6 Figure 7 shows the nuclei of four atoms.

$^{234}_{92}U$	$^{235}_{92}U$	$^{238}_{94}Pu$	$^{238}_{95}Am$
uranium-234	uranium-235	plutonium-238	americium-238

Figure 7

(a) Which two nuclei have the same number of neutrons?

(1)

☒ **A** plutonium-238 and uranium-235

☒ **B** uranium-235 and americium-238

☒ **C** uranium-234 and americium-238

☒ **D** americium-238 and plutonium-238

(b) (i) State what is meant by the term 'half-life'.

(1)

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(ii) Plutonium-238 is used in spacecraft to provide heat to power generators.

One of these generators contains 925 g of plutonium-238 when it is manufactured.

One gram of plutonium-238 has a power density of 0.54 W/g.

Plutonium-238 has a half-life of 87.7 years.

Calculate the average energy released per second by the generator after 263 years.

(4)

average energy released per second = ... (J)

(c) The nucleus of americium-238 can absorb an electron.

When this happens, one of the protons in the nucleus becomes a neutron, as shown in Figure 8.

$$ {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}\mathrm{e} \longrightarrow {}^{1}_{0}\mathrm{n} $$

Figure 8

(i) Describe how absorbing an electron affects the proton number and the nucleon number of a nucleus.

(2)

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(ii) Deduce which nucleus is formed when americium-238 absorbs an electron.

(1)

☒ **A** uranium-234

☒ **B** uranium-235

☒ **C** plutonium-238

☒ **D** americium-238

(Total for Question 6 = 9 marks)

10 In a nuclear reactor, a chain reaction is produced and controlled.

(a) (i) Uranium-235 is the isotope used in many nuclear reactors.

Explain how the fission of uranium-235 can lead to a chain reaction.

(4)

(ii) Nuclei of beryllium-9 do not absorb neutrons.

Instead, nuclei of beryllium-9 absorb alpha particles and emit neutrons.

Give a reason why a chain reaction can result from the emission of neutrons by uranium nuclei but not by beryllium nuclei.

(1)

(b) Explain what happen inside a nuclear reactor if neutron speeds are not controlled.

(3)

(c) Describe how the energy released in the chain reaction in a nuclear reactor is used to drive a turbine in a nuclear power station.

(3)

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(Total for Question 10 = 11 marks)

TOTAL FOR PAPER = 100 MARKS

Radioactivity and health

6 (a) Radioactive materials can be a risk to health.
Some food contains radioactive material.

Explain why people can eat this food without serious risk.

(2)

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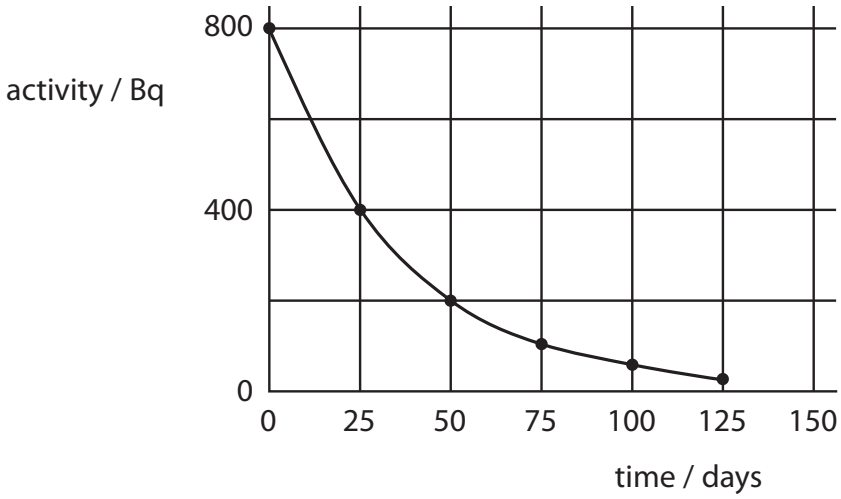
(b) A radioactive material can be used to help diagnose heart disease.
The graph shows the decay curve for this material.



(i) A scientist measures the activity of a sample of this material as 400 Bq.
Some time later, he measures the activity as 100 Bq.

Put a cross (☒) in the box next to your answer.

The time between the two measurements is about

(1)

☒ **A** 25 days

☒ **B** 50 days

☒ **C** 75 days

☒ **D** 100 days

(ii) Estimate the activity that should appear on the graph for a time of 150 days.

(1)

activity at 150 days = ... Bq

(c) Half-life is an important factor to consider when choosing isotopes for medical treatments.

