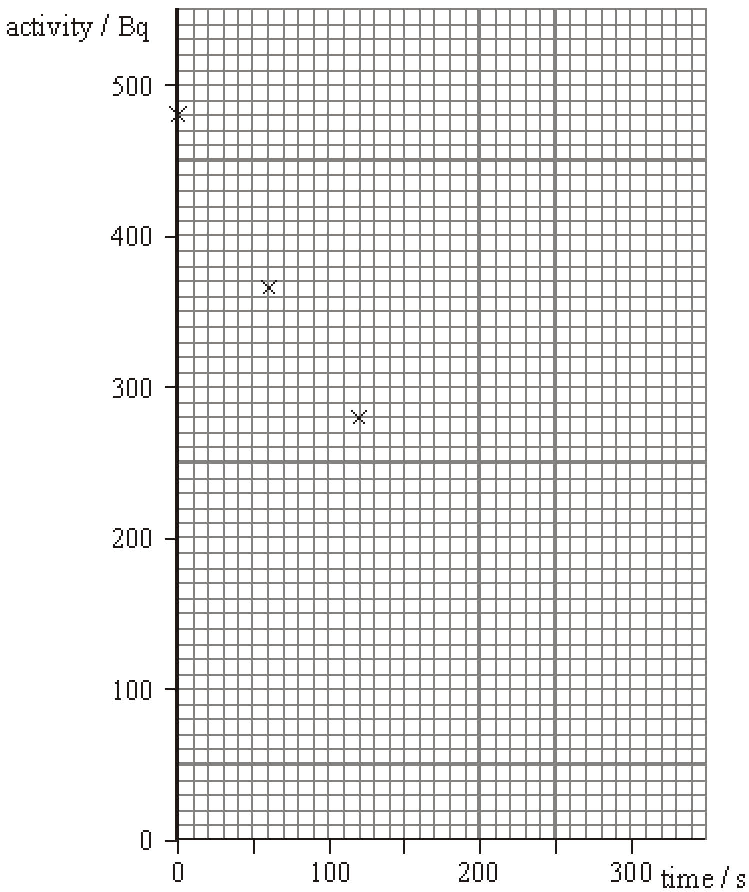
1 The table below gives the values for the activity of a radioactive isotope over a period of a few minutes.

time/s	0	60	120	180	240	300
activity/Bq	480	366	280	214	163	124

(a) Complete the graph below by plotting the remaining points and drawing an appropriate curve.



(3)

(b) Use the graph to determine the half-life of the isotope.

half-life ____________________

(3)

(c) Initially there were 1.1×10^5 atoms of the isotope present. Calculate the decay probability of the isotope.

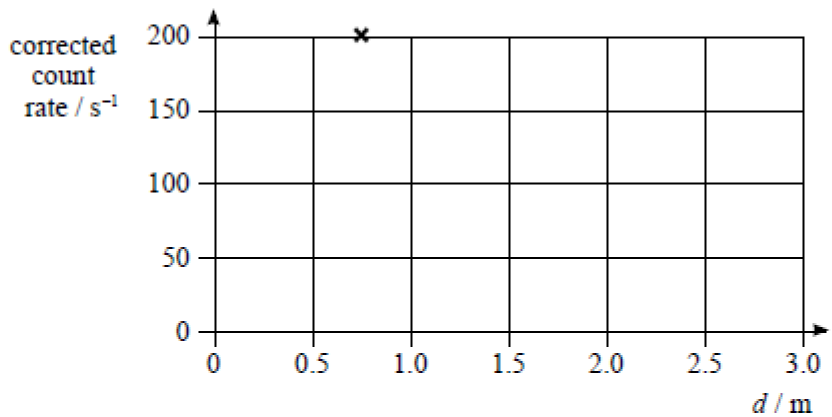
decay probability ____________________

(2)

(Total 8 marks)

2 A detector and counter are used to measure the count rate from a gamma source.

(a) Complete the graph to show how the corrected count rate will vary with the distance, d, between the source and the detector. One point has been plotted. To complete the graph accurately, you should perform a suitable calculation to determine the position of one other point on the graph.



(2)

(b) (i) State what is meant by *corrected* count rate.

____

____

(1)

(ii) State **one** means by which you would ensure that the measurement of count rate is accurate.

____

____

(1)

(Total 5 marks)

3 (a) Sketch a graph to show how the activity of a radioactive sample changes with time. You are not expected to give any numerical values.

(2)

(b) The activity of 5.0×10^{16} nuclei of a radioisotope is 1.1×10^{14} Bq. Calculate the probability of decay for a nucleus of the sample.

