Mark schemes

Q1.

(a) The idea that the coolant extracts heat from the core and delivers it to the boiler/turbine via a heat exchanger. ✓

OWTTE
Condone the omission of the heat exchanger
Reject answers which suggest the coolant is turned directly into steam (to drive the turbine).

1

(b) Any two points from the following list ✓✓

- Ability to absorb neutrons (It should not absorb neutrons or should have small neutron absorption cross-section (this is function of moderator))
- Stability under conditions of high temperature and/or high levels of radiation
- (It should be) non-corrosive / unreactive / reactivity / inert
- (It should have a high) boiling point
- (It should have low) viscosity / ability to flow
- (It should have a high) specific heat capacity

Condone: (it should have a)

- *(low) melting point*
- *(high) thermal conductivity.*

Ignore references to latent heat / cost / flammability / availability / mass / density
Apply the list principle.

2

(c) Idea that control rods are inserted (further) / lowered into the core ✓

OWTTE
Condone insert (more) control rods for mp1
Condone for control named material from boron, cadmium, silver, indium.

Decrease the neutron flux in the reactor/core OR decreases the rate of fission reactions (and hence the power output) ✓

Condone decrease the number of neutrons / absorb neutrons for decrease neutron flux
Condone number of fissions for rate of fissions
*Do **not** allow reduce the speed of neutrons.*

2

[5]

Q2.

(a) Data covers 3/multiple (allow 2) orders of magnitude

Ignore reference to determination of gradient.

Condone large range of N.

OR

To allow trends across the range of data to be seen on a reasonably sized sheet of paper.

OR

The relationship (between *N* and number of throws) is expected to be exponential ✓

Condone radioactive decay is exponential.

Condone to make a straight line.

1

(b) Draw line of best fit from 0 to 19✓1

Correct readings from log scale i.e. one correct reading other than *N* = 10

OR

half-life of 2.5 - 2.7 (throws)

OR

Use of ruler on vertical axis to give a relative log value (values can then be used so (λ = gradient) ✓2

(Can be awarded from points or line, evidence can been seen on the graph)

Step to correct answer ✓3

(See additional guidance)

If there is no line of best fit or the data is taken from points not on the line, max 3

Alternative 1

number of throws taken for undecayed dice to half (or multiple of half)

or use of $\lambda = \frac{\ln 2}{t_{0.5}}$ *with their* $t_{0.5}$ ✓3

Alternative 2

number of throws for undecayed dice to reduce by a factor of e^{-1}

or use of $\lambda = \frac{1}{t_{e^{-1}}}$ *with their* t_{e-1} ✓3

Alternative 3

stating or implied in a calculation that

λ = -gradient ✓3

$$\lambda = -\frac{(\ln(N_2) - \ln(N_1))}{(t_2 - t_1)}$$

Alternative 4

use of $\lambda = \frac{\ln\left(\frac{N}{N_0}\right)}{-t}$ *with their readings* ✓3

Alternative 5

Use of $\lambda = \frac{\Delta N}{N}$ *do **not** allow over more than 1 throw* ✓3

λ = 0.25 to 0.28 (throw^{-1}) when rounded to 2SF correctly deduced from the figure. ✓4

relate *n* to λ, $n = \frac{1}{\lambda}(= 4)$ ✓5

*Do **not** credit* $\lambda = \frac{1}{4} = 0.25$ *for ✓4 but condone for ✓5*

MP5 can be awarded independently.
(when n is referred to it must be an integer)

5

(c) Suitable precaution ✓
Valid assessment of suitability based on the increased activity of the medical source ✓

Example answers

Mp1	Mp2
Keep distance of at least 2 m / keep a long distance	distance does reduce intensity / inverse square law but 2 m not enough / not be in the room
Condone don't point at people	Not being in the room
Put warning sign on the door	Install permanent warning signs
Store in lead-lined box	increase thickness of lead (condone concrete for mp2)
Put away when not using it	Exclude unnecessary people
Handle with **long** tongs / forceps / tweezers	need to keep larger distance so use eg robot arms or remote handling Do NOT allow longer tongs
Using a small portable lead screen while source is in use	need a larger / thicker screen

Ignore references to wearing gloves

2

(d) Ionising radiation damages cells/kills cells/causes cancer/causes mutations ✓

comment reflecting balance of risk and benefits when a filling is required e.g. risk of single scan is balanced by the benefits of treating the tooth decay✓

Example of second point:

Condone for mp2 the risk can be minimised by reducing or minimising the number of X-rays taken

ignore references to exposure to dentist.