Explain what **half-life** means.

(2)

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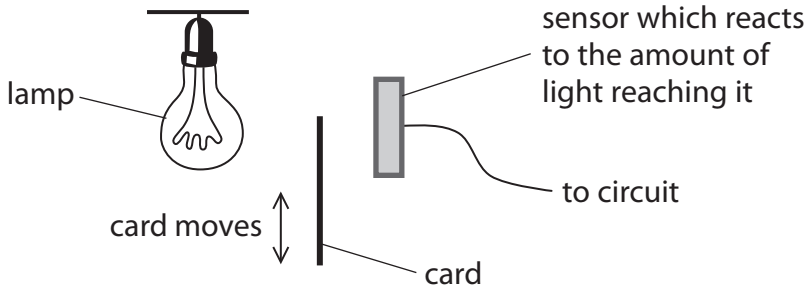
*(d) A teacher decides to model how a machine checks the level of the liquid in medicine bottles.
The machine uses a radioactive source to sound an alarm when the level of liquid becomes too low.

He sets up the arrangement shown.



The piece of card can be moved up and down between the lamp and the detector.
Each part of the teacher's arrangement corresponds to a part of the machine.

By comparing the parts of the teacher's arrangement to the parts of the machine, discuss how effective this model is.

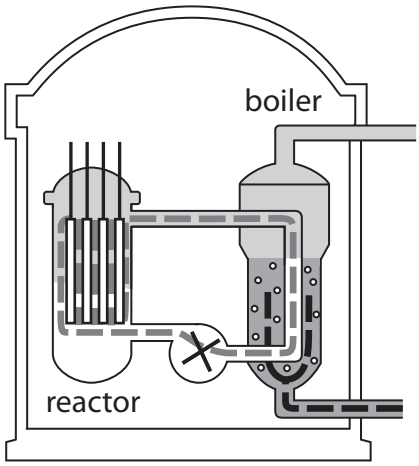
(6)

(Total for Question 6 = 12 marks)

TOTAL FOR PAPER = 60 MARKS

Nuclear energy

4 Electricity is generated in a nuclear power station.
The diagram shows the first stages in this process.



(a) The thermal energy released in the reactor is used to generate steam.

Describe how the steam is used to generate electricity.

(2)

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(b) Energy is released by a nuclear chain reaction.

Describe how the fission of a uranium-235 nucleus can start off a chain reaction.
You may draw a diagram to help with your answer.

(3)

(c) One of the products of the fission of uranium-235 is barium-142.

Which of these could be a product of the same reaction?

Put a cross (☒) in the box next to your answer.

(1)

☒ **A** krypton-91

☒ **B** krypton-95

☒ **C** krypton-98

☒ **D** krypton-100

(d) Barium-142 emits beta radiation.
Beta radiation is ionising.

Explain what happens when beta radiation ionises.

(2)

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(e) A fusion reaction does not have radioactive products.
However, it needs large amounts of energy to make it happen.

Explain why large amounts of energy are needed to make a fusion reaction happen.

(2)

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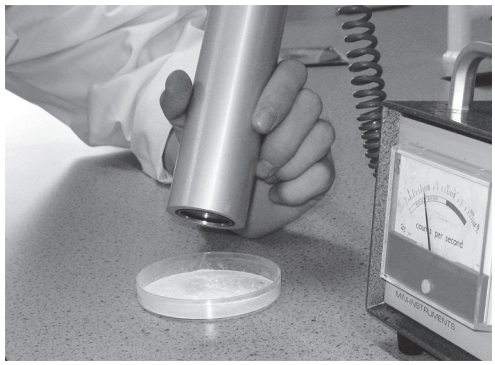
(Total for Question 4 = 10 marks)

Measuring radioactivity

2 (a) A scientist uses a Geiger counter to measure the radioactivity of a sample.



She writes down the results in her notebook.
The Geiger counter gives a count rate of 120 counts per minute.
The average background radiation in her laboratory is 10 counts per minute.

(i) What should she write down for the count rate of this sample?

Put a cross (☒) in the box next to your answer.

(1)

☒ **A** 12 counts per minute

☒ **B** 110 counts per minute

☒ **C** 130 counts per minute

☒ **D** 1200 counts per minute

(ii) Name **one** source of background radiation.

(1)

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(iii) Explain why some people are exposed to more background radiation than others.

(2)

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(iv) Complete the sentence by putting a cross (☒) in the box next to your answer.