(3)

(Total 5 marks)

4 (a) Draw a labelled diagram to illustrate the main features of the apparatus used in the scattering experiment that provided evidence for the existence of a positively charged nucleus.

(3)

(b) Explain how the outcome of this experiment supports the model of atoms having a **small positively charged** nucleus.

____

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____

____

(2)

(Total 5 marks)

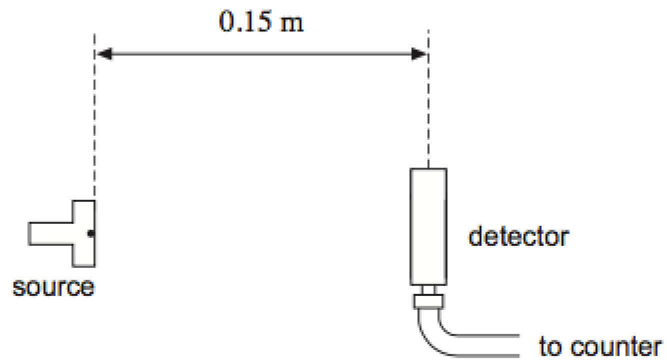
5 (a) The exposure of the general public to background radiation has changed substantially over the past 100 years.
State **one** source of radiation that has contributed to this change.

____

____

(1)

(b) A student measures background radiation using a detector and determines that background radiation has a mean count-rate of 40 counts per minute. She then places a γ ray source 0.15 m from the detector as shown below.



With this separation the average count per minute was 2050.

The student then moves the detector further from the γ ray source and records the count-rate again.

(i) Calculate the average count-rate she would expect to record when the source is placed 0.90 m from the detector.

count-rate = ____________________ min^{-1}

(3)

(ii) The average count per minute of 2050 was determined from a measurement over a period of 5 minutes. Explain why the student might choose to record for longer than 5 minutes when the separation is 0.90 m.

____

____

____

____

(1)

(iii) When the detector was moved to 0.90 m the count-rate was lower than that calculated in part **(b)(i)**. It is suggested that the source may also emit β particles.

Explain how this can be checked.

___

___

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___

___

(2)

(Total 7 marks)

6 (a) Explain what is meant by a **thermal** neutron.

___

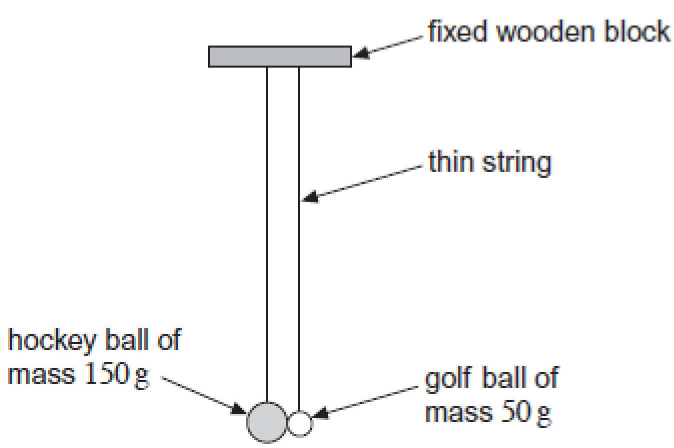
___

___

___

(2)

(b) A student sets up the arrangement, shown in the diagram below, to demonstrate the principle of moderation in a nuclear reactor.



A golf ball of mass 50 g is initially hanging vertically and just touching a hockey ball of mass 150 g. The golf ball is pulled up to the side and released. It has a speed of 1.3 m s^{-1} when it collides head-on with the hockey ball. After the collision the balls move in opposite directions with equal speeds of 0.65 m s^{-1}.

(i) Calculate the height above its initial position from which the golf ball is released. Assume that there is no air resistance.

height ____________________ m

(2)

(ii) Show that momentum is conserved in the collision and that the collision is perfectly elastic.

(4)

(iii) Calculate the percentage of the kinetic energy of the golf ball transferred to the hockey ball during the collision.

percentage transferred ____________________ %

(2)

(iv) Explain how this demonstration relates to the moderation process in a reactor and state **one** way in which the collisions in a reactor differ from the collision in the demonstration.

____

____

____

____

(2)

(v) Name the substance used as the moderator in a pressurised water reactor (PWR).

____

(1)

(Total 13 marks)

7 In stars, helium-3 and helium-4 are formed by the fusion of hydrogen nuclei. As the temperature rises, a helium-3 nucleus and a helium-4 nucleus can fuse to produce beryllium-7 with the release of energy in the form of gamma radiation.

