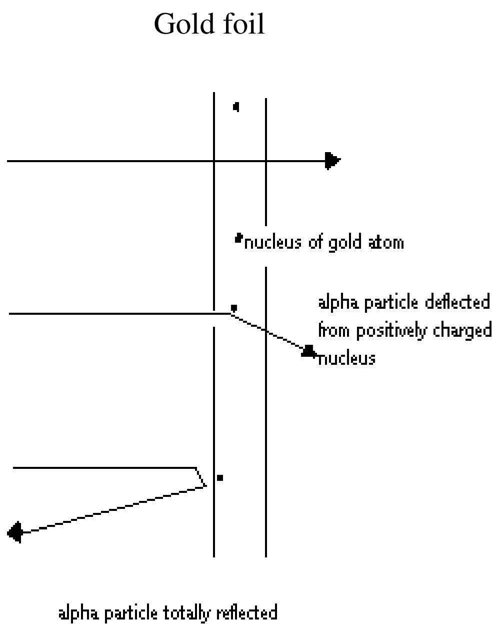
What is radioactivity?

People used to believe that an atom was solid all the way through with electrons and protons. Ernest Rutherford did not believe that electrons and protons were embedded together. However he did know that alpha particles have a positive electric charge. He said

'Atoms are not made up of electrons, protons and neutrons all stuck together like raisons, cherries and dried fruit pieces in a plum pudding.' Instead, Rutherford deduced that 'atoms consist largely of empty space with a massive positively charged central region which he called the nucleus (protons and neutrons) surrounded by orbiting electrons.'



Rutherford had made an important discovery. We now know that the nucleus is made up of two types of particle called protons and neutrons.

Q2 What is the charge and mass of a proton?________________________________

Q3 What is the charge and mass of a neutron?_______________________________

Q4 What do we mean by the atomic number of an atom?_______________________

____

Q5 What do we mean by the Relative Atomic Mass of an atom? ________________

____

The smallest atom that we know of is called _________. It simply has one proton in its nucleus. However, in its simplest form, it does not have any _________ in its nucleus. It just has one orbiting _________ around the nucleus.

Electrons have the opposite charge to protons. They are ________ and have 1/1850 the mass of a proton.

Possible words: neutrons, electron, hydrogen, negative

Q6; Draw a labelled hydrogen atom below

We can represent the hydrogen atom in this way:

$$^{1}_{1}H$$

The top '1' represents the Relative Atomic Mass or the number of protons and neutrons
The bottom '1' represents the Atomic Number or the number of protons.

Question 7; How many neutrons in this atom?

The atomic number of an atom tells us which type of ELEMENT the atom belongs to. For instance, atomic number =1, the atom must be hydrogen. Atomic number=2; helium

Refer to a periodic table-complete the table below;

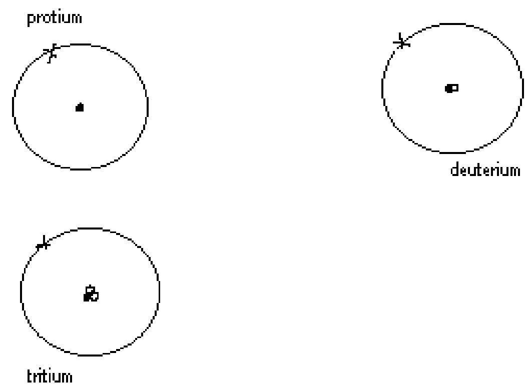
Atomic Number of atom	Element atom belongs to
1	Hydrogen
2	
3	
4	
10	
20	
30	
60	
70	
73	
78	
87	
98	
99	
100	

Elements are substances containing atoms, all of which are the same i.e. all have the same atomic number. However, some atoms of the same element have different numbers of neutrons. They therefore have different **RELATIVE ATOMIC MASSES**. Different forms of atom of the same element are called **ISOTOPES.**

Hydrogen, for instance has 3 Isotopes

These isotopes are called **protium, deuterium and tritium. Consider these three isotopes of hydrogen on the next page. In order to draw these atoms, we calculate the number of neutrons as follows:**

Number of neutrons (n) =Number of p+n (Relative at mass) – Number of p (at no)



Key Proton (positive charge 1 atomic mass unit)
Neutron (neutral/no charge 1 atomic mass unit)
Electron (negative charge 1/1850 atomic mass units)

Radioactive Isotopes

Some isotopes have very big atomic numbers and relative atomic masses. However, as they get bigger, a problem arises!

Do you remember the electrical charge on a proton? It is positive. Similar charges eg lots of positive charges don't like coming close together (repel). The nucleus therefore has increasing difficulty in holding itself together, as it gets bigger.

Very large isotopes e.g. ${}^{238}_{92}U$, need to lose some mass and energy to remain stable.

This is called RADIATION and consists of three types.

(A) **Alpha particles** (α particles). An alpha particle is the same as helium nucleus i.e. 2 protons and 2 neutrons stuck together.

Question: What will happen to the Relative Atomic Mass (P+N), of an isotope when an alpha particle is emitted from it?

____

____

Question: Imagine that ${}^{238}_{92}U$ tries to lose some mass and energy by emitting an alpha particle. Complete this radioactive symbol equation

${}^{238}_{92}U$ = ___________ + alpha particle (α particle)

Question: How far can an alpha particle travel through the air?

____

Question: Can alpha particle travel through paper?

(B) Beta particles (β particles)

A beta particle is an electron!

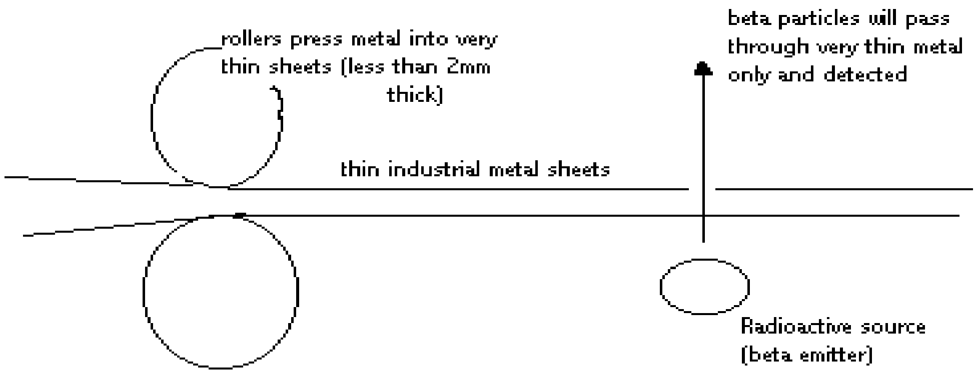
Question: Why should we find it surprising that an electron might be emitted from a nucleus?

