times 0.03 \approx 2.4 \times 10^{12}$ (J) **(1)**

mass of fuel needed per year $= \frac{2.0 \times 10^{17}}{2.4 \times 10^{12}} \approx 8 \times 10^4$ kg **(1)** 5

[13]

7. (a) neutron speed [or kinetic energy] reduced **(1)**
to thermal energies [or speeds] **(1)**
by collisions **(1)**
absorbed to produce fission of uranium-235 **(1)**
(power constant when) one net fission per absorbed neutron **(1)**
others neutrons absorbed [or escape] **(1)** max 5

(b) (i) (control rods) absorb neutrons **(1)**
neutron flux [or power or reaction rate] kept constant **(1)**
by raising or lowering control rods **(1)**
rapidly dropped in emergency **(1)**
to stop reaction **(1)**

(ii) neutrons and gamma radiation must be contained
by concrete shielding **(1)**

(iii) keep underwater (in ponds) **(1)**
then store safely for long period **(1)**
reference to long and short half-life products max 8

(c) element bombarded with neutrons **(1)**
absorption by nucleus **(1)** 2

[15]

8. (a) (i) ${}^{1}_{0}\text{n} + {}^{235}_{92}\text{U} > {}^{236}_{92}\text{U}$

(ii) ${}^{236}_{92}\text{U} \rightarrow {}^{145}_{56}\text{Ba} + {}^{87}_{36}\text{Kr} + 4\,{}^{1}_{0}\text{n}$ **(1)** 2

(b) ($\Delta m = m_u - m\text{Ba} - m\text{Kr} - 4m_n$, electron masses balance)
$\Delta m = 236.04573 - 144.92694 - 86.91340 - 4 \times 1.00867$ **(1)**
$= 0.17071\text{u}$ **(1)**
$Q(= 0.17071 \times 931.3\text{MeV}) = 159(\text{MeV})$ **(1)** 3

[5]

9. (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]

10. (a) (i) proton number = 36 **(1)**
neutron number = 56 **(1)**

(ii) krypton **(1)** 3

(b) one-fifth efficiency so total output ($= 10 \times \frac{100}{20} = 50(\text{MW})$) **(1)**

energy in one day = 50× 10^6 × 24 × 3600(J) **(1)** (4.32 × 10^{12} J)

fission atoms per day = $\dfrac{4.32\times10^{12}}{3.2\times10^{-11}}$ =1.35 ×10^{23} **(1)** 3

[6]

11. (a) (i) $^{235}_{92}\text{U} + {}^{1}_{0}n \rightarrow {}^{98}_{38}\text{Sr} + {}^{135}_{54}\text{Xe} + 3\,{}^{1}_{0}n(+Q)$ **(1)**

(ii) three correct positions to within ±2 on x-axis **(1)** **(1)** (one mark if two correct)

(iii) *estimate of energy released*:
binding energy of U-235 nucleus = (235 × 7.5) = 1763(±15)(MeV) **(1)**
binding energy of Sr-98 = (98 × 8.6) = 843(±15)(MeV) **(1)**
binding energy of Xe-135 = (135 × 8.4) = 1134(±15)(MeV) **(1)**
binding energy released = 1134 + 843 – 1763 = 214MeV **(1)**
(±40MeV) max 6

(b) (i) 235g of U-235 releases 6 × 10^{23} × 214 × 1.6 × 10^{-13}J = 2.1 × 10^{13}(J) **(1)**
1.0 kg of uranium containing 3% U-235 contains 30g of U-235 **(1)**
energy from 1.0kg of uranium = $\dfrac{2.1\times10^{13}\times30}{235}$ = 2.6 × 10^{12}J [[1.6 × 10^{25} MeV]] **(1)**

(ii) *advantage*:
less mass of fuel used **(1)** because more energy per kilogram **(1)**
[alternative: less harm to environment **(1)** because does not generate greenhouse gases **(1)**
or any statement **(1)** argued **(1)**]
disadvantage:
hazardous waste **(1)** because fission products are radioactive **(1)**
[alternative: long term responsibility **(1)** because waste needs to be stored for many years **(1)**
or any statement **(1)** argued **(1)**] max 6

[12]

12. (a) 100y = 100 × 365 × 24 × 3600 (= 3.15 × 10^9 s) **(1)**
energy needed = 3.15 × 10^9 × 300 **(1)** × 10 **(1)** (= 9.46 × 10^{12} J)

number of disintegrations = $\dfrac{9.46\times10^{12}}{3.2\times10^{-11}}$ (= 2.96 × 10^{23}) **(1)**

number of moles needed = $\dfrac{2.96\times10^{23}}{6.02\times10^{23}}$ (= 0.49) **(1)**

molar mass = 0.239kg **(1)**
mass needed = 0.49 × 0.239 = 0.117 kg **(1)**

[7]