The table below shows the masses of these nuclei.

Nucleus	**Mass / u**
Helium-3	3.01493
Helium-4	4.00151
Beryllium-7	7.01473

(a) (i) Calculate the energy released, in J, when a helium-3 nucleus fuses with a helium-4 nucleus.

energy released ____________________ J

(4)

(ii) Assume that in each interaction the energy is released as a single gamma-ray photon.

Calculate the wavelength of the gamma radiation.

wavelength ____________________ m

(3)

(b) For a helium-3 nucleus and a helium-4 nucleus to fuse they need to be separated by no more than 3.5×10^{-15} m.

(i) Calculate the minimum total kinetic energy of the nuclei required for them to reach a separation of 3.5×10^{-15} m.

total kinetic energy ____________________ J

(3)

(ii) Calculate the temperature at which two nuclei with the average kinetic energy for that temperature would be able to fuse.
Assume that the two nuclei have equal kinetic energy.

temperature ____________________ K

(3)

(c) Scientists continue to try to produce a viable fusion reactor to generate energy on Earth using reactors like the Joint European Torus (JET). The method requires a plasma that has to be raised to a suitable temperature for fusion to take place.

(i) State **two** nuclei that are most likely to be used to form the plasma of a fusion reactor.

1. ____

2. ____

(2)

(ii) State **one** method which can be used to raise the temperature of the plasma to a suitable temperature.

____

____

(1)

(Total 16 marks)

8 In a geothermal power station, water is pumped through pipes into an underground region of hot rocks. The thermal energy of the rocks heats the water and turns it to steam at high pressure. The steam then drives a turbine at the surface to produce electricity.

(a) Water at 21°C is pumped into the hot rocks and steam at 100°C is produced at a rate of 190 kg s^{-1}.

(i) Show that the energy per second transferred from the hot rocks to the power station in this process is at least 500 MW.

specific heat capacity of water = 4200 J kg^{-1} K^{-1}
specific latent heat of steam = 2.3×10^6 J kg^{-1}

___

___

___

___

___

(ii) The hot rocks are estimated to have a volume of 4.0×10^6 m^3. Estimate the fall of temperature of these rocks in one day if thermal energy is removed from them at the rate calculated in part (i) without any thermal energy gain from deeper underground.

specific heat capacity of the rocks = 850 J kg^{-1} K^{-1}
density of the rocks = 3200 kg m^{-3}

___

___

___

___

___

___

___

(7)

(b) Geothermal energy originates as energy released in the radioactive decay of the uranium isotope $^{238}_{92}$U deep inside the Earth. Each nucleus that decays releases 4.2 MeV.

Calculate the mass of $^{238}_{92}$U that would release energy at a rate of 500 MW.

half-life of $^{238}_{92}$U = 4.5×10^9 years

molar mass of $^{238}_{92}$U = 0.238 kg mol^{-1}

____

____

____

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____

____

____

(5)

(Total 12 marks)

9 The radius of a nucleus, R, is related to its nucleon number, A, by

$$R = r_0 A^{1/3}$$, where r_0 is a constant.

The table lists values of nuclear radius for various isotopes.

Element	$R/10^{-15}$ m	A	
carbon	2.66	12	
silicon	3.43	28	
iron	4.35	56	
tin	5.49	120	
lead	6.66	208	

(a) Use the data to plot a straight line graph and use it to estimate the value of r_0.

(8)

(b) Assuming that the mass of a nucleon is 1.67×10^{-27} kg, calculate the approximate density of nuclear matter, stating **one** assumption you have made.

(4)

(Total 12 marks)

10 A space probe contains a small fission reactor, fuelled by plutonium, which is designed to produce an average of 300 W of useful power for 100 years. If the overall efficiency of the reactor is 10%, calculate the minimum mass of plutonium required.

energy released by the fission of one nucleus of $^{239}_{94}\mathrm{Pu}$ = 3.2×10^{-11} J

the Avogadro constant = 6.0×10^{23} mol^{-1}

(Total 7 marks)

11 In the reaction shown, a proton and a deuterium nucleus, ${}^{2}_{1}\mathrm{H}$, fuse together to form a helium nucleus, ${}^{3}_{2}\mathrm{He}$

$${}^{1}_{1}\mathrm{p} + {}^{2}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + \mathrm{Q}$$

What is the value of Q, the energy released in this reaction?

mass of a proton = 1.00728 u

mass of a ${}^{2}_{1}\mathrm{H}$ nucleus = 2.01355 u

mass of a ${}^{3}_{2}\mathrm{He}$ nucleus = 3.01493 u

A 5.0 MeV

B 5.5 MeV

C 6.0 MeV

D 6.5 MeV

(Total 1 mark)

12 For a nuclear reactor in which the fission rate is constant, which one of the following statements is correct?

A There is a critical mass of fuel in the reactor.