The beta particle is made in a very special way! In a fraction of a second, one neutron in the nucleus of a radioactive isotope turns into one **proton** and one **electron (beta particle).**

neutron =		**proton**	**+**	**electron (beta particle)**
	(no charge)	**(positive charge)**		**(negative charge)**
atomic mass units	**1**	**1**		**1/1850**
	neutron	**= proton**	**+**	**electron**

Question: What happens to the Relative Atomic Mass (p+n) when a beta particle is emitted from the nucleus of a radioisotope?

We can use the fact that beta particles are absorbed by thick metal, to our advantage!



Question: Explain how this process works

© **Gamma radiation**: This is given off during radioactive decay. It can travel several kilometres and is stopped by several cm thickness of lead.

Question: Complete the text using the words that follow:

Nuclear radiation (gamma rays) and high energy x-rays are used to treat _______. When a patient has a brain ______, their head is held in place by a metal frame. Gamma radiation is targeted at a specific area of the brain and has minimal effect on ________ areas. It is non-invasive and produces access to areas of the _____ that cannot be reached by other techniques.

Possible words: tumour, cancers, brain, surrounding

Type of radiation	Ionising power	Range in air	What stops it	Medical use	limitations
alpha	Very strong	centimetres	paper	No use for diagnosis or therapy	Can cause extensive ionisation if an alpha emitter is taken into the body and this can cause cancer.
beta	medium	metres	3mm aluminium	Can pass through skin but not bone. So it is used to treat the eyes	Limited medical use.
gamma	weak	Large, its intensity decreases with distance	Few centimetres lead	Cobalt-60 is gamma emitter used to treat cancers	Cancer cells can be destroyed by exposing them to large amounts of gamma radiation and this is called radiotherapy.

X-rays and gamma rays are both exactly the same type of electromagnetic wave. The only difference is their origin. X-rays are made in a machine and gamma rays are produced by the decay of radioactive nuclei to lose surplus energy.

They can both have the same wavelength and frequency. However, x-rays can be made with a higher frequency and smaller wavelength if needed which gives them more energy and ionising power to destroy tumours.

Question: What is the difference between diagnosis (emitters of gamma rays) and therapy?

____

Danger of alpha particles

Alpha particles are damaging if they enter the body. This happens if a source of alpha radiation is swallowed or breathed in. Radon gas decays by emitting alpha particles and is dangerous if it is breathed in.

Radiation protection

People who work with radioactive substances wear a film badge. It monitors a worker's exposure to radiation. The badge contains a piece of photographic film. Radiation affects the film in a similar way to light. The badge's exterior is of different thicknesses; this allows different areas of the film to be used as a measure of a worker's exposure to different types of radiation having different penetrating powers.

Question: Alpha radiation is of no use in medicine. Why?

____

____

Question: Why must exposure to nuclear radiation be avoided?

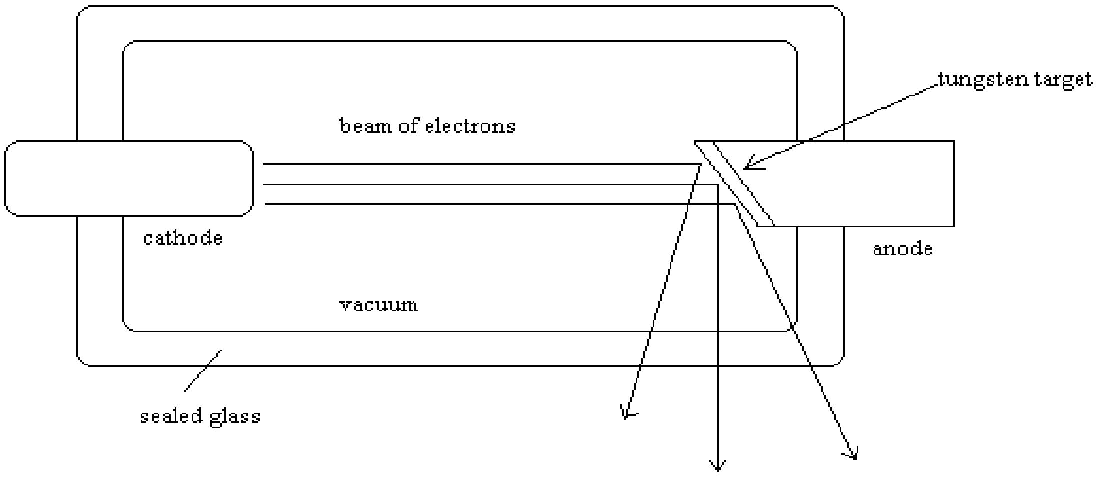
____

____

Question: Which type of nuclear radiation is used to treat a cancer deep inside the body?

____

____



How X rays are produced

In the above diagram, a hot cathode emits electrons that are attracted by a highly positive target. When the fast moving electrons hit the target some of their kinetic energy is used to emit X-rays but most of it is converted to heat.

Question: Suggest why there is a vacuum in an X-ray machine.

____

____

Question: Give one advantage of using X-rays rather than gamma rays as a source of radiation.

____

____

Using gamma radiation

Question: Complete the following text using the words that follow:

Gamma radiation is used to treat cancer; it damages and destroys ________ cells. Large doses of radiation are sometimes used in the place of _______. However, it is more common to use ________ after surgery. This helps to make sure all cancerous cells are removed or destroyed.

If any cancerous ____ are left, they can multiply and cause secondary cancers at different sites in the body.

Cobalt-60 is the radioactive source commonly used in _______. The side effects of a _______ can be unpleasant but it can slow down the growth of a cancer or completely cure it.

Possible words: medicine, treatment, cells, cancerous, radiation, surgery

Sterilising hospital equipment

Gamma radiation kills bacteria. It is used to sterilise hospital equipment to prevent the spread of disease.

Each item is put in a sealed plastic pack e.g. used plastic tubing, and is exposed to intense gamma radiation. This is a much simpler process than old fashion methods that used high-pressure steam treatments.

Radiographers

A radiographer is a person who carries out procedures using X-rays and nuclear radiation (includes gamma and beta).

Question: What are the advantages of sterilising medical equipment in this manner?

____

____

Question: Why is it important to try to remove all cancerous cells during a treatment?

____

____

Question: Suggest how radiographers protect themselves from exposure to radiation.

____

Radiographers position an X-ray generator over a patient's cheek for treatment of a skin cancer. There is a lead block on the patient's eye and cheek. Can you suggest why? The lead is covered in cling film because it is toxic to skin.

____

Using tracers

A radioactive tracer is used to investigate inside a patient's body without surgery.