"only when necessary" is insufficient for mp2.

Condone references to γ for X rays.

2

[10]

Q3.

(a) Any **two** from: ✓✓

- using electrons gives greater resolution (as the wavelength can be made very small)
- electrons can get closer to the nuclei (as there is no electrostatic repulsion)
- electrons have less recoil (as their mass is small compared to the nucleus)
- free electrons are easier to accelerate **OR** give energy to (as charge-to-mass ratio is higher)
- electrons are easier to produce
- scattering distributions are easier to interpret **OR** strong nuclear interaction is not involved
- using alpha particles only gives the distance of closest approach/upper limit to the radius.

OWTTE on each advantage

Allow reverse arguments

2

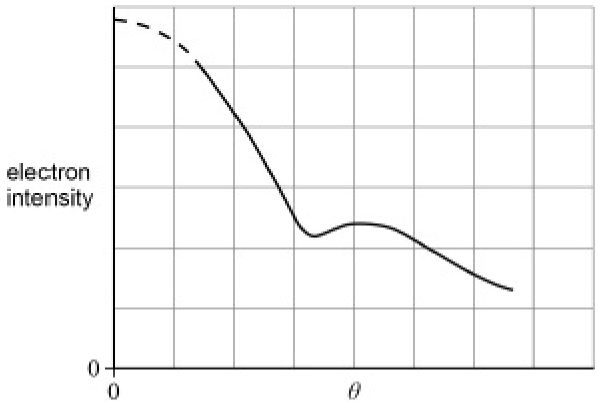
(b) A curved line showing an decrease in intensity with increase in θ.✓

There is a single **non-zero** minimum. ✓

Do not allow U-shaped graphs.

The initial part of the curve may be absent.

Award MAX 1 for a line that covers less than half the θ axis.



2

(c) Density (= mass÷volume) = $\frac{Am_{\text{nucleon}}}{\frac{4}{3}\pi R^3}$ ✓1

(substituting density = $\frac{Am_{\text{nucleon}}}{\frac{4}{3}\pi\left(R_0 A^{\frac{1}{3}}\right)^3}$)

✓1 Do not accept M unlabelled.

Accept m (ie lowercase) unlabelled.

Condone m_n (mass of neutron in Data sheet) for $m_{nucleon}$.

Accept only 1.67 ×10^{-27} (kg) for mass of nucleon (ie to 3 sf).

Density = $\frac{3m_{\text{nucleon}}}{4\pi(R_0)^3}$ (in which) all (terms are) constant **OR** the expression does not depend on *A* ✓2

Allow ecf to MP2 for any misrepresentation of m provided it is clear that it signifies mass of a single nucleon.

✓2 If the constants are identified the equation may be converted into a ratio. The equation may be rearranged to have R_0 as the subject with work to show that this is a constant when the density is constant.

2

(d) Any **one** of: ✓

The mass of the nucleus is not exactly $A \times m_{\text{nucleon}}$

(because this ignores the binding energy)

OR

The volume equation assumes that the nucleus is a perfect sphere (which is not true) OWTTE

OR

The density equation that uses the nuclear radius formula implies that the density is uniform within a nucleus which is not true. OWTTE

OR

Protons have a slightly different mass to a neutron

Do not accept "density of individual nucleons can be different from each other". It is not allowed as it does not occur in the working equation.

1

(e) $R_0 = \left(\frac{R}{A^{\frac{1}{3}}} = \frac{4.02\times10^{-15}}{(35)^{\frac{1}{3}}} \right) = 1.2(3)\times10^{-15}$(m) ✓1

Substitutes values into density equation ✓2

✓2 *e.g. Density=* $\left(\frac{\text{mass}}{\text{volume}} = \frac{Am}{\frac{4}{3}\pi R^3} \right) = \frac{35\times1.67\times10^{-27}}{\frac{4}{3}\pi(4.02\times10^{-15})^3}$

Density = 2.1×10^{17} (kg m^{-3}) ✓3

✓3 *Evidence of a calculation must be given to gain this mark*

Accept 2.15 but not 2.2

3

[10]

Q4.

