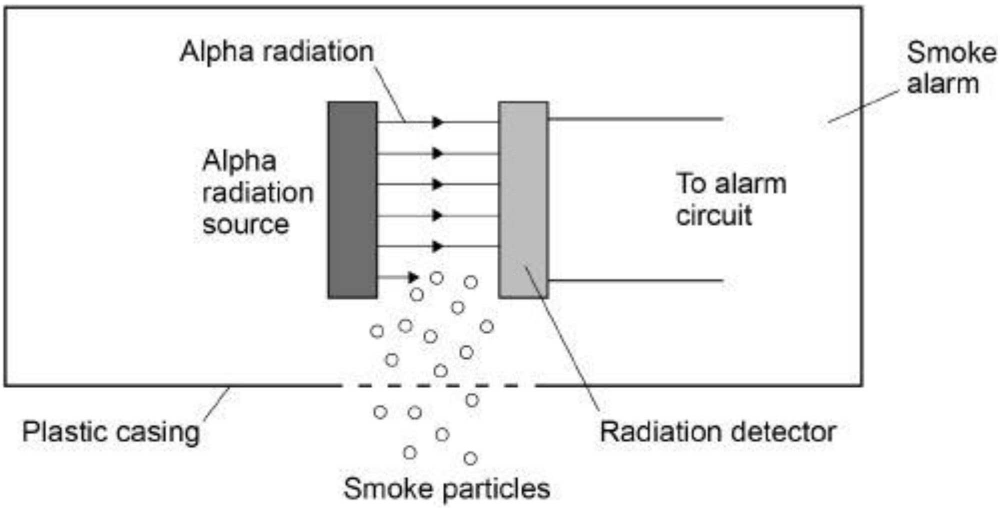
Q1.

Smoke alarms contain an alpha radiation source and a radiation detector.

Figure 1 shows part of the inside of a smoke alarm.

Figure 1



(a) The smoke alarm stays off while alpha radiation reaches the detector.

Why does the alarm switch on when smoke particles enter the plastic casing?

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(1)

(b) Why is it safe to use a source of alpha radiation in a house?

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(1)

(c) The smoke alarm would not work with a radiation source that emits beta or gamma radiation.

Explain why.

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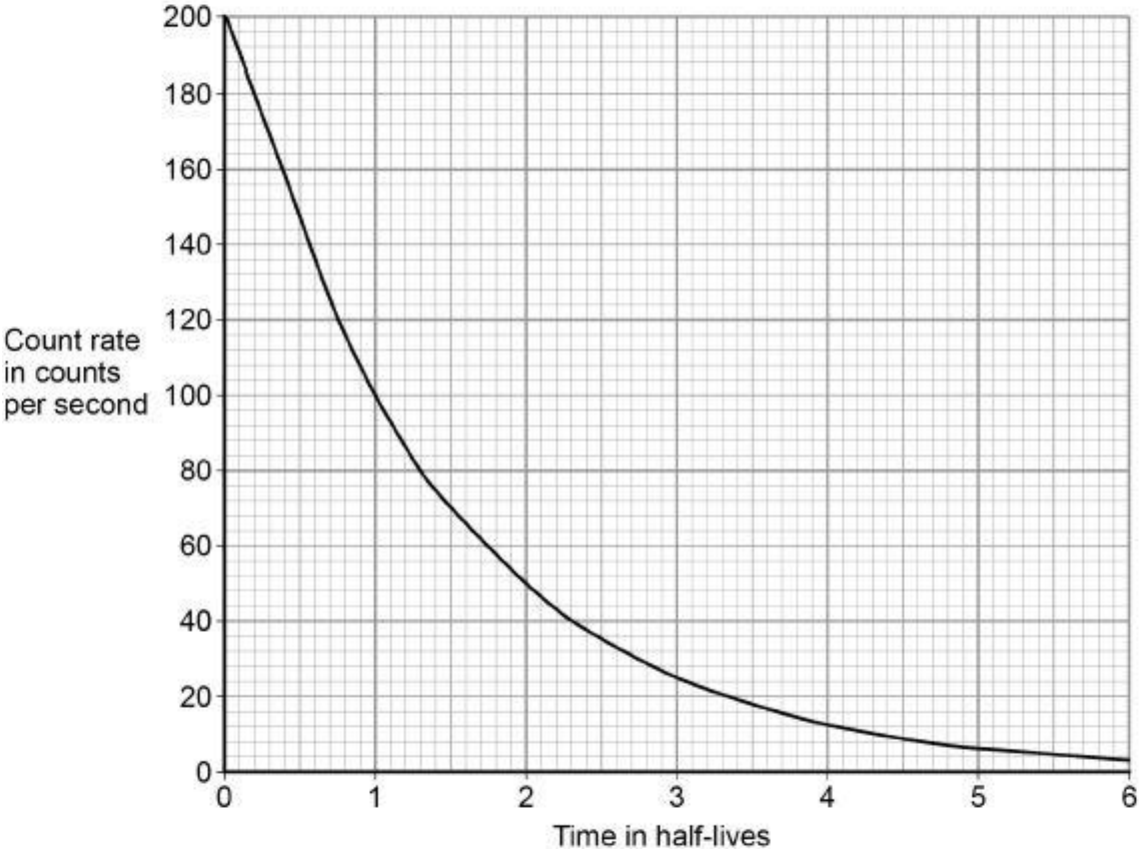
(2)