- Technetium-99m is a commonly used tracer. It emits gamma radiation.

- Iodine-123 is an artificially produced radioisotope of iodine and emits gamma radiation. It is used to investigate the thyroid gland. The thyroid is important because it controls the rate at which the body functions. The thyroid absorbs iodine, so a small amount of radioactive iodine is given to the patient orally (by mouth). It is absorbed into the bloodstream and collects in the thyroid. The radiation given out is monitored over a period of about 24 hours and is compared with the result from a 'normal' thyroid gland.

Comparing the use of gamma rays and X-rays as tracers

- Gamma rays and X-rays have similar wavelengths but are produced in different ways.

- X-rays are not suitable as tracers as they are produced in an X-ray tube

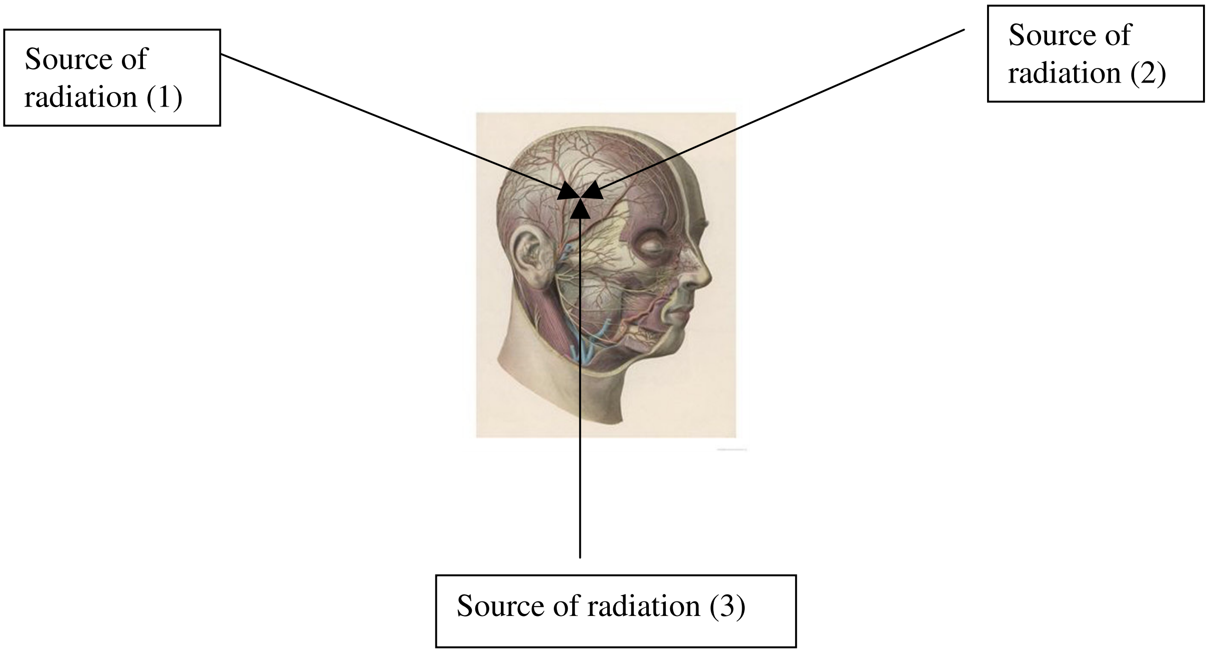
- Gamma rays from a radioisotope used as a tracer are emitted from inside the body and the progress of the tracer can be monitored.

Question: Suggest two essential properties that make a radioisotope suitable as a tracer.

Question: Technetium-99m is the radioisotope most widely used as a tracer in medicine. Suggest why.

Treating cancer

High-powered gamma radiation from a radioisotope such as cobalt-60 can be used to destroy a tumour inside the body, such as a brain tumour. A dose large enough to destroy the tumour would also destroy the healthy tissue it passes through.



- Three sources of radiation, each providing one third of the required dose, are arranged around the patient's head. Each source is focused on the tumour, but the surrounding healthy tissue only receives one third of the dose.

- The radiation source is slowly rotated around the patient, with the tumour at the centre of the circle. The tumour receives constant radiation and healthy tissues receive only intermittent doses.

Using tracers

- A radioactive tracer is mixed with food or drinks and swallowed, or it is injected into the patient's body.

- Its progress through the body is monitored using a detector, such as a gamma camera connected to a computer.

Question: Why is a syringe used to inject technetium-90m into a patient surrounded by lead?

Question: What happens to the atomic number when a beta particle is emitted from the nucleus of a radioisotope?

____

____

Question: How far, on average can a beta particle travel through the air?

____

Question: Can a beta particle travel through a piece of paper?

____

Question: What will stop a beta particle (travels at one tenth the speed of light)

____

Question: Complete this radioisotope symbol equation

$^{238}_{92}U$ = __________________ + beta particle (β particle)

(C) Gamma radiation

A gamma ray (γ) is just a tiny packet of electromagnetic energy emitted from the nucleus of a radioisotope. It is a **TRANSVERSE WAVE** or in other words, it vibrates up and down at right angles to the direction it is travelling.

All electromagnetic waves (light, infra red, gamma etc) are transverse waves.

Gamma rays can be emitted at any time from a radioisotope as a means to release some excess energy from the nucleus e.g. when an alpha particle is emitted.

When a gamma ray is emitted, this action does not affect the atomic number or the Relative Atomic Mass.

Question: What distance, on average, can gamma rays travel from a stationary radioactive source?

____

Question: What can stop gamma rays?

____

Radioactive substances may emit only one of these types of radiation, or all three!
If we place different types of material over a radioactive source and then measure how much radiation is passing through (counts per minute), we can determine which type of emission; alpha, beta or gamma, is being produced.

Can we determine what types of radiation are emitted from a radioisotope?

Question: A Geiger counter was used to measure the background radiation. The count rate was 50 counts per minute. The Geiger counter was then placed over the radioactive source. The count rate was then measured as 700 counts per minute. What count rate per minute was due to the radioactive source?

____

A very thin sheet of aluminium (0.5mm) was now placed over the radioactive source.

The count rate now became 620 counts per minute. What type of radioactive particle had been stopped? ___________________. If the count rate had stayed at 700 counts per minute when the very thin sheet of aluminium had been placed on top, what could you have deduced about the radiation being produced?

____

____

Question: What is the difference between an alpha particle and a helium atom?

____

A thicker piece of aluminium 2 to 3 mm in thickness was now placed over the radioactive source. The radioactive emissions passing through the aluminium was then recorded and found to be 400 counts per minute. Can you explain these new readings?