(a) Heavy water

OR

Beryllium / Be

OR

(normal) Water ✓

Accept D_2O and H_2O

1

(b) Any **two** points from: ✓✓

- U-235/Uranium fuel will (be more likely to) absorb the neutron
- slow neutrons are less damaging **OR** cause less fatigue to the structure of the reactor/shielding/etc
- slow neutrons (spend longer within the fissionable material and) increase the chance of causing fission
- slowing neutrons transfers heat energy to the moderator (which can make heat easier to extract)

all points OWTTE

Condone the answer:

As an alternative to the first point Fission of U-236 is much more likely.

Condone the answer:

Absorption by U-238 is less likely.

2

(c) $$\frac{\text{final kinetic energy}}{\text{initial kinetic energy}} = \left(\frac{\frac{1}{2}m_N v^2}{\frac{1}{2}m_N u^2}\right) = \left(\frac{v}{u}\right)^2$$ $= 0.85^2 = 72\%$ ✓$_1$

(Hence) proportion of kinetic energy lost = 28% ✓$_2$

✓$_1$ can be for any of the terms shown equating to the kinetic energy ratio.

✓$_2$ can be an ecf but only for an arithmetic error.

2

(d) final kinetic energy = ($\frac{3}{2}$ kT =) 7.2 × 10^{-21} (J) ✓1

initial kinetic energy = (W = QV) = 1.6 × 10^{-13} (J) ✓2

OR

final kinetic energy = 0.045 (eV) ✓1

initial kinetic energy = 1.0 × 10^{6} (eV) ✓2

(Rearranging equation $y = \dfrac{\ln\left(\frac{E_0}{E_t}\right)}{b}$)

✓1+2 Both marks must come from the same alternative route and have consistent units (which may not be seen).

✓1 Initial kinetic energy =

$\frac{3}{2}$ *× 1.38 × 10^{-23} × 350 = 7.245 × 10^{-21} J*

$= \dfrac{7.245\times10^{-21}}{1.60\times10^{-13}}$ *= 0.045 eV*

✓2 Using the eV unit alternative the second mark cannot be given without an attempt at the first mark.

The 1.0 × 10^{6} eV can be seen in a later substitution provided eV is used throughout.

y = 23.(2) ✓3

✓3 $y = \dfrac{\ln\left(\frac{1.0\times10^{6}}{0.045}\right)}{0.73}$ = 23.2

Condone answer 24 provided it is given as an integer.

3

(e) Idea that the model/**Figure 3** shows that low nucleon number (and so low mass) gives a greater change/reduction in speed/KE (in a collision) ✓

Idea that fewer collisions needed (with a low mass number so moderator can be thinner) ✓

Condone the use of nuclear mass instead of mass number.

2

[10]

Q5.

(a) Energy required/work done to separate the nucleus ✓
into its individual nucleons/protons and neutrons ✓
OR
Energy given out when a nucleus is formed ✓
from its individual nucleons/protons and neutrons ✓

MP2 can only be awarded when there is some reference to energy via MP1.

Alternative words may be used instead of 'separate' but when used they must convey the correct idea.

If no other marks are awarded, condone the idea that "binding energy is how much greater the rest energy/mass of the constituent nucleons is than that of the nucleus" for one mark.

2

(b) Statement of binding energy/mass defect = (mass of nucleons) – (mass of nucleus) ✓1 (which may be seen from a full equation with data or implied from clear statements of what numbers represent)

Use of Data Booklet values leads to a correct answer of 338 (337.6)MeV. Allow 340 ± 10 RB TO CONFIRM.

Standing alone or contained in the binding energy equation show the total mass of nucleon constituents of $^{56}_{26}Fe$ ✓2

✓1 condone simple numerical errors such as powers of 10 if mark comes from substituted equation.

the correct binding energy converted to MeV = 490 ± 10 (MeV)
Or use of data booklet values and $E = mc^2$
= 340 ± 10 (MeV) ✓3

✓2 for giving data to at least 4 sig figs but calculations can use less.