The recommended safe limit for exposure to radiation has been reduced over the last 80 years.
This is because now

(1)

☒ **A** better instruments allow scientists to make measurements more quickly

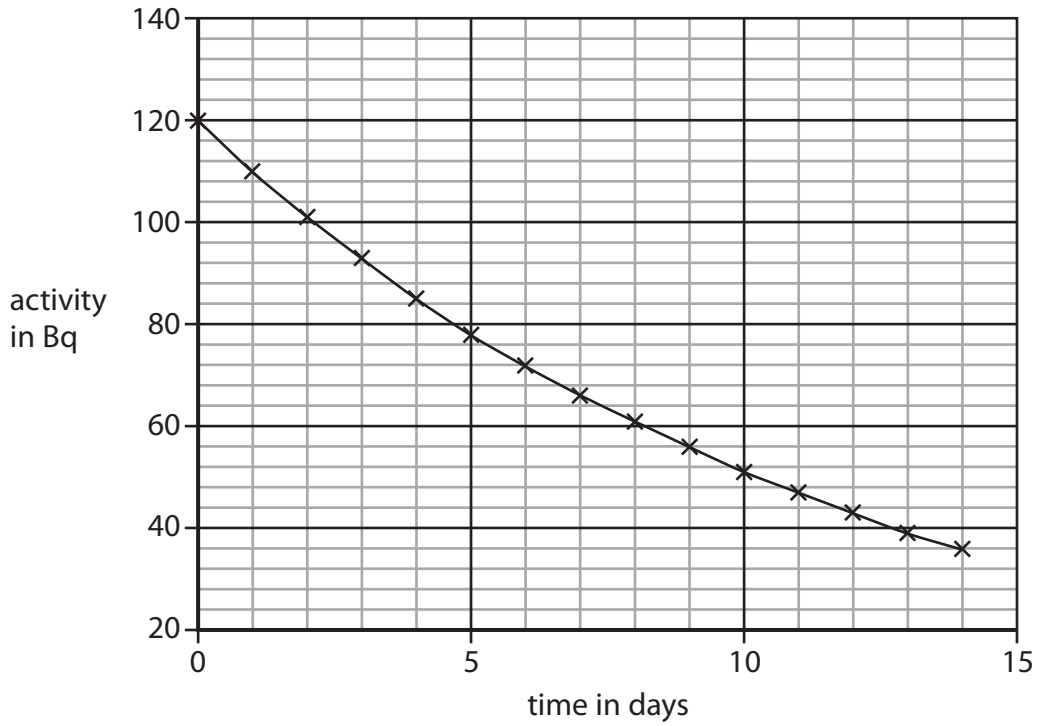
☒ **B** global warming has increased the rate of decay of radioactive materials

☒ **C** humans release more radioactive materials into the environment

☒ **D** scientists have a better understanding of the dangers of radiation

(b) After the accident at the Fukushima nuclear plant in Japan, some drinking water became contaminated with radioactive iodine-131.

The graph shows how the activity of a sample of iodine-131 changes over two weeks.



(i) Use the graph to estimate the half-life of the iodine-131.
Show your working clearly.

(2)

half-life = ... days

(ii) The recommended safe limit for a sample of this size is 100 Bq.

How long did it take for the activity of the sample to decay until it was below the safe limit?

(1)

time taken = ... days

(iii) When iodine-131 decays, it emits beta radiation.

State one possible danger to health from exposure to beta radiation.

(1)

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.....

(Total for Question 2 = 9 marks)

Nuclear power

3 (a) Two isotopes of uranium are U-235 and U-238.

Here are the symbols of the nuclei of these isotopes.

$$^{235}_{92}U \quad \text{and} \quad ^{238}_{92}U$$

(i) Complete the sentence by putting a cross (☒) in the box next to your answer.
The U-235 isotope has

(1)

☒ **A** the same number of neutrons as U-238

☒ **B** the same number of protons as U-238

☒ **C** more neutrons than U-238

☒ **D** more protons than U-238

(ii) U-235 is radioactive.
When it decays, it releases an alpha particle.

Describe an alpha particle.

(2)

(b) U-235 can also be made to undergo fission.

Describe what happens during nuclear fission.

(4)

(c) Fission is used in nuclear reactors.
Graphite is used as a moderator in nuclear reactors.

Explain why a moderator is needed in a nuclear reactor.

(2)

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(Total for Question 3 = 9 marks)

Carbon dating

4 Carbon-14 is a radioactive isotope that occurs naturally.

Scientists use carbon-14 to help find the age of old pieces of wood.

This technique is called carbon dating.