____

____

If the count rate had become the same as the background count, what could you have deduced?

____

Activity is measured by counting the average number of counts per second with a Geiger – Muller tube and a rate meter (together called a Geiger counter). Each click sound represents one type of emission (alpha, beta or gamma) passing into it.

Activity is measured by counting the average number of nuclei that decay every second (emissions produced per second). This is also called the count rate. Activity is measured in counts per second or **becquerels (Bq).**

$$\textbf{Activity} = \frac{\textbf{number of nuclei that decay (number of emissions produced)}}{\textbf{time taken in seconds}}$$

The activity of a radioactive substance decreases with time. The count rate falling shows this.

Question: The activity of a radioactive source is 200 Bq. How many counts would be recorded in 10 seconds?

____

____

Question: Sam records a count of 4000 in 25 seconds from a radioactive source. What is its activity?

____

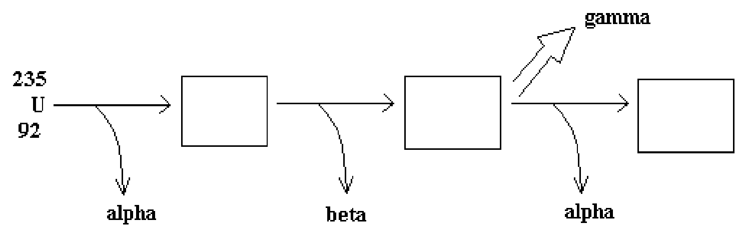
Question: What can you say about all the isotopes of the elements above lead in the periodic table?

____

Question: Sita records the count rate from a radioactive source. She takes four readings. They are 138 Bq, 149Bq, 133Bq and 142Bq. Why are the readings different?

____

Try to complete the following decay-series



Well, these series of decays would continue until stable lead $^{211}_{82}Pb$ is produced.

<u>The Half Life of Radioactive Isotopes</u>

There is a special term that we need to learn called **<u>the half life</u>** of a radioactive isotope. This quite simply means the time taken for half the isotope atoms to become stable, or in this case, turn into lead atoms!

Imagine that we start with just 8 radioactive isotope atoms [half-life of 8 minutes].

<u>Question</u>: How many atoms will be left which are radioactive after 8 minutes? _____

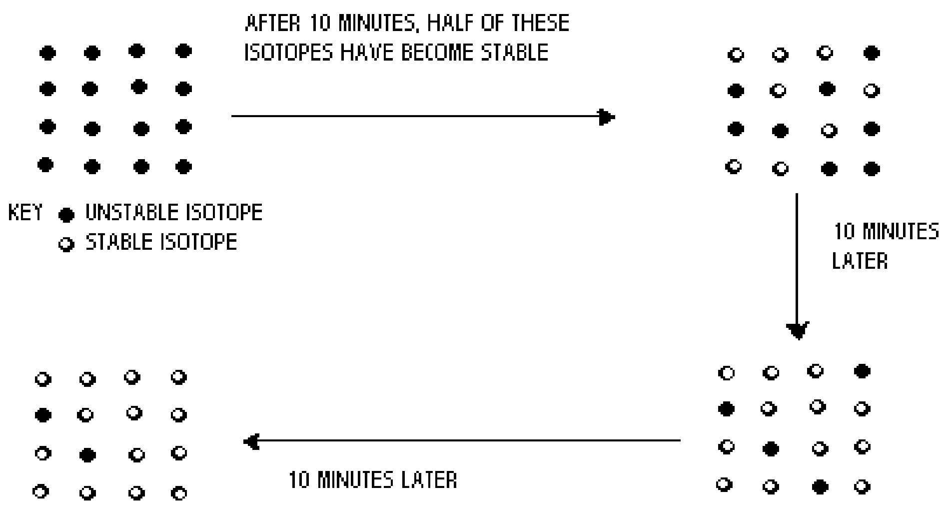
<u>Question</u>: How many radioactive atoms will be left after 16 minutes? _______

<u>Question</u>: Complete: After ____ minutes, there will be 1 atom which is still radioactive

This appears quite simple to work out. However, what happens if we start with 203 radioactive atoms or maybe 4123 atoms? The best way to calculate how much radioactivity remains is with a decay curve drawn on graph paper**.**

<u>Half-Lives</u>

If we have a substance <u>initially</u> made up of a billion Isotopes, they will not all change into the same element at the same time. They all change into elements at <u>different rate.</u>



The time taken for **half** of the isotopes in a substance (or the amount of radioactivity measured) to become stable is called the **half-life**. In this case the half-life is 10 mins.

Question Consider the above example. How long would it take for the amount of radioactivity measured by a Geiger-Muller tube to become 10% of its original value?

Answer – At the start, the radioactive count rate = 100% [Half life = 10 minutes]

So it will take 10 minutes for count rate to become 50% (i.e. only 50% of the unstable Isotopes remain).

The radioactive count rate with time is shown with a radioactive-decay curve.

Question: Why is the half-life of a radioisotope an approximate value?

____

Question: The activity of a radioactive sample took four hours to decrease from 100Bq to 25Bq. What is its half-life?

____

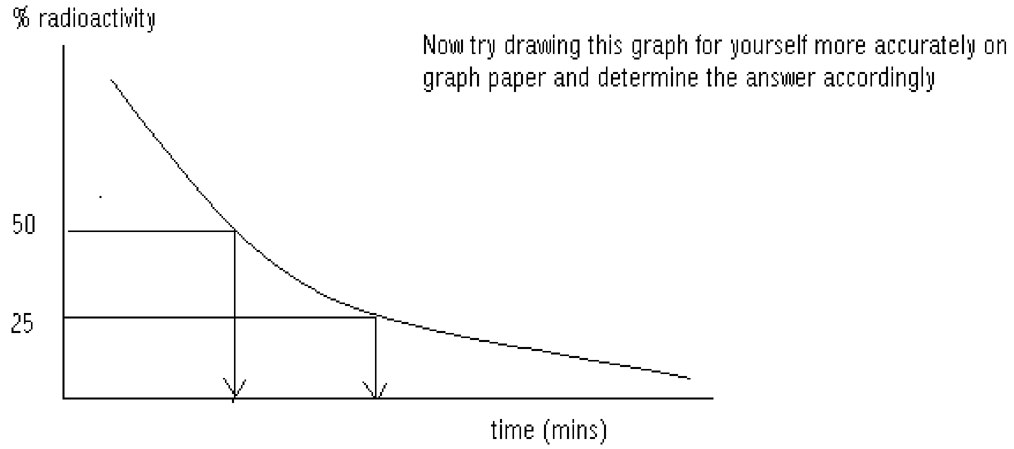
Question: A radioactive substance has a half-life of 2 hours. How much of it remains after 6 hours?