(d) **Figure 2** shows how the count rate detected from the radiation source in the smoke alarm changes with time.

Figure 2



The smoke alarm switches on when the count rate falls to 80 counts per second.

Explain why the radiation source inside the smoke alarm should have a long half-life.

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(2)

(e) **Figure 3** shows a patient who has been injected with a radioactive source for medical diagnosis.

Figure 3

Explain the ideal properties of a radioactive source for use in medical diagnosis.

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(4)

(Total 10 marks)

Q2.

Nuclear fission and nuclear fusion are two processes that release energy.

(a) The following nuclear equation represents the fission of uranium-235 (U-235).

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{236}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + \text{energy}$$

Chemical symbols:

- Ba = barium

- Kr = krypton
- $^{1}_{0}n$ = neutron

Describe the process of nuclear fission.

Use the information in the equation.

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(4)

(b) Explain what happens in the process of nuclear fusion.

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(3)

(c) Fission reactors are used in nuclear power stations.

Engineers are developing fusion reactors for use in power stations.

Fusion uses isotopes of hydrogen called deuterium and tritium.

- Deuterium is naturally occurring and can be easily extracted from seawater.
- Tritium can be produced from lithium. Lithium is also found in seawater.

The table shows the energy released from 1 kg of fusion fuel and from 1 kg of fission fuel.

Type of fuel	**Energy released from 1 kg of fuel in joules**
Fusion	3.4×10^{14}

Fission	8.8×10^{13}

Suggest **two** advantages of the fuel used in a fusion reactor compared with the fuel used in a fission reactor.

1. ____

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2. ____

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(2)

(Total 9 marks)

Q3.

Atoms are different sizes.

One of the heaviest naturally occurring stable elements is lead.

Two of its isotopes are lead-206 ($^{206}_{82}Pb$) and lead-208 ($^{208}_{82}Pb$).

(a) (i) What is meant by 'isotopes'?

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(2)

(ii) How many protons are in the nucleus of a $^{206}_{82}Pb$ atom?

____

(1)

(iii) How many neutrons are in the nucleus of a $^{206}_{82}Pb$ atom?

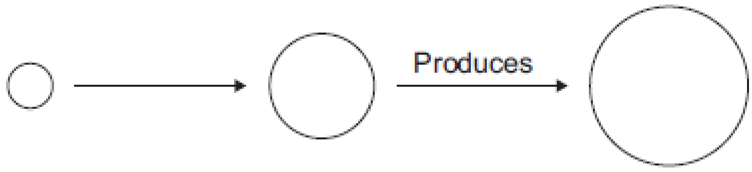
____

(1)

(b) A nucleus can be accelerated in a particle accelerator and directed at a large nucleus. This produces a heavy nucleus that will decay after a short time.

This is shown in **Figure 1**.

Figure 1



(i) In 1984, nuclei of iron (Fe) were directed at nuclei of lead (Pb). This produced nuclei of hassium (Hs).

Complete the equation for this reaction by writing numbers in the empty boxes.

$$^{58}_{\square}\mathrm{Fe} + ^{\square}_{\square}\mathrm{Pb} = ^{265}_{108}\mathrm{Hs} + ^{1}_{0}\mathrm{X}$$

(3)

(ii) Use the correct answer from the box to complete the sentence.

an electron	**a proton**	**a neutron**

The particle **X** in part (b)(i) is ________________________________ .

(1)

(iii) After acceleration the iron nuclei travel at a steady speed of one-tenth of the speed of light.