It uses the idea of half-life.

(a) Which of these describes half-life?

Put a cross (☒) in the box next to your answer.

(1)

☐ **A** the time it takes for half of the undecayed nuclei to decay

☐ **B** the time it takes for all of the undecayed nuclei to decay

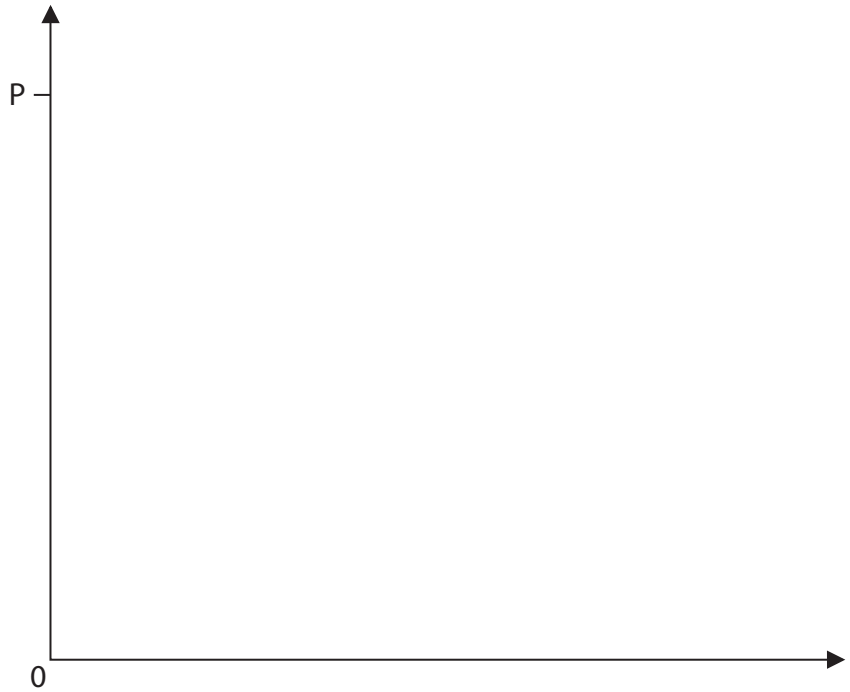
☐ **C** half the time it takes for all of the undecayed nuclei to decay

☐ **D** half the time it takes for half of the undecayed nuclei to decay

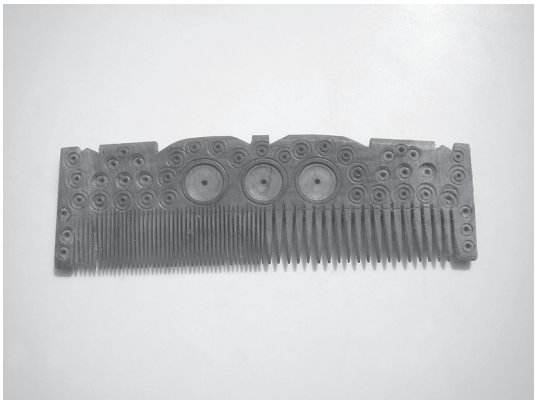
(b) Sketch a graph to show how the activity of a radioactive isotope changes with time.

Use the axes below. Start your line from point P.

(3)



(c) A scientist investigates an old wooden comb.



The activity of the carbon-14 in it is 0.55 Bq.

The estimated age of the comb is 11 400 years.

The half-life of carbon-14 is 5700 years.

(i) Calculate the activity of the carbon-14 in the comb when it was new.

(3)

activity = ... Bq

(ii) The scientist takes several readings of background radiation.

Explain why this is necessary to improve the accuracy of the investigation.

(2)

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(iii) Old objects like the comb emit a very small amount of radiation.

The activity from the comb is about the same as comes from background radiation.

Scientists have stopped measuring the activity of carbon-14 for carbon dating.

Instead, they can measure the mass of undecayed carbon-14 left in the sample.

Suggest a reason for this change.

(1)

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(Total for Question 4 = 10 marks)

Ionising radiation

6 Alpha, beta and gamma are types of ionising radiation.

(a) State **two** ways in which gamma radiation is different from alpha radiation.

(2)

(b) (i) Complete the sentence by putting a cross (☒) in the box next to your answer.

A beta particle is emitted by

(1)

- ☒ **A** an alpha particle
- ☒ **B** a fusion particle
- ☒ **C** a gamma ray
- ☒ **D** an unstable nucleus

(ii) Complete the sentence by putting a cross (☒) in the box next to your answer.