____

____

____

Question: A radioactive substance has a half-life of 10 minutes. How long will it take before its activity decreases by 75% (activity in Bq – the graph below will help)



Question: A radioactive substance has a half-life of 2.3 hours. You are given 20 grams of this material. How long will it be before 5.7 grams have lost its radioactivity and become stable?

Question: A radioactive substance has a half-life of 2.9 years. How long will it be before it is only 10% as radioactive as it was at the beginning of its existence?

Question: A radioactive substance has an activity of 345 Bq. It has a half-life of 3.5 minutes. How long will it take before its activity decreases by 56 Bq?

Uses of radioisotopes

Radon Risks

Complete the following text using the words that follow:

Granite rocks contain small amounts of radioactive ________. When uranium decays it emits radon gas that is also ________.

In granite areas, such as Devon and Cornwall, where houses were traditionally built from ______, there is concern about the _______ risks to the inhabitants who may be harmed by breathing in radon gas.

Possible words: health, granite, radioactive, uranium.

Background radiation

This is ionising radiation that is always present in the environment. It varies from place to place and from day to day. The levels of background radiation are low and do not cause harm.

Question: What is meant by ionising radiation? What are the different types of background radiation?

____

____

____

Tracers

Radioisotopes are used as **tracers** in industry, research and medicine.

Tracers are used to:

- detect leaks in underground pipes
- monitor the uptake of fertilisers in plants
- check for a blockage in a patient's blood vessel.

Question: For each of the above types of tracer, consider the length of the half-life of its isotopes. Should it be in minutes, hours or days? What type of radioactive emission should be produced? Should it be alpha, beta or gamma? (give reasons).

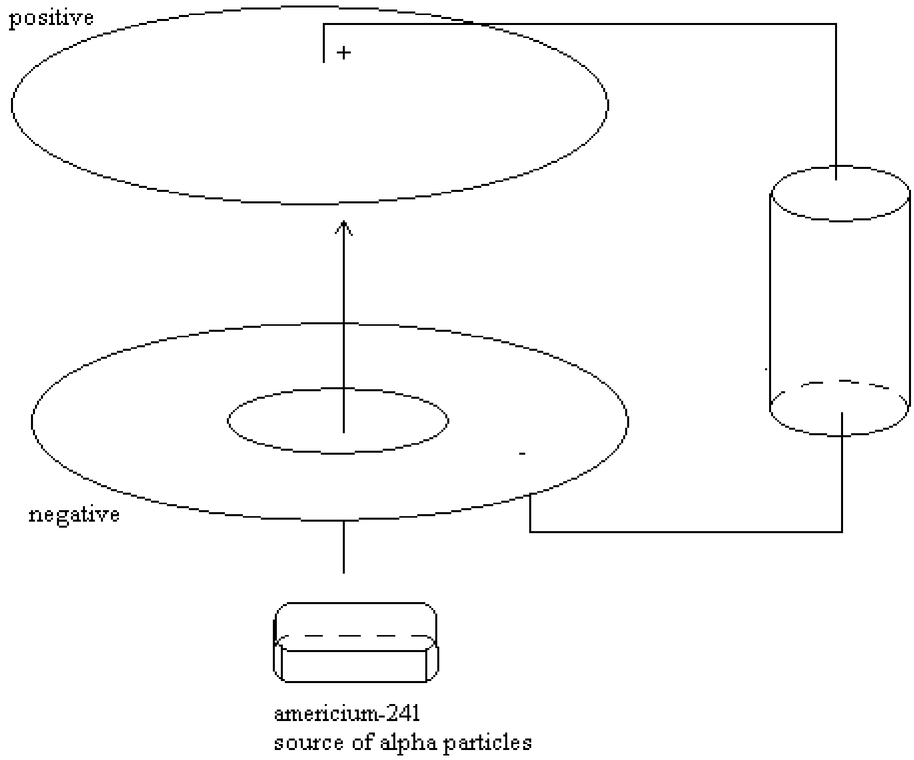
____

____

____

____

How a smoke alarm works



The alpha particles ionise some of the oxygen and nitrogen atoms in the air (show this on the diagram). The positive ions and negative electrons move towards the negative and positive plates respectively (show this on the diagram). This creates a tiny current that is detected by electronic circuitry in the smoke alarm (show this on the diagram). If smoke particles enter they attach themselves to the ions, neutralising them (show this).
The smoke detector senses the drop in current and sets off an alarm.

Americium-241 has a half-life of about 28 years and produces alpha particles. The alarm is designed with several advantages

(1) Americium does not have to be replaced frequently.
(2) If the ionisation is weak or strong, it does not matter. As long as the current is blocked by smoke particles, the alarm will be raised.

Question: Why an alpha source rather than beta or gamma?

____

____

Question: Suggest why background radiation varies in (a) different regions (b) at different times.

____

____

Background radiation

Most background radiation is from natural sources such as rocks and cosmic rays

Human activity accounts for less than 1% of background radiation. Examples include:

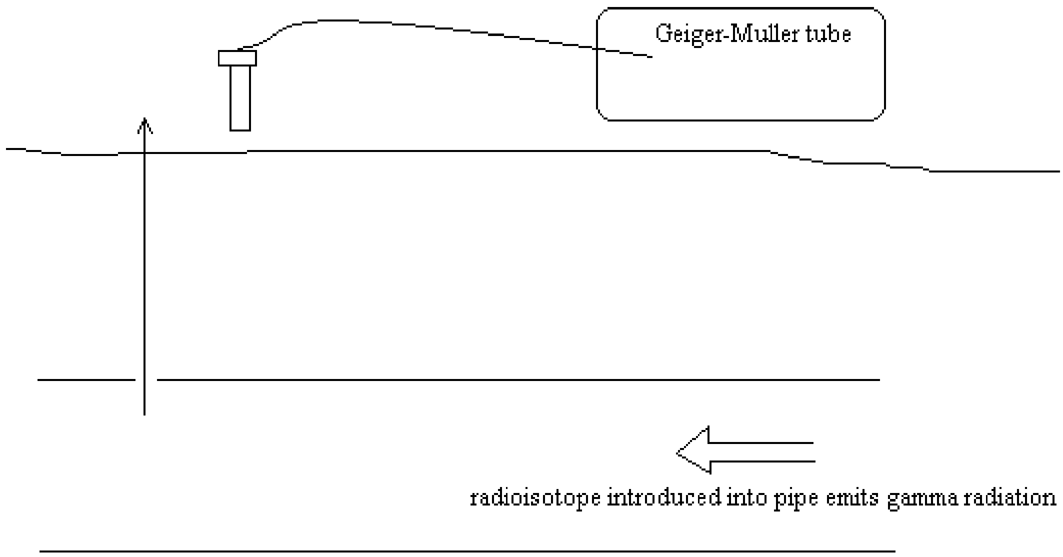
- Wastes from nuclear power stations and other industries
- Waste products from hospitals
- Man-made radioisotopes obtained by firing neutrons at stable nuclei, making them unstable and causing them to decay.