The speed of light is 3.00×10^8 m/s.

Calculate the time taken for the iron nuclei to travel a distance of 12 000 m.

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Time taken = ____________________ s

(2)

(iv) Linear accelerators, in which particles are accelerated in a straight line, are **not** used for these experiments. Circular particle accelerators are used.

Suggest why.

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(3)

(c) Hassium-265 ($^{265}_{108}Hs$) decays by alpha emission with a half-life of 0.002 seconds.

(i) What is meant by 'half-life'?

Tick (✓) **two** boxes.

	Tick (✓)
The average time for the number of nuclei to halve	
The time for count rate to be equal to background count	
The time for background count to halve	
The time for count rate to halve	

(2)

(ii) Complete the equation for the decay of Hs-265 by writing numbers in the empty boxes.

$$^{265}_{108}Hs = ^{\square}_{\square}Sg + ^{\square}_{\square}\alpha$$

(2)

(d) The table below shows how the atomic radius of some atoms varies with atomic number.

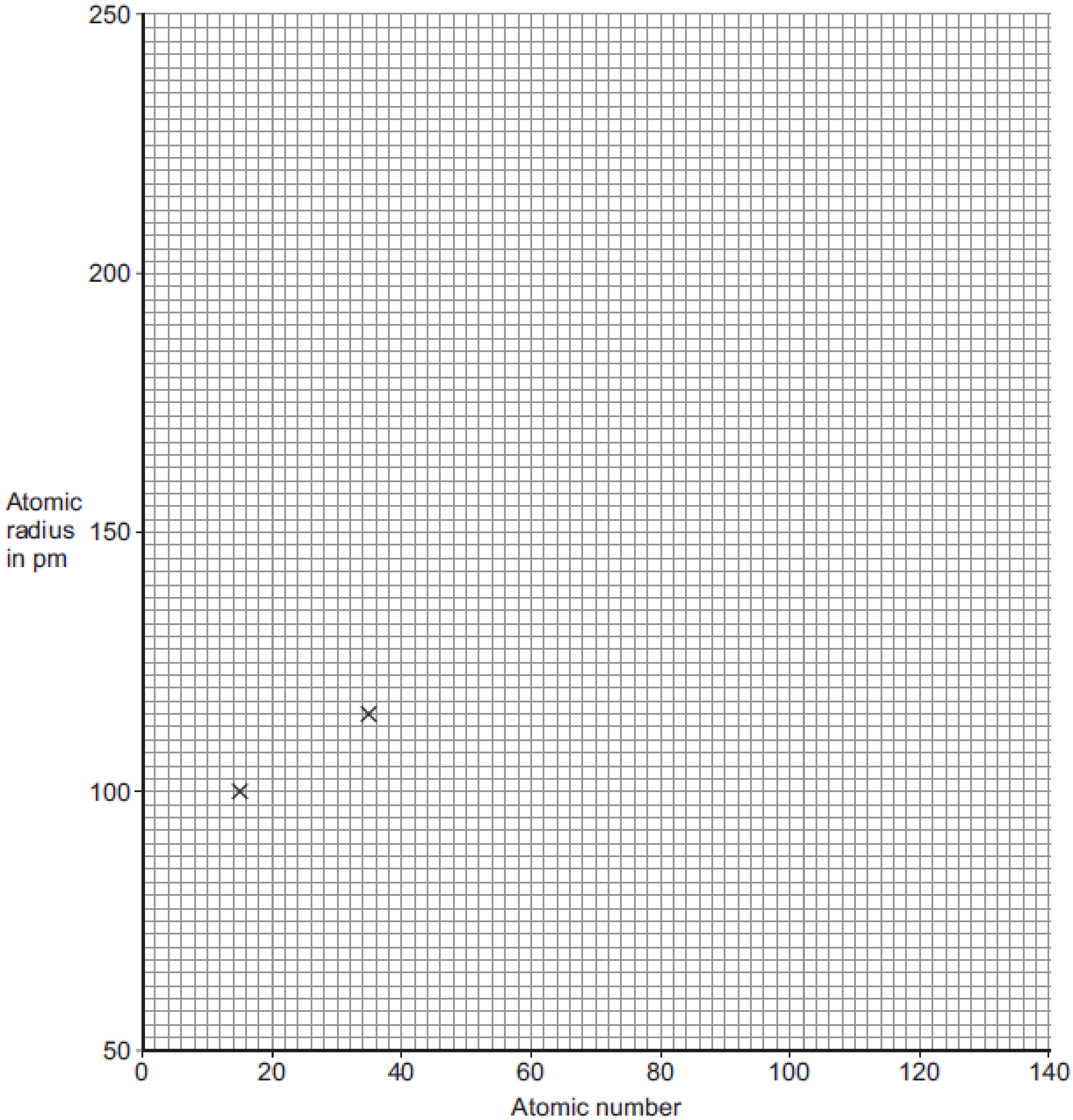
Atomic number	**Atomic radius in picometres (pm)**
15	100
35	115
50	130
70	150
95	170