B For every fission event, there is, on average, one further fission event.

C A single neutron is released in every fission event.

D No neutrons escape from the reactor.

(Total 1 mark)

13 The reaction shown below occurs when a proton and a deuterium nucleus, ${}^{2}_{1}H$, fuse to form a helium nucleus, ${}^{3}_{2}He$.

$${}^{1}_{1}P \quad + \quad {}^{2}_{1}H \longrightarrow {}^{3}_{2}He \quad + \quad Q$$

If the energy released, Q, is 5.49 MeV, what is the mass of the helium nucleus?

mass of ${}^{2}_{1}H$ nucleus = 2.01355 u
mass of proton = 1.00728 u
1u is equivalent to 931.3 Me V

A 0.00589 u

B 3.01494 u

C 3.02083 u

D 3.02323 u

(Total 1 mark)

14 Which line, **A** to **D**, in the table gives a combination of materials that is commonly used for moderating, controlling and shielding respectively in a nuclear reactor?

	moderating	**controlling**	**shielding**
A	graphite	carbon	lead
B	cadmium	carbon	concrete
C	cadmium	boron	lead
D	graphite	boron	concrete

(Total 1 mark)

15 Which one of the following statements is **not** true about the control rods used in a nuclear reactor?

A They must absorb neutrons.

B They must slow down neutrons to thermal speeds.

C They must retain their shape at high temperatures.

D The length of rod in the reactor must be variable.

(Total 1 mark)

Mark schemes

1 (a) all plots correct to ½ small square
deduct 1 mark for one incorrect, 2 marks for 2+ incorrect

B2

line appropriate

B1

3

(b) one correct determination from correct numbers

B1

154 ± 10 s

B1

two correct determinations and average

B1

3

(c) (use of $A = \lambda N$) $480 = \lambda \times 1.1 \times 10^{-5}$

[allow $\lambda = \ln 2/t_{½}$]

C1

4.4×10^{-3} s^{-1} [4.36]

A1

2

[8]

2 (a) curve drawn of approximately correct general shape

C1

curve shows inverse square law e.g.
includes the point (3.0 , 12.5) **or** (1.5, 50) **or** (2.0, 28.1)

A1

(2)

(b) (i) measure and deduct background count (rate)

B1

(1)

(ii) count for large periods (to ensure large N)
or repeat counts and average

B1

(1)

[4]

3 (a) curve that has intercept on activity axis at $t = 0$ (not 0,0) **B1**

tending to but not intersecting t axis;
exponential decay shape single line **B1** **(2)**

(b) $A = \lambda N$ **or** $A = -\lambda N$ **or**
substituted values $1.1 \times 10^{14} / 5.0 \times 10^{16}$ **C1**

2.2×10^{-3} **A1**

s^{-1} **or** / s **or** Bq or "each second" **not** % **B1** **(3)**

[5]

4 (a) source / scatterer / detector labelled **M1**

vacuum **A1**

(thin / gold / metal) foil **A1** **(3)**

(b) some backscattered (> 90°) => α's and nuclei both +ve **B1**

few deflections / most pass through ∴ nuclei small **B1** **(2)**

[5]

5 (a) nuclear fallout / testing / weapons / nuclear accidents / Chernobyl / nuclear waste / nuclear medicine / X-rays / specific uses of radioactive sources eg medical tracers CT scan etc. / cosmic rays as a result of air travel ✓
(Any source of radiation that an individual may encounter which would not have existed 100 years ago)

No mark for general answers such as 'medical' or Nuclear Power / nuclear plant.

If a list is given all must be correct but ignore generalisations such as medical or nuclear power.

1

(b) (i) I_{15CCR} = 2050 – 40 = 2010 ✓

Use of inverse square law eg $I_{CCR90} = I_{CCR15}\left(\frac{d_{15}}{d_{90}}\right)^2$ √ = 2010 × (0.15 / 0.90)^2 = 55.8

I_{90CR} = 55.8 + 40

I_{90CR} = 96 counts min^{-1} ✓

regardless of order:

1st mark subtraction of background in original data

2nd mark is for using inverse square function

3rd mark is for the answer

3

(ii) (reduce impact of) random error / decrease the (percentage) uncertainty / improve the statistics (because the percentage error is proportional to the inverse square-root of the count) ✓ (owtte)

The answer must be an uncertainty related statement and not increases reliability / accuracy or increased chance of a reading (although these ideas can accompany a correct answer) Ignore comparisons with the background count.