Question: What use would man-made isotopes be? Wastes from nuclear power stations can be used to sterilise medical equipment. How might this be an advantage over heart treatment?

____

____

How are tracers used in industry?



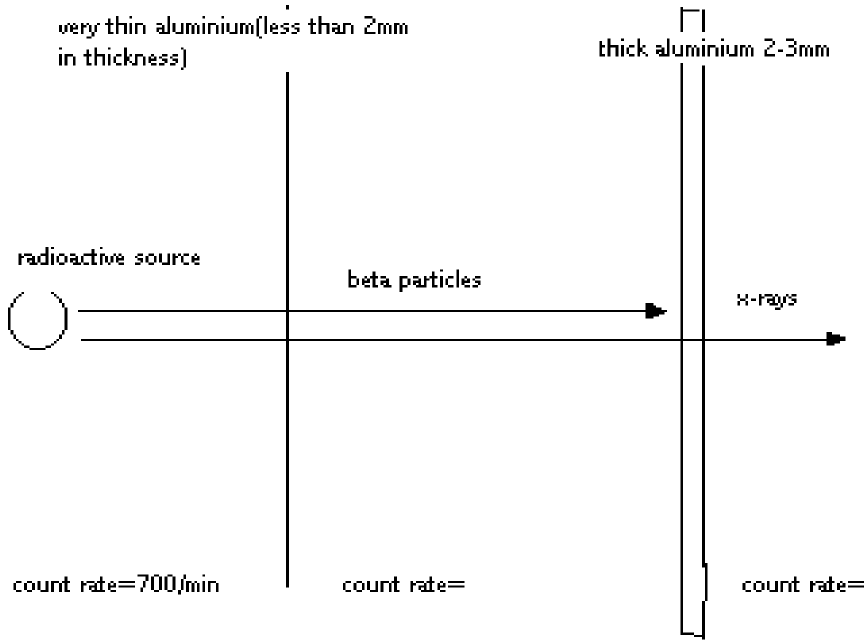
The detector is passed along the ground and the count rate increases when gamma radiation can pass freely out of a leak up to the detector.

Question: Why must a gamma source be used to detect a leak in an underground?

____

Question: It is thought that the mouth of a river is sitting up from one or two sites upstream. How could a tracer be used to locate which site is the source?

____



Now imagine that another radioactive source gives off 800 count per minute. When covered with paper the count rate is still 800 counts per minute. When covered with 3 ml of aluminium the count rate becomes 320 counts per minute.

Question: When covered with 3 cm of lead the count rate is the same as background i.e. 50 counts per minute. What type of radiation is being emitted by this source?

____

Dating rocks

Some rock types such as granite contain traces of uranium. All uranium isotopes are radioactive. These uranium isotopes go through a series of decays, eventually forming a stable isotope of lead.
By comparing the amounts of uranium and lead present in a rock sample, its approximate age can be found.

Radiocarbon-dating

Carbon-14 is a radioactive isotope of carbon. Carbon is present in all living things. By measuring the amount of carbon-14 present in an archaeological find, its approximate age can be found.

In 1947 a shepherd discovered the Dead Sea Scrolls in caves at Qumran in Jordan. Radioactive-carbon dating was used to estimate their age. They were found to be about 2000 years old and are likely to be genuine.

Question: Which of the following could **not** be dated using carbon-14?

Wool jumper wooden axe iron nail nylon shirt cotton sheet

Question: Why is lead always found with granite radioactive rocks?

____

____

Dating rocks and the radioactive series

Use of uranium-238

Uranium-238 decays with a very long half-life of 4500 million years, to form thorium which is also **unstable.**

Question: Complete the first two stages of this decay below for $^{238}_{92}U$. Firstly an alpha particle is emitted. Then a beta particle is emitted (eventually the decay series would produce lead).

A series of unstable isotopes is formed, all with relatively short half lives, until a stable isotope, lead-206 is formed (lead is the element with the highest atomic number that has stable isotopes.)

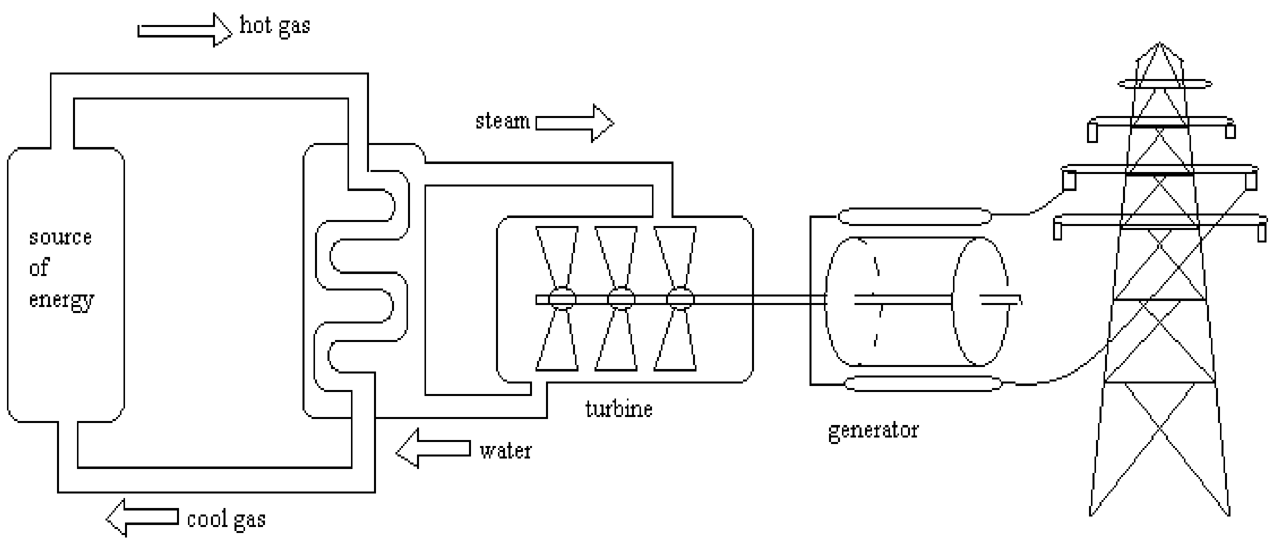
The ratio of uranium to lead in a sample of rock indicates the age of the rock. The proportion of lead increases as time increases. If there are equal quantities of

$^{238}_{92}U$ to $^{206}_{82}Pb$, the rock is 4500 million years old. (What is this in half lives?)