1 pm = 10^{-12} m

(i) On **Figure 2**, use the data from the table above to plot a graph of atomic radius against atomic number and draw a line of best fit.

Two points have been plotted for you.

Figure 2



(2)

(ii) Scientists believe that the element with atomic number 126 can be produced and that it will be stable.

Use your graph in **Figure 2** to predict the atomic radius of an atom with atomic number 126.

Atomic radius = ____________________ pm

(1)

(Total 20 marks)

Q4.

(a) Nuclear fuels and the wind are two of the energy sources used to generate electricity in the UK.

Explain the advantages of using energy from nuclear fuels to generate electricity rather than using energy from the wind.

Include in your answer a brief description of the process used to generate electricity from nuclear fuels.

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(4)

(b) In the UK, most electricity is generated in power stations that emit carbon dioxide into the atmosphere. The impact of these power stations on the environment could be reduced by the increased use of 'carbon capture' technology.

Describe how 'carbon capture' would prevent the build-up of carbon dioxide in the atmosphere.

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(2)

(Total 6 marks)

Q5.

In 2011 an earthquake caused severe damage to a nuclear power station in Japan.

The damage led to the release of large amounts of radioactive iodine-131 $(^{131}_{53}I)$ into the atmosphere.

(a) The table gives some information about an atom of iodine-131 $(^{131}_{53}I)$.

Complete the table.

mass number	131
number of protons	53
number of neutrons	

(1)

(b) Complete the sentence.

The number of protons in an atom is called the proton number or

the ________________ number.

(1)

(c) An atom of iodine-131 decays into an atom of xenon (Xe) by emitting a beta particle.

(i) The decay of iodine-131 can be represented by the equation below.

Complete the equation by writing the correct number in each of the **two** boxes.

$$^{131}_{53}\text{I} \longrightarrow {}^{\square}_{\square}\text{Xe} + \text{beta particle}$$

(2)

(ii) A sample of rainwater contaminated with iodine-131 gives a count rate of 1200 counts per second.

Calculate how many days it will take for the count rate from the sample of rainwater to fall to 75 counts per second.

Half-life of iodine-131 = 8 days

Show clearly how you work out your answer.

____

____

________________ days

(2)

(iii) If people drink water contaminated with iodine-131, the iodine-131 builds up in the thyroid gland. This continues until the thyroid is saturated with iodine-131 and cannot absorb any more. The radiation emitted from the iodine-131 could cause cancer of the thyroid.

In Japan, people likely to be drinking water contaminated with iodine-131 were advised to take tablets containing a non-radioactive isotope of iodine.

Suggest why this advice was given.

(2)

(Total 8 marks)

Mark schemes

Q1.

(a) smoke absorbs / stops alpha radiation

allow alpha particles for alpha radiation

alpha radiation does not reach the detector is insufficient

1

(b) alpha radiation is not very penetrating

allow alpha particles for alpha radiation

or

alpha radiation does not penetrate skin

allow alpha radiation does not travel very far (in air)

1

(c) beta and gamma radiation will penetrate smoke

allow beta and gamma radiation will not be stopped by smoke

1

no change (in the count rate) would be detected

allow the change detected (in the count rate) would be too small

1

(d) (a long half-life means) the count rate is (approximately) constant

allow activity of source is (approximately) constant

or

a short half-life means the count rate decreases quickly

1

until 1.3 half-lives the count rate is above 80 per second

allow after 1.3 half-lives the count rate is below 80 per second

or

until 1.3 half-lives the count rate is above the threshold for the smoke alarm to be activated

or

after 1.3 half-lives the smoke alarm will be activated all the time

so don't have to replace source or smoke detector is insufficient

1

(e) **Level 2:** Relevant points (reasons / causes) are identified, given in detail and logically linked to form a clear account.

3−4

Level 1: Relevant points (reasons / causes) are identified, and there are attempts at logically linking. The resulting account is not fully clear.