A beta particle has an identical charge to

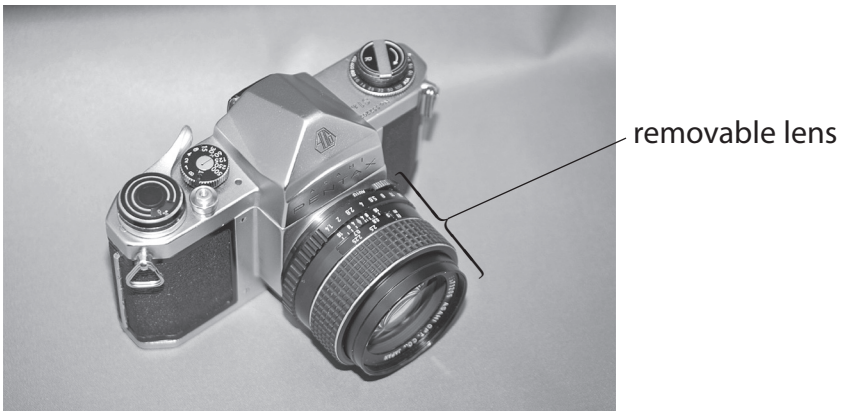
(1)

- ☒ **A** an alpha particle
- ☒ **B** an electron
- ☒ **C** a neutron
- ☒ **D** a nucleus

(c) Explain how an atom becomes ionised by radiation.

(2)

*(d) The removable lens of this old camera has four pieces of glass in it.



One of the pieces of glass is radioactive. Its surface is covered with a thin layer of magnesium fluoride.

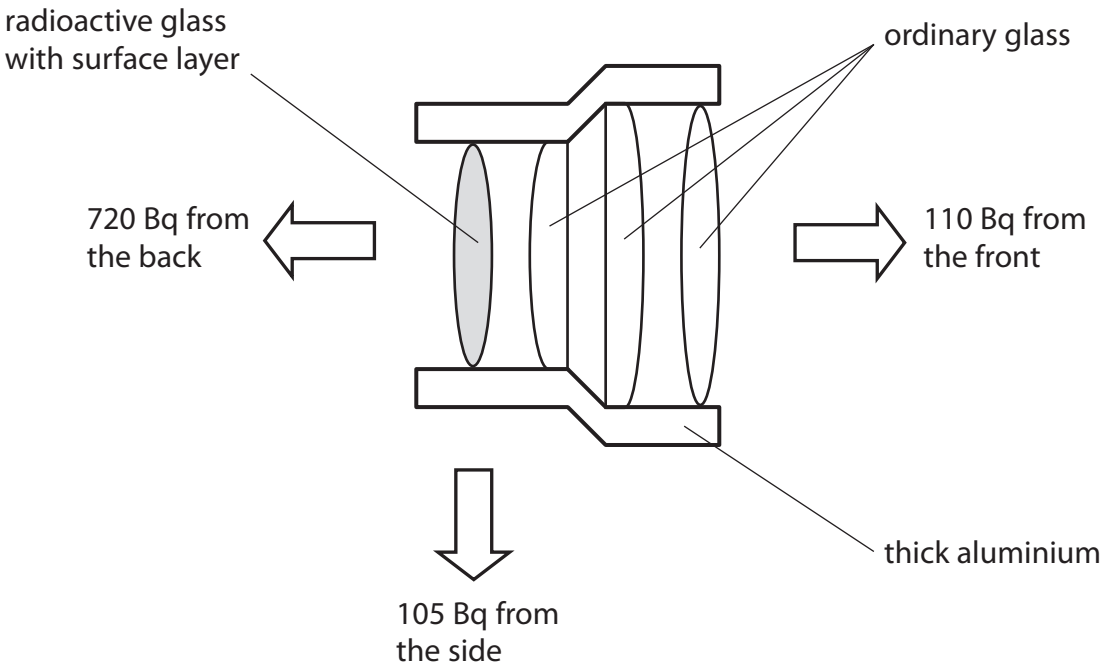
Radioactive isotopes in the glass emit alpha, beta and gamma radiation in all directions.

A scientist removes the lens from the camera. She measures the radiation coming from the back, front and side of the lens.

The amount of radiation is different in each direction.

No alpha radiation is detected.

The readings are shown on the diagram.



Explain why the readings in the three directions are different.

(6)

(Total for Question 6 = 12 marks)

TOTAL FOR PAPER = 60 MARKS

Answer ALL questions.