1

(iii) use (sensible) absorber between source and detector ✓ (sensible absorber means it must have a noticeable effect e.g. 1mm of metal / aluminium sheet / 5mm perspex but do not allow metal foil / paper sheets. Also its effect must not be so great that it reduces the gamma rays noticeably)

(These two marks are independent)

β shown by count rate falling when sheet of aluminium absorber is used ✓ Or (using the existing apparatus)

Compare the results (at various distances) in air with the expected inverse square law ✓

Below the range of beta law does not work but above range it does. ✓

2nd mark no mark given if count rate falls to zero as γ is still present

(magnetic deflection is not common but if seen.

Use of magnetic deflection ✓ correct deflection of beta from the beam ✓)

(If a cloud chamber is suggested. Observe the tracks in a cloud chamber ✓ beta tracks have varying lengths or they are curly / not straight ✓

(The value of the range of beta is not a marking point so accept 15 – 80 cm if a number is given)

2

[7]

6 (a) ANY 2 from

- Slow moving neutrons or low (kinetic) energy neutrons

B1

- (They are in) thermal equilibrium with the moderator / Are in thermal equilibrium with other material (at a temperature of about 300 K)

B1

- Have energies of order of 0.025 eV
- Have (range of) KE similar to that of a gas at 300 K or room temperature

2

(b) (i) Use of $mgh = ½ mv^2$ by substitution or rearranges to make h the subject

PE for use of equation of motion (constant acceleration)

C1

0.086(1) (m) or 0.086(2) (m)

A1

2

(ii) Correct equation for conservation of momentum

m_1u_1 $(+ m_2u_2)= m_1v_1 + m_2v_2$

or states momentum before = momentum after **or** $p_{before}= p_{after}$

B1

(Correct clear Manipulation =) 0.065 (+ 0) = − 0.0325 + 0.0975

or −0.065 (+ 0) = 0.0325 − 0.0975 must see signs

Condone non−SI here:
65 (+0) = − 32.5 + 97.5

B1

States initial kinetic energy = final kinetic energy **or**
States kinetic energy is conserved

Allow equivalent on RHS where masses are summed in one KE term

B1

(Correct clear Manipulation=) 0.04225 = 0.0105625 + 0.0316875

Or equivalent workings with numbers seen

and 0.04225 = 0.04225 / KE before = KE after

B1

4

(iii) (Percentage / fraction remaining after 1 collision =) ¼ = 25% **seen**

C1

OR

% remaining = $100 \times \frac{1}{2} m(1.3^2 - 0.65^2)/ \frac{1}{2} m1.3^2$

or hockey ball = 0.0317 **and** initial ke = 0.04225

or their KE_{hb} / 0.04225 or their KE_{hb} / their KE_T

75(%) range 75 to 76

A1

2

(iv) **Demonstrates:**
Slowing down / loss of KE of golf ball is like neutrons slowed down / Neutrons can lose KE by elastic collisions also

B1

Differs:
Collisions in a reactor are not always / rarely head-on
or
KE loss is variable
or
Collisions are not <u>always</u> elastic
or
Ratio of mass of neutron to mass of nucleus is usually much smaller in a reactor

B1

2

(v) Water

B1

1

[13]

7 (a) (i) (Mass change in u=) 1.71×10^{-3} (u)
or (mass Be−7) – (mass He−3) – (mass He−4) seen with numbers

C1

2.84×10^{-30} (kg)
or Converts their mass to kg

Alternative 2nd mark:
Allow conversion of 1.71×10^{-3} (u) to MeV by multiplying by 931 (=1.59 (MeV)) ***seen***

C1

Substitution in $E = mc^2$ *condone their mass <u>difference</u> in this sub but must have correct value for c^2 $(3\times10^8)^2$ or 9×10^{16}*

Alternative 3rd mark:
Allow their MeV converted to joules ($\times 1.6 \times 10^{-13}$) ***seen***

C1

2.55×10^{-13} (J) to 2.6×10^{-13} (J)

Alternative 4th mark:
Allow 2.5×10^{-13} (J) for this method

A1

4

(ii) Use of $E = hc / \lambda$ ***ecf***

C1

Correct substitution in rearranged equation with λ *subject* ***ecf***

C1

7.65×10^{-13} (m) to 7.8×10^{-13} (m) ecf

A1

3

(b) (i) Use of E_p formula:

C1

Correct charges for the nuclei **<u>and</u>** correct powers of 10

C1

$2.6(3) \times 10^{-13}$ J

A1

3

(ii) Uses K$E = 3 / 2\ kT$: ***or*** *halves* KE_T, $KE = 1.3 \times 10^{-13}$ *(J)* ***seen ecf***

C1

Correct substitution of data **and** makes T subject **ecf**
Or uses KE_T value **and** divides T by 2

C1

6.35×10^9 (K) or 6.4×10^9 (K) or 6.28×10^9(K) or 6.3×10^9 (K) **ecf**

A1

3

(c) (i) Deuteron / deuterium / hydrogen−2

B1

Triton / tritium / hydrogen−3

B1

2

(ii) Electrical heating / electrical discharge / inducing a current in plasma / use of e−m radiation / using radio waves (causing charged particles to resonate)

B1

1

[16]

8 (a) (i) heat water to 100 °C, energy (= 190 × 4200 × 79) = 63 (MJ) **(1)**
vapourise water, energy
(=190 × 2.3 × 10^6) = 440(MJ) **(1)**
(437MJ)

energy transferred (per sec) = (437 + 63) MJ **(1)**
(= 500 MJ)

(ii) mass of rocks (= 4.0 × 10^6 × 3200)

= 1.3 × 10^{10}(kg) **(1)**

(1.28 × 10^{10})

temperature fall of ΔT in one day, energy removed
(= 1.28 ×10^{10} × 850 × ΔT) = 1.1 × 10^{13} ΔT **(1)**

(1.09 x 10^{13} AT)
(allow C.E. for value of mass of rocks)

energy transfer in one day (= 500 × 10^6 × 3600 × 24)
= 4.3 × 10^{13} (J) **(1)**

in one day $\Delta T\left(=\frac{4.3\times10^{13}}{1.1\times10^{13}}\right)=3.9(1)$ K **(1)**

7

(b) number of nuclei in 1 kg of ^{238}U $= \left(\dfrac{6.02 \times 10^{23}}{0.238}\right) = 2.5(3) \times 10^{24}$ **(1)**

activity of lkg of ^{238}U $= \dfrac{\ln 2}{T_{1/2}} \times 2.53 \times 10^{24}$ **(1)**

$\left(= \dfrac{\ln 2}{4.5 \times 10^{9} \times 3.1 \times 10^{7}} \times 2.53 \times 10^{24}\right) = 1.2(6) \times 10^{7} (s^{-1})$ **(1)**

energy released per sec per kg of ^{238}U

$= 1.2(6) \times 10^{7} \times 4.2 \times 1.6 \times 10^{-13}$(J) **(1)**

$(8.47 \times 10^{-6}$(J))

mass of ^{238}Uneeded $= \dfrac{500 \times 10^{6}}{8.47 \times 10^{-6}} = 5.9(0) \times 10^{13}$kg **(1)**

5

[12]

9 (a) $(R^3 = R_0^3 A)$

plot R^3 against A with axes labelled **(1)**
units on axes **(1)**
scales chosen to use more than 50% of page **(1)**

element	$R/10^{-15}$ m	A	$R^3/10^{-45}$ m^3
carbon	2.66	12	18.8
silicon	3.43	28	40.4
iron	4.35	56	82.3
tin	5.49	120	165.5
lead	6.66	208	295

calculate data for table **(1)**
plot data **(1)(1)** lose one mark for each error
calculation of gradient

e.g. gradient = $\frac{1}{3}$ **(1)** (= 1.41×10^{-45} m^3)

r_0 (= gradient)$^{1/3}$ **(1)**

$= (1.41 \times 10^{-45})^{1/3} = 1.1(2) \times 10^{-15}$ m **(1)** *alternative:*

plot R against $A^{1/3}$ with axes labelled **(1)**
units on axes **(1)**
scales chosen to use more than 50% of page **(1)**

element	$R/10^{-15}$ m	A	$A^{1/3}$
carbon	2.66	12	2.29
silicon	3.43	28	3.04
iron	4.35	56	3.83
tin	5.49	120	4.93
lead	6.66	208	5.93

calculate data for table **(1)**
plot data **(1)(1)** lose one mark for each error
calculation of gradient

e.g. gradient = $\frac{6.72 \times 10^{-15}}{6.0}$ **(1)** = $(1.1(2) \times 10^{-45}\ m^3)$

r_0 = gradient **(1)**
= $1.1(2) \times 10^{-15}$ m **(1)**
[or plot ln$R$ against ln$A$...]