1−2

No relevant content

0

Indicative content

- short half-life or half-life of a few hours
- (short half-life means) less damage to cells / tissues / organs / body
- low ionising power
- (low ionising power means) less damage to cells / tissues / organs / body
- highly penetrating
- (highly penetrating means) it can be detected outside the body
- emits gamma radiation

[10]

Q2.

(a) a uranium <u>nucleus</u>

1

absorbs a neutron

1

(uranium-236 nucleus) splits into two smaller nuclei
or
Kr and Ba nuclei
or
krypton and barium nuclei

1

and releases 3 neutrons and energy

1

(b) light nuclei

1

join to form a heavier nucleus

allow hydrogen nuclei for light nuclei

allow helium nucleus for heavier nucleus

1

(some of the) mass of the nuclei is converted to energy

allow particles for nuclei

1

(c) any **two** from:

- easy to obtain / extract
- available in (very) large amounts
- releases more energy (per kg)

*do **not** accept figures **only***

naturally occurring is insufficient

seawater is renewable is insufficient

less cost is insufficient

allow produces little / no radioactive waste

2

[9]

Q3.

(a) (i) (atoms with the) same number of protons

allow same atomic number
***or** same proton number*

1

(atoms with) different number of neutrons
allow different mass number

1

(ii) 82

1

(iii) 124

1

(b) (i) $^{58}_{26}Fe + ^{208}_{82}Pb$

***1** mark for each correct box*

3

(ii) (a) neutron

1

(iii) 4.0×10^{-4} (s)
or
0.0004
$3.00 \times 10^{8} \times 0.1 = 12\,000 / t$
*gains **1** mark*

2

(iv) particles need to travel a large distance

1

equipment would have to be very long

1

with circular paths long distances can be accommodated in a smaller space

1

(c) (i) the average time for the number of nuclei to halve

1

the time for count rate to halve

1

(ii) $^{261}_{106}Sg + ^{4}_{2}\alpha$

***1** mark if top boxes total = 265*
***and** bottom boxes total = 108*
***1** mark for 4 and 2 for alpha*

2

(d) (i) 3 plotted points
± ½ small square

1

best line through points

1

(ii) 190−205 (pm)
or correct from student's line

1

[20]

Q4.

(a) *answers must be in terms of nuclear fuels*

concentrated source of energy
idea of a small mass of fuel able to generate a lot of electricity

1

that is able to generate continuously
accept it is reliable
***or** can control / increase / decrease electricity generation*
idea of available all of the time / not dependent on the weather
ignore reference to pollutant gases

1

the energy from (nuclear) <u>fission</u>

1

is used to heat water to steam to turn turbine linked to a generator

1

(b) <u>carbon dioxide</u> is not released (into the atmosphere)

1

but is (caught and) stored (in huge natural containers)

1

[6]

Q5.

(a) 78

1

(b) atomic

1

(c) (i) 131

correct order only

1

54

1

(ii) 32 (days)

*allow **1** mark for showing 4 half-lives provided no subsequent step*

2

(iii) limits amount of iodine-131 / radioactive iodine that can be absorbed

accept increases level of non-radioactive iodine in thyroid

*do **not** accept cancels out iodine-131*

1

so reducing risk of cancer (of the thyroid)

accept stops risk of cancer (of the thyroid)

1

[8]

Examiner reports

Q1.

(a) 57% of students scored 2 marks for this question, with 32% scoring 1 mark. The most common mistake was not stating which quantity should remain constant, ‘charge’ being a commonly seen incorrect answer.

(b) 74% of students scored a mark for this question, usually for the idea of low penetrating ability. ‘Doesn’t penetrate skin’ was creditworthy, ‘doesn’t penetrate paper’ was insufficient. ‘Doesn’t penetrate the case’ was allowed.

(c) 53% of students scored 1 mark for this question but very few scored 2 marks. Most students answered in terms of beta and gamma radiation being able to penetrate the smoke, but didn’t link this idea to the need for a change in the radiation reaching the detector for the alarm to sound.

(d) Very few 2 mark answers were seen. Most students scored zero, with insufficient responses having to do with saving money, or not having to replace the source very often. Very few linked the graph to the question, and realised that 1.3 half-lives could be any amount of time depending on the radioisotope used.