Some questions must be answered with a cross in a box ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Nuclear power

1 Many countries generate electricity using nuclear fission.

(a) The decay products from nuclear fission emit different types of ionising radiation.

Draw **one** line from each type of radiation to its correct description.

(2)

type of radiation	description
alpha	electromagnetic wave
beta	electron
gamma	helium nucleus

(b) There are both fuel rods and control rods inside each fission reactor.

Explain how pushing control rods between the fuel rods changes the rate of nuclear fission in the reactor.

(2)

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.....

(c) Engineers are trying to generate electricity using the energy from nuclear fusion reactions.

(i) Complete the sentence by putting a cross (☒) in the box next to your answer.

High temperatures and pressures are needed in a nuclear fusion reactor.
This is to overcome

(1)

☒ **A** the kinetic energy of nuclei

☒ **B** the electrostatic repulsion of protons

☒ **C** the magnetic repulsion of neutrons

☒ **D** nuclear fission

(ii) Describe what happens to nuclei in a nuclear fusion reaction.

(2)

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(Total for Question 1 = 7 marks)

Radiation from rocks

4 (a) One isotope of the element potassium is potassium-40.

A nucleus of potassium-40 is represented by:

$$^{40}_{19}K$$

(i) Complete the sentence by putting a cross (☒) in the box next to your answer.

The number of neutrons in a nucleus of potassium-40 is

(1)

☒ **A** 19

☒ **B** 21

☒ **C** 40

☒ **D** 59

(ii) Which of these symbols is correct for the nucleus of a different isotope of potassium?

Put a cross (☒) in the box next to your answer.

(1)

$^{39}_{19}K$ ☒ **A**

$^{40}_{20}K$ ☒ **B**

$^{19}_{40}K$ ☒ **C**

$^{39}_{20}K$ ☒ **D**

(iii) A sample of potassium-40 is left for a long time.

Some of the potassium-40 nuclei will emit gamma radiation as they turn into argon-40 nuclei.

Argon-40 nuclei never change.

Describe what information this gives about the isotope potassium-40.

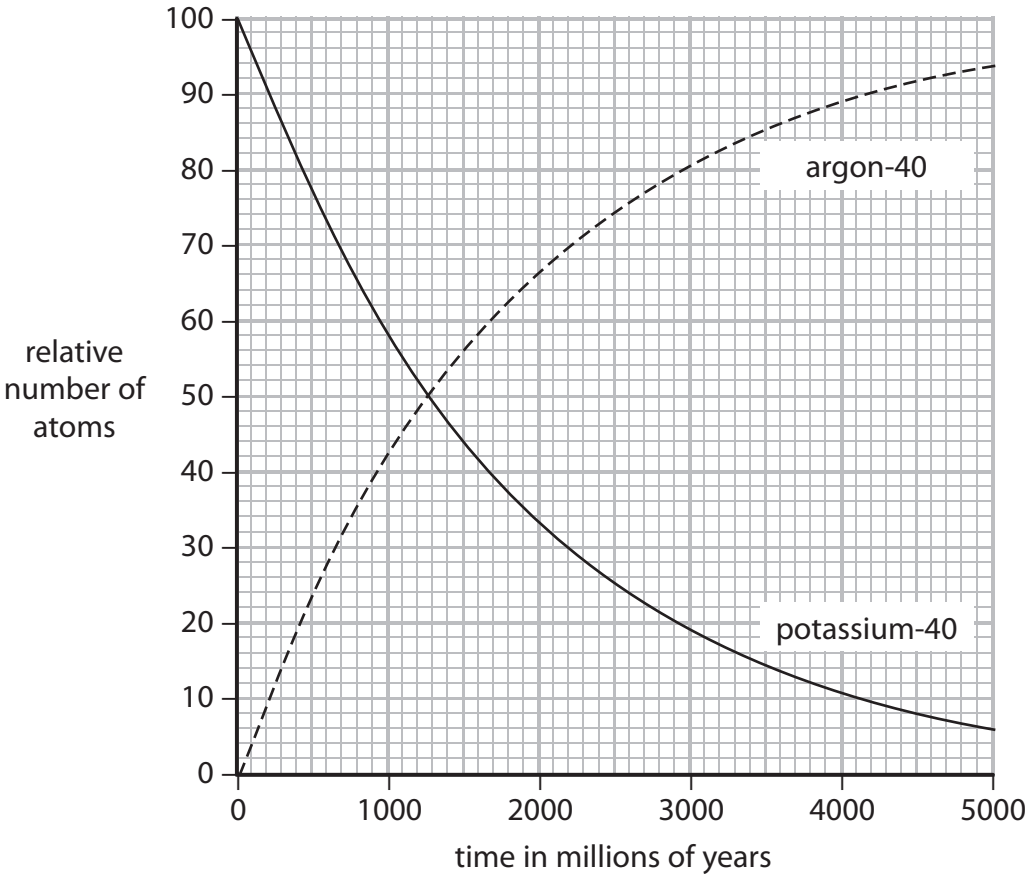
(2)

(b) Some rocks containing potassium were formed many millions of years ago.