Fission – friend or foe?

Fission is the splitting of a large nucleus such as uranium to release energy. Fission was used with devastating effects in the atom bombs dropped on Hiroshima and Nagasaki in 1945.

Controlled fission can be used in nuclear power stations to produce electricity.



The stages of producing electricity in a power station.
What types of fuels can be used?

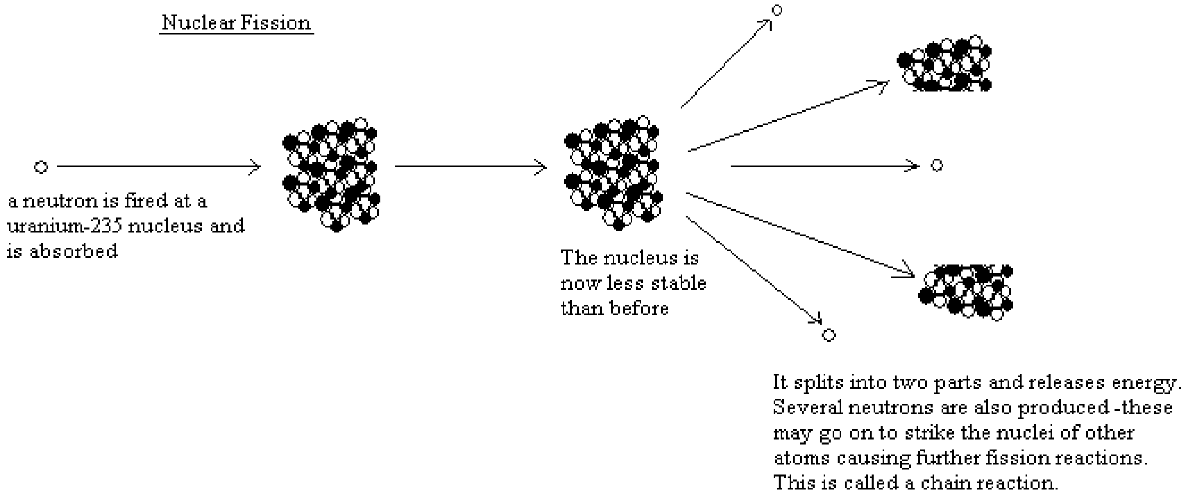
Question: Complete the text using the words that follow:

The source of energy could be burning ______ fuel or it could be the heat produced from a controlled chain reaction in uranium fuel rods. This heat makes a circulating gas convection current very ____. This very hot gas passes to an energy exchanger (label this on the diagram). As the hot gas passes through the pipes in the exchanger, it heats and _____ water around it, turning it into ______.

This highly pressurised steam then pushes against turbine blades making a ______ spin. The turbine is connected to a _______, which in turn spins. The generator is infact a massive ________ suspended between coils of wire (label these on the diagram). Whenever a moving magnetic _____ cuts a wire, a current is induced in that wire. As a result an alternating current (A.C) is produced in the coils of wire around the spinning magnet, which is fed into the ________ grid.

Possible words: National, field, electromagnet, generator, turbine, fossil, steam, boils, hot.

How does uranium release energy?



The decay of uranium-235 can be shown as:

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{90}_{36}Kr + ^{143}_{56}Ba \quad 3(^{1}_{0}n) + \gamma \text{ rays}$$

The extra electrons emitted cause a chain reaction and produce a large amount of energy.

Uranium-235 nuclei do not always split in the same way but extra neutrons are always emitted.

Uses of nuclear fuel

(1) An atomic bomb – if the uranium is above a certain critical size (about the size of a tennis ball), fission occurs spontaneously.
(2) A nuclear submarine is powered by a nuclear reactor in a similar way to a nuclear power station.

Question: In what way is fission?

(a) Similar to radioactive decay?

____

(b) Different to radioactive decay?

____

Question: The fission of a uranium-235 nucleus releases three neutrons that initiate a chain reaction. How many uranium nuclei can be split after four more stages of the chain reaction?

____

Remember: The fuel used in a nuclear power station contains a greater proportion of the uranium-235 isotope than occurs naturally. The fuel is called 'enriched uranium' and forms the fuel rods.

Chain reaction

A chain reaction can carry on for as long as any of the uranium fuel remains. This allows large amounts of energy to be produced.

- A chain reaction is uncontrolled in an atomic bomb whose power is many times that of ordinary bombs. It poses massive radiation risks to health.
- A chain reaction is controlled in a nuclear power station producing a steady supply of heat.

Artificial radioactivity

Materials can be made radioactive by putting them in a nuclear reactor. The atoms are bombarded with neutrons, which are absorbed by the nuclei, making unstable isotopes. Such man-made radioisotopes can be produced with different properties that make them ideal for different uses in:

- Hospitals to diagnose and treat patients
- Industry as tracers to detect leaks.

Question: Why are people still affected by the atomic bomb dropped on Hiroshima in 1945?

____

Question: How can materials be made radioactive?

____

Question: What is meant by the term 'chain reaction'?

____

Radioactive waste

Nuclear fission produces **radioactive waste**. This is a major problem since the waste products have to be handled carefully and disposed of safely.

Question: Complete the table using the text that follows:

Type of waste	Becomes low level radioactive waste	Becomes high level radioactive waste
Waste produced by medical applications		
Waste tracers produced in industry to detect leaks		
Spent radioactive uranium fuel rods from power stations.		

Medical equipment that could melt with heat treatment is sealed in bags and irradiated. It must be buried or incinerated	Such waste may be embedded in glass discs and buried in the sea.	They have to be reprocessed to make radioactive materials for reuse (Sellafield reprocessing plant).

Question: Magnesium sulphate is irradiated with neutrons in a reactor making radioactive magnesium – 28. A tiny amount of this radioisotope can be added to plant fertiliser. How might this be useful?

____

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Question: The radioisotope cobalt-60, used to treat cancers, is made by firing neutrons at cobalt-59.

What happens to:

(a) The atomic number of the cobalt nucleus?
(b) The mass number of the cobalt nucleus?

What type of radiation is emitted?

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Question: Suggest two problems associated with nuclear power stations (think transportation and disposal).