(e) Well answered by many students, 36% scoring 3 or 4 marks. Those who didn’t usually gave opposite statements to the ideal properties, such as low penetrating ability but highly ionising, which will have limited their overall score. The minimum required for a 4 mark answer would have been two properties with explanations, or four simple statements. Many students gave much fuller answers than this, however.

Q3.

(a) (i) Two thirds of students scored both marks. Those failing to score often confused which particle had the same number and which had different numbers or included incorrect references to electrons but more commonly referred to ‘elements’ rather than ‘an element’ or ‘atoms’. Few students scored the marks by referring to atomic number and mass number.

(ii) Nine tenths of students gained the mark on this question for identifying the atomic number.

(iii) Similarly, nine tenths of students gained the mark on this question for correctly calculating the number of neutrons.

(b) (i) More than half of students gained all three marks here. Poor arithmetic was as much to blame as poor understanding for those who made mistakes.

(ii) Three-quarters of students correctly identified the neutron. Incorrect answers included electron, proton, hydrogen, uranium and gamma.

(iii) Half of students gained both marks, but nearly as many scored zero. The most common mistake was to not recognise the speed of the iron nuclei as one-tenth the speed of light resulting in their answer being incorrect by a factor of ten. Omitting the 0.1 gave a value of 0.00004 but often seen was some other power of 10 error - possibly due to calculator misuse. Occasionally students rearranged incorrectly and got a value of 2500. The use of standard form was not as common as hoped; approximately half the correct answers were not in standard form and many partially correct answers were expressed as a fraction.

(iv) Three fifths of students scored zero marks on this question. Very few realised that a linear accelerator would need to be very long, while a circular accelerator could be built in a smaller space. Some students described acceleration in a circle and centripetal forces. Many students clearly did not understand what the question was asking.

(c) (i) Nearly all students gained at least one mark and three-quarters gained both. Some students failed to tick two boxes.

(ii) Two thirds of students gained both marks. Most students realised that the combined mass numbers and proton number should total 265 / 108. There were often unusual mass and atomic numbers written for the alpha particle; 0 & -1 were often seen, but also numbers containing figures to the right of a decimal point and numbers greater than 4.

(d) (i) Two thirds of students scored both marks for correct plotting and a suitable line of best fit. Only a small number of students did not draw a straight line. Some straight lines were drawn to far from the data and so did not score a mark. Mis-plotting could lead the student to draw a curve and these were accepted if they were drawn well.

(ii) Nine tenths of students gained the mark for correctly extrapolating the line and estimating a suitable number.

Q4.

(a) The term ‘nuclear fission’ was well known. However, it is alarming how many students think that nuclear fuels are burned in order to release energy. The process of generating electricity was not well described; many students seem to think that it is the turbine that generates the electricity. An advantage of nuclear fuels ‘reliability’ was often given. However, many students spent a lot of time and filled a lot of space describing numerous disadvantages of nuclear energy and / or the advantages and disadvantages of wind with no reference at all to nuclear energy.

(b) Nearly a fifth of students did not attempt this question. Many students simply repeated the stem of the question and had no idea about the storage of the carbon dioxide following its ‘capture’. A common error was the assumption that ‘carbon capture’ involves the removal of the existing carbon dioxide from the atmosphere.

Q5.

(a) A majority of students scored this mark.

(b) Again, a majority of students scored this mark.

(c) (i) Over half of students scored zero, the most common error being an attempt to change mass and proton numbers in accordance with alpha decay. Students who got the proton number correct almost always scored full marks. The most common mistake made with the mass number was subtracting 1 rather than adding 1.

(ii) Under half of students correctly answered this for both marks. A minority of students scored one mark for correctly identifying four half-lives sufficiently well to gain credit. The most common mistake amongst students scoring one mark was to neglect to multiply 4 by 8, leaving 4 as the answer. Of the students who failed to score any marks 1200/75 to give 16 days was one common misconception, another was in counting five half-lives, i.e. 1200 as 1 half-life, 600 as 2 half-lives etc. resulting in an answer of 40. A disappointing number of students could not multiply 4×8 correctly, giving answers of 24 or 36.

(iii) Only 10% of students scored both marks for this question. Some students scored one mark for correctly stating that the tablets inhibit the absorption of I-131 but not stating the link to a reduced chance of developing cancer. Some students scored one mark for indicating that the tablets did reduce the chance of developing cancer but with incorrect reasoning. Two common misconceptions were that the tablet acted like a vaccination to prepare the body to deal with the radioactive iodine using anti-bodies, or that the non-radioactive iodine would in some way neutralise the radioactivity of I-131.