There was no argon-40 in the rocks when they were formed.

When scientists analyse samples of these rocks, they find small amounts of argon-40 trapped inside.

The graph shows how the relative amounts of potassium-40 and argon-40 change over time.



(i) Use the graph to find the half-life of potassium-40.

(1)

half-life = ... million years

(ii) Scientists analyse a sample taken from inside a rock.

They find that there is exactly 3 times as much argon-40 as there is potassium-40.

Use the graph to find the age of the rock.

(2)

age of rock = ... million years

(c) Some other rocks contained uranium when they were formed.

Radioactive decay in these rocks produces radon gas.

Explain why people living near these rocks have an increased health risk from background radiation.

(3)

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(Total for Question 4 = 10 marks)

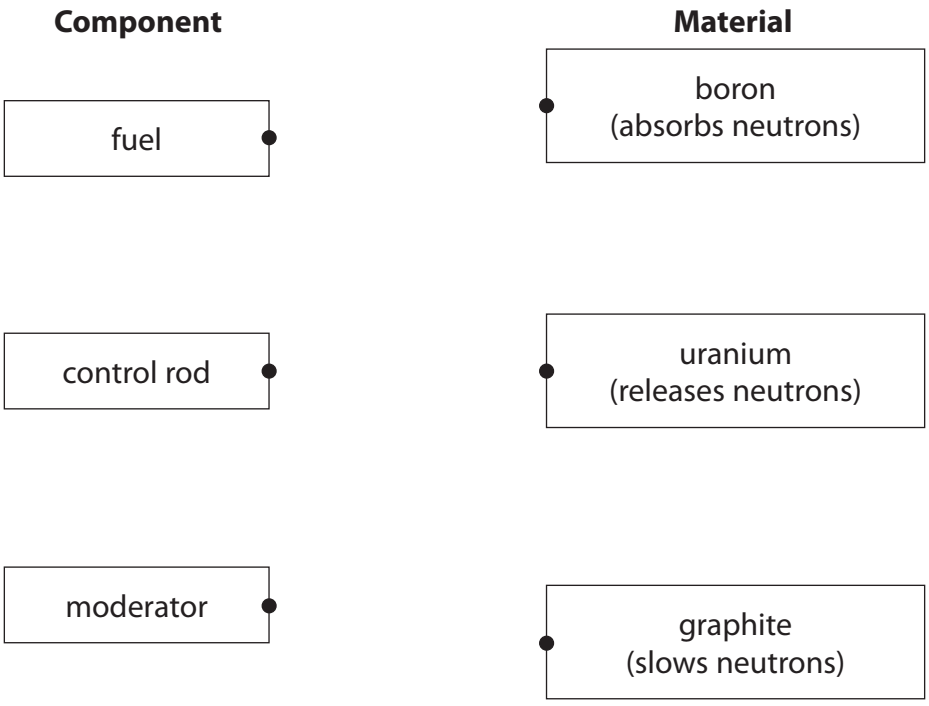
Nuclear reactors

5 (a) Fast neutrons are released during nuclear fission.

(i) Three different components of a nuclear fission reactor are shown.
Three different materials used in a nuclear fission reactor are also shown.

Draw one line from each component to the material it contains.

(2)



(ii) Another type of nuclear reactor is a fusion reactor.
Nuclear fusion also releases fast neutrons.

Suggest why a nuclear fusion reactor does not need anything to slow these neutrons down.

(1)

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(b) Both nuclear fission and nuclear fusion release thermal energy.

Describe how the thermal energy released could be converted into electrical energy in a power station.

(3)

*(c) Scientists and engineers are still trying to build a practical and economic nuclear fusion reactor.

They have not been able to sustain the extreme conditions needed for controlled nuclear fusion.

Explain what these conditions are and why they are needed.

(6)

(Total for Question 5 = 12 marks)

Using radioactive materials

6 (a) In some countries food is sold with this label.

This food has been deliberately exposed to gamma radiation.