(max 8)

(b) assuming the nucleus is spherical
ignoring the gaps between nucleons
assuming all nuclei have same density
assuming total mass is equal to mass of constituent nucleus
any one assumption **(1)**

$M = \frac{4}{3}\pi R^3 \rho$ **(1)**

$\left(\therefore M = \frac{4}{3}\pi R_0^3 a\rho\right)$

$\left(\therefore \rho = \frac{3m}{4\pi R_0^3}\right) = \frac{3 \times 1.67 \times 10^{-27}}{4\pi \times (1.12 \times 10^{-15})^3}$ **(1)**

= 2.8×10^{17} kg m^{-3} **(1)**

(4)

[12]

10 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 = $\frac{9.46 \times 10^{12}}{3.2 \times 10^{-11}}$ (= 2.96×10^{23}) **(1)**

number of moles needed = $\frac{2.96 \times 10^{23}}{6.02 \times 10^{23}}$ (= 0.49) **(1)**

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

[7]

11 B

[1]

12 B

[1]

13 B

[1]

14 D

[1]

15 B

[1]

Examiner reports

1 (a) Graph drawing was poor in this question. Data points were misplaced, curves were inappropriate or, more commonly, simply careless with kinks and double lines that avoided being truly best-fit.

(b) Many candidates failed to obtain full credit because they only made one determination of the half-life. Two or more with a clear calculation of the mean value were required for full credit. Most values were within the tolerance of ± 10 s. A common error (treated as a lost determination) was to assume that the t = 0 s count-rate was 500 s^{-1} not the 480 that was both clearly stated in the table and also shown on the graph.

(c) Although most could calculate the decay constant with some facility, a correct unit (indeed, any unit at all) was rare. Candidates evidently do not recognise the physics here with any clarity even though they can jump through the arithmetic hoop.

3 (a) This was well answered by the majority of candidates. Weaker candidates were penalised for showing no activity value at zero time or the curve intersecting the time axis or curving upwards.

(b) Nearly all candidates were able to write down the equation for the probability of decay but many confused the activity with the number of nuclei and calculated the reciprocal of the correct answer. Few candidates gave the correct unit for probability of decay (s^{-1}) and many quoted their answer as a percentage.

4 (a) Virtually no candidates gained full marks for a description of the alpha scattering experiment. Most candidates seemed unaware of the need for the chamber to be evacuated and many failed to describe the scatterer as being a foil. Many candidates simple regurgitated the well-love diagram of alpha particles approaching a nucleus at different alignments.

(b) The description of the analysis of the alpha scattering results was often incomplete and not helped when, in many cases, candidates referred to the bombarding particles as *protons, neutrons*, electrons or as having a *negative charge*. This last version left candidates trying to describe the repulsion of negative particles by positive nuclei – inevitable doomed from the outset!

5 (a) Acceptable answers were seen regularly and showed that many students understood the nature of the question about how modern military, industrial and medical practices and also the increased use of air travel by the public have led to an average increase in exposure to background radiation. A significant number of students failed to gain the mark by being too brief. They gave answers like, 'medicine' or 'flying'. With a few more words these could have been converted into scoring answers. There were also some students that simply quoted a source of background radiation such as 'cosmic rays' and 'radon gas'.

(b) (i) A majority of students could use the inverse relationship correctly. The main problem came in dealing with the background. About half subtracted the background from the 2050 but following the calculation very few of those added the background to obtain the expected reading.

(ii) A large number of students failed to refer to the randomness of the count-rate in any respect. They instead focused on the number of counts being reduced because of the distance from the source. Alternatively some tried to express the idea that the background had more effect at larger distances. The idea that a larger count helps reduce the statistical percentage uncertainty inherent in smaller readings proved too much for the vast majority of students.

(iii) A range of approaches were accounted for within the mark scheme and a range of responses were seen. The most direct, common and successful approach was the use of a sensible absorber placed between the source and detector. There were a number of students who did not know the approximate thickness of a material that would absorb most of the beta particles. The most common alternative approach was to consider the count- rate fall with distance. Using this approach a majority did not compare the count-rate with the expected inverse square function in and out of the range of beta particles. Most simply thought the count-rate would suddenly fall as the detector moved out of range of the beta particles. While some non-standard approaches could gain full marks, such as the use of magnetic/electric fields and cloud chambers, students were expected to say exactly how the nature of the suspected beta radiation would be revealed which proved too much for the majority who took these routes.