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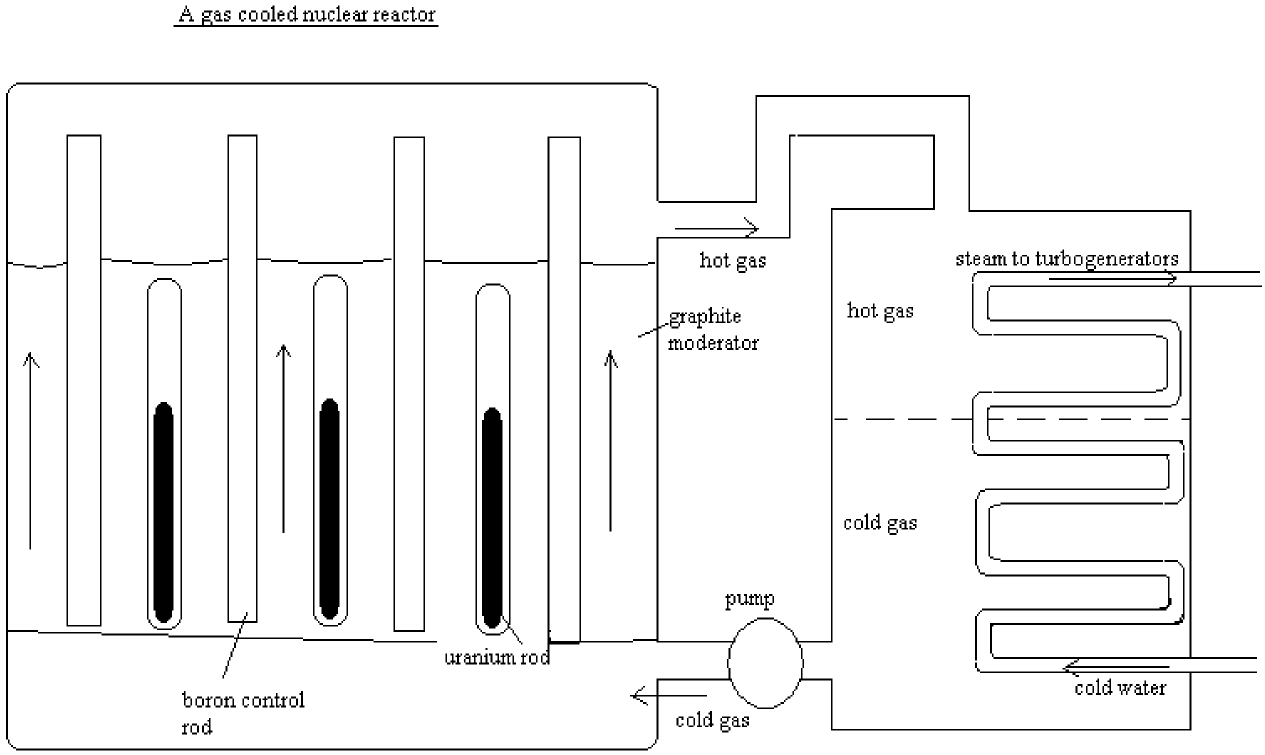
Controlling nuclear fission



Question: Complete the text using the words that follow:

Neutrons are fired at the ________ rods. The neutrons pass through the graphite moderator (colour this grey on the diagram) so that they pass at the correct speed. The nuclei split (fission) releasing highly energetic ________. These neutrons then pass from rod to ____ splitting more and more uranium nuclei releasing more and more heat energy.

Between the uranium rods are ______ control rods. These absorb excess neutrons and prevent an _______ chain reaction.

A cold gas is pumped into the reactor and it passes up through the graphite moderator around the rods, becoming very ____ as it does so. This hot gas then passes to the ______ exchanger. Here is a pipe through which cold water flows. The hot gas passes around this pipe and the heat boils the water producing ______.

(Colour the cold gas blue and the hot gas yellow)

Possible words: Steam, heat, hot, uncontrolled, boron, neutrons, rod, uranium

Decommissioning

A nuclear power station cannot be demolished nor the site developed for other purposes. The reactor building is embedded in thick concrete and left for approximately 150 years until radiation levels have become safe.

Question: The boron control rods in the reactor can be raised. Explain how this affects the energy produced.

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Nuclear fusion

Loads of energy is released when you break apart really big nuclei or join together really small nuclei.

Nuclear fusion – the joining of small atomic nuclei

Nuclear fusion is the opposite of nuclear fission. In nuclear fusion, two light nuclei combine to create a larger nucleus. The example you need to know is two atoms of different hydrogen isotopes combining to form helium:

$^{1}H + {}^{2}H = {}^{3}He$ + energy

Fusion releases a lot of energy (more than fission for a given mass). All the energy released in stars comes from fusion at extremely high temperatures and pressures. So people are trying to develop fusion reactors to make electricity.

Fusion does not leave behind much radioactive waste and there is plenty of hydrogen about to use as a fuel.

The big problem is that fusion only happens at really high temperatures and pressures (about 10 000^{o}C).

No material can physically withstand that kind of temperature and pressure – so fusion reactors are really hard to build.

It is also hard to safely control the high temperatures and pressures.

There are a few experimental reactors in operation at the moment. The biggest one is JET (joint European Torus), but none of them are generating electricity yet. It takes more power to get up to the temperature than the reactor can produce.

International groups carry out research into fusion power production. They share the costs, expertise, experience and benefits (when they eventually get it to work reliably).

Question: Explain the main differences between nuclear fission and nuclear fusion. Why is it easier to produce electricity at present with a nuclear fission power station than a nuclear fusion power station?

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Question: Write down the nuclear equation for the alpha decay of the following:

Complete the following radioactive symbol equations

$^{241}_{95}Am$ = __________ + alpha particle (α particle)

$^{90}_{38}Sr$ = __________________ + beta particle (β particle) + gamma radiation

<u>Question</u>: Give the proper definition of half-life.

<u>Question</u>: Briefly describe what nuclear radiation does to living cells.

<u>Question</u>: Why are alpha particles so good at ionising atoms?

<u>Question</u>: What is the main difference between X-rays and gamma rays?

<u>Question</u>: Describe in detail how radioactive sources are used in each of the following:

(a) Treating cancers

(b) Tracers in medicine

<u>Question</u>: Describe in detail how radioactive sources are used in each of the following:

(a) Tracers in industry

(b) Smoke alarms

<u>Question</u>: An odd bit of cloth was found to contain 1 part in 80 000 000 carbon-14. If carbon-14 decays with a half-life of 5730 years, find the age of the cloth.

Question: What type of particle is uranium-235 bombarded with in a nuclear reactor to make it split?

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Question: Explain how a chain reaction is created in a nuclear reactor.

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Question: Which creates the higher temperature and why? Is it nuclear fission or nuclear fusion?

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