Complete the sentence by putting a cross (☒) in the box next to your answer.

The gamma radiation is used to

(1)

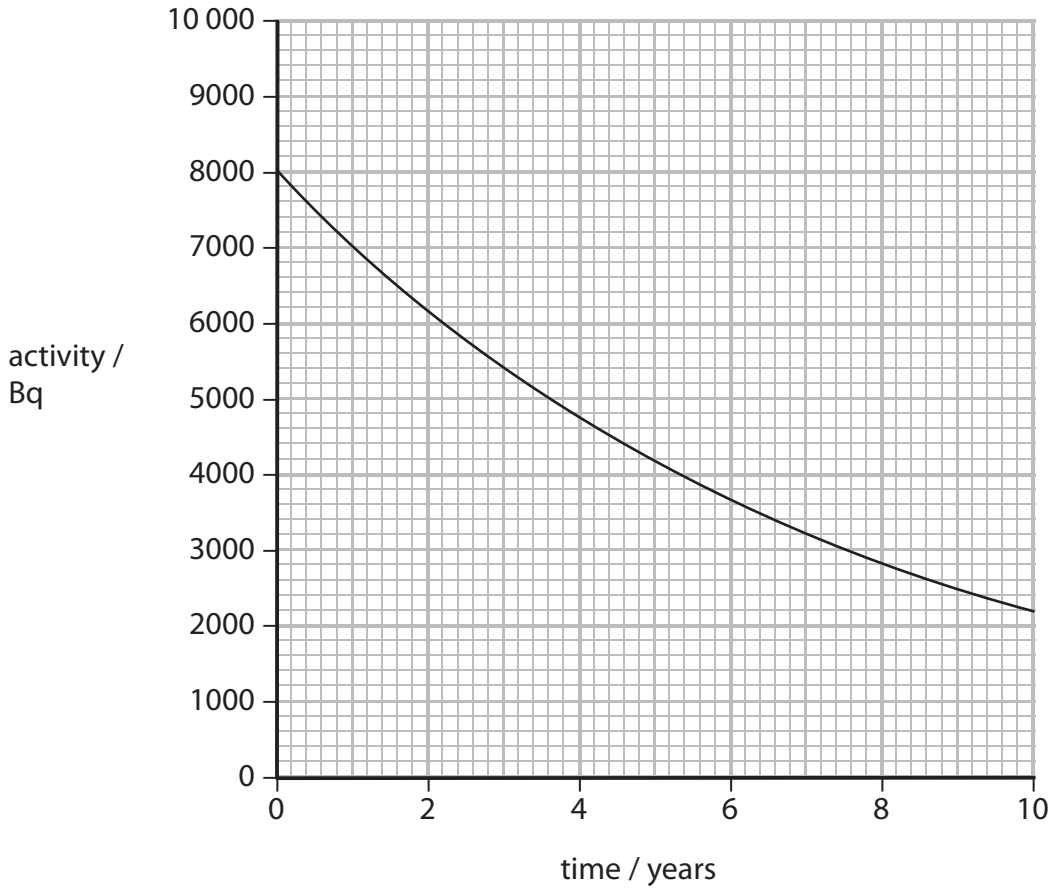
☒ **A** produce cancer cells in the food

☒ **B** kill cancer cells in the food

☒ **C** kill microbes in the food

☒ **D** make the food radioactive.

(b) Cobalt-60 is one source of gamma radiation used for food irradiation.
This graph shows how the activity of a sample of cobalt-60 changes over 10 years.



(i) Use the graph to find the half-life of cobalt-60.

(2)

half-life = ... years

(ii) The cobalt-60 has to be replaced when its activity has fallen below 1000 Bq.

Estimate how long it takes for the activity to fall from 8000 Bq to 1000 Bq.

(1)

time taken = ... years

(c) The cobalt-60 sources used to irradiate the food are small metal rods about the size of a pencil. They are made from stable cobalt-59 which is put inside a nuclear reactor. Some of the cobalt-59 is turned into cobalt-60 by the radiation in the reactor.

(i) The nuclei of the two isotopes can be represented as

$^{60}_{27}Co$ $^{59}_{27}Co$

Compare these two isotopes of cobalt.

(2)

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*(ii) When it is time to replace the cobalt-60 rods there are two options.

- The rods can be disposed of.
- The rods can be transported to a nuclear reactor to turn more of the cobalt-59 into cobalt-60 so that they can be used again.

Discuss the hazards in these two options.

(6)

(Total for Question 6 = 12 marks)

TOTAL FOR PAPER = 60 MARKS