Examples looked for are

$26 \times 1.673 \times 10^{-27} + 30 \times 1.675 \times 10^{-27}$ (= 9.375×10^{-26} kg)

OR

26 × 938.257 + 30 × 939.551 (= 52580 MeV)

OR

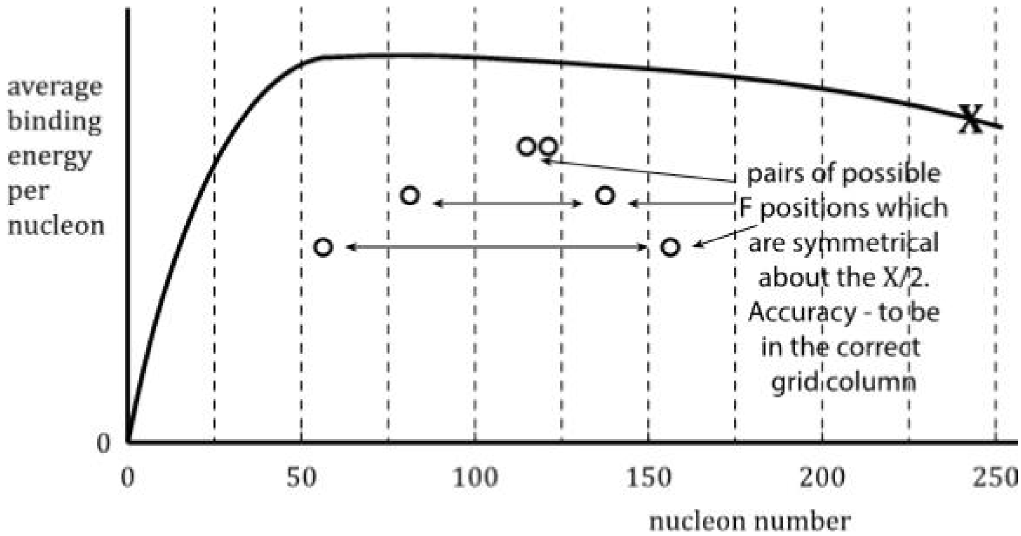
26 × 1.00728 + 30 × 1.00867 (= 56.44938 u)

✓3 no ecf. and mark is only available if the mass of a neutron and proton are different in part 2.

Might see
$(9.375 \times 10^{-26} - 9.288 \times 10^{-26}) \times 931.5 / 1.661 \times 10^{-27}$
$= 488 \pm 2\ MeV$
OR
$52580 - (9.288 \times 10^{-26} \times 931.5 / 1.661 \times 10^{-27})$
$= 492 \pm 2\ MeV$
OR
$\{56.44938 - 9.288 \times 10^{-26} / 1.661 \times 10^{-27}\} \times 931.5$
$= 495 \pm 2\ MeV$
OR
when the calculation involves the use of $E = mc^2$
$338 \pm 2\ MeV$
Note calculations may vary being dependant on how may sig figs are retained and how many individual stages of calculation are used.

3

(c) Both $\mathbf{F_1}$ and $\mathbf{F_2}$ to be to the right of the peak and marked on the graph or x-axis ✓
$\mathbf{F_1}$ and $\mathbf{F_2}$ to be in the correct grid regions t symmetrical about half the nucleon number corresponding to **X**. ✓[2]



*Note that an **F** position cannot have a nucleon lower than the peak. So the 3 examples shown indicate the possible range of an answer.*

The position of F_1 and F_2 are taken from the centre of the cross or blob drawn by the candidate. The range of each grid region includes the boundary dotted line.

✓1 If it is clear that nucleon numbers of F_1 and F_2 add to 240 give mark

The circles shown in the diagram show the horizontal positions – to gain the marks the circles have to be on the line or the x-axis.

2

(d) The starting point of the fission fragments is given the first mark ✓1

✓1 fission fragments have a high N/Z ratio

OR

fission fragments are positioned above/left of the line plot in Fig 2

too many neutrons is not given a mark – high N/Z ratio or neutron rich terms must be used

(normally the initial decay mode is) β^- ✓2

✓2 Mark may be given in isolation but the minus must be indicated

Moves closer to the stable region as:
a neutron changes to a proton OR
position (on the graph) moves down and to the right ✓3

The discussion of the decay and positioning of F_1 and F_2 must be the same. Any differences will be marked as a contradiction.

✓3 the mark could be seen on Fig 2

3

[10]