6 (a) The majority of candidates were able to score at least 1 mark in this explanation. Only the best candidates were producing quality answers that gained full credit. Many candidates were unfamiliar with the term and offered answers suggesting that these were neutrons that were produced due to heat.

(b) (i) Surprisingly, only 50% of candidates gained full marks here. A significant proportion of candidates attempted to use the equations of motion and consequently were awarded no marks. Candidates must be aware that these equations only apply to situations were acceleration is constant. Some candidates lost marks by rounding the final answer to 1 significant figure. Many lower achieving candidates failed to correctly rearrange $\frac{1}{2}\ m\,v^2 = m\,g\,h$, dropping the factor of $\frac{1}{2}$ was a common mistake.

(ii) This was another “Show that...” style question and again it posed problems for many candidates with just over 20% of candidates gaining 3 or 4 marks. A very large proportion of candidates did not attempt the elastic collision part of the question and limited themselves to 2 marks. Many of these candidates had difficulty with the vector nature of momentum and their signs were often inconsistent or incorrect. Grade A candidates typically presented well laid out workings that were easy-to-follow, convincing.

(iii) Most candidates achieved both marks here. However, some had casual use of powers of 10 errors on their KE calculations due to keeping the mass in grams. This of course cancelled due to the ratio aspect of the question. A number of candidates thought that 25% was the answer; this was due to not reading the question carefully enough.

(iv) Most candidates gained 1 mark for stating how the demonstration related to the moderation process. Only a small number of candidates were able to develop their answer by providing information that was more than the converse of the information provided, thus demonstrating a sound knowledge of the moderation process.

(v) Just under 80% of candidates knew that water was the moderator in a PWR. A few candidates incorrectly thought that the moderator was heavy water.

7 (a) (i) These calculations were well known and competently completed by the vast majority of candidates. Where mistakes occurred these were more common in part (i) with significant number of candidates failing to convert their mass to kg or forgetting to square the speed of light in $E = m\,c^2$.

(ii) As above.

(b) (i) These calculations proved to be good discriminators with only the better candidates able to achieve all 6 marks. There were a significant number of non-attempts, 10% for this part.

(ii) There were a significant number of non-attempts, 23% for this part. There were lots of mistakes in the formula for potential energy with r^2 instead of r. Candidates were unsure about how to proceed in this part with many neglecting to divide the total kinetic energy by 2.

(c) (i) Just over 30% of candidates could recall that H-2 and H-3 were most likely. The most common answer seen was hydrogen and helium.

(ii) Candidates enjoyed more success in this part with over 50% able to state a method used to heat the plasma in the JET reactor.

8 The calculation, in part (a) (i), of the energy needed to heat the water and to turn it to steam at 100°C was usually done correctly. Some failed by choosing an incorrect temperature change. In part (ii), many candidates obtained full marks although some correctly worked out the temperature change per second, but did not proceed to calculate the temperature change in one day. A small minority of candidates used an incorrect density formula or an incorrect value of the specific heat capacity.

In part (b) most candidates knew how to convert MeV into joules correctly and used the given mass number correctly. They also knew how to calculate the total activity of the rocks from the energy released per second and the energy released per decay. Many of these candidates correctly used their activity value and the decay constant, worked out from the half-life, to calculate the total number of atoms and their mass. Some lost a mark in their calculation of the decay constant as a result of not converting the half-life into seconds. A significant number of candidates considered their answer for the total activity to be the total number of atoms and consequently lost two marks because they failed to use the total activity and the decay constant to calculate the total number of atoms.

9 Almost all the candidates realised how to find r_0 by graphical techniques. The most common approach was to plot R against $A^{\frac{1}{3}}$ As expected, the weaker candidates misused of powers of 10 and surprisingly, gave incorrect units for r_0.

Part (b) was generally done well, but many mistakes were seen in using standard form calculations leading to ludicrous values of density. Some candidates did not know the equation for density and “density = mass × volume” was not an uncommon statement.

10 Even weaker candidates often scored high marks in this question although, conversely, if a question was omitted then it was usually this one. Mistakes in calculating the number of seconds in a year were common, with much unnecessary concern about leap years and some uncertainty about the number of weeks or days in a year. Commonly, the number of moles was calculated correctly, although occasionally it was equated to the mass in kg, and most candidates could then convert to the mass in g or kg. Some candidates dropped a mark for forgetting the 10% efficiency, and those who gave no indication of their reasoning were penalised one mark, although they often penalised themselves by losing the thread. Again, candidates who got ridiculous answers, often by misplacing the Avogadro constant, rarely bothered to check.