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**GCSE key words**

Radioactivity  
Isotopes  
Half life

# Decommissioning

*As the first generation of nuclear power stations reaches the end of its useful life this article looks at what is involved in decommissioning them and how the process is affected by the properties of radioactive elements.*

*Above: Cutting up components from a disused reactor to pack into a waste container*

The world's first use of nuclear energy to produce electricity on a commercial scale was in 1956 at Calder Hall in Cumbria. This paved the way for the magnox series of power reactors. These first-generation gas cooled reactors are now reaching the end of their useful life and a staged programme to close and decommission them has already begun.

The processes involved in decommissioning are all complicated by hazards due to radiation. In the case of a magnox reactor the process is more difficult because there were a number of different designs and because, unlike modern reactors, they were not designed with decommissioning in mind.

The name magnox comes from the magnesium oxide casing of the uranium metal fuel.

## WHAT IS DECOMMISSIONING?

Decommissioning is the series of activities through which a nuclear reactor is taken out of service. It may include operations such as decontamination of equipment and buildings, dismantling and demolition, management of the resulting wastes and restoration of the land under and around the reactor.

## WHEN DOES IT HAPPEN?

Decommissioning is generally carried out in a series of stages (see Figure 1). When a nuclear reactor reaches the end of its operating life, the nuclear fuel, any mobile nuclear material in the plant and the radioactive waste produced by the plant are usually removed immediately.

Certain other parts of the reactor can be taken out but this is not done straight away because it would

Figure 1 Stages of decommissioning

Operational phase	Stage 1	Stage 2	Stage 3
	Remove fuel and coolant Post-operational clean out Manage mobile radioactivity Remove non-fixed plant	Dismantle plant outside of biological shielding	Remove remainder of plant Return site to condition where no significant radioactive hazard remains

Plant shutdown Time →



The queen in the turbine hall at the opening of Calder Hall, the world's first nuclear power station, 1956

Topham/PA



Removing the heat exchanger through the dome of Windscale's advanced gas cooled reactor using the world's largest crane. The metal could not be decontaminated so the entire exchanger has been buried in low-level waste disposal (an engineered trench lined with concrete)

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# a nuclear reactor

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## BOX 1 TYPES OF RADIATION

**Gamma rays** are electromagnetic radiation with the speed of light. They have great penetrating power and can pass through the human body. Thick barriers of concrete, lead or water are used to stop them.

**Beta particles** are fast-moving electrons which travel at about 90% of the speed of light. They can penetrate up to 2 cm of human flesh. A sheet of aluminium a few millimetres thick can stop them.

**Alpha particles** consist of two neutrons and two protons and travel at about 10% of the speed of light. They have little penetrating power and can be stopped by a sheet of paper. However, if alpha emitting radionuclides are inhaled or ingested, the alpha particles can cause damage to the body's cells as they lose their energy quickly over relatively short distances.

**Neutron radiation** is very penetrating and requires thick barriers of concrete to stop it.

expose workers to unnecessarily high levels of radiation. These high levels result mainly from gamma-emitting radionuclides produced by **activation** of the construction materials of the reactor, especially the core, shielding and pressure vessels.

In magnox reactors the most dominant radionuclide is typically Co-60 in the activated steelwork. Co-60 has a half life of 5.27 years, so it will decay naturally in a few decades and there will then be a much smaller radiation dose to decommissioning workers (but see Box 3). If decommissioning had to be done immediately, robots could be used, but this would be more difficult and costly.

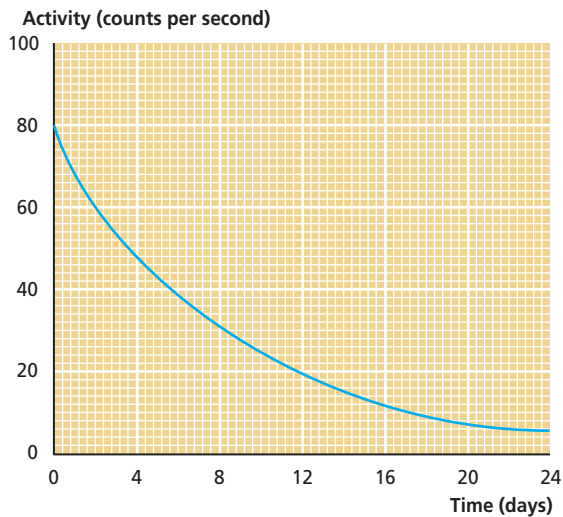


Figure 2 Graph to show how radioactive decay changes over time

**Activation** occurs when elements in structural components such as steels are changed to radioactive isotopes by neutron bombardment, e.g. natural Co-59 in steel can absorb a neutron to produce radioactive Co-60.

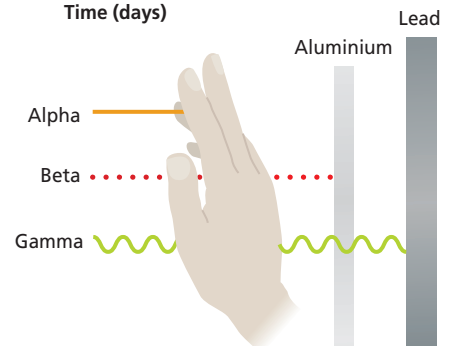


Figure 3 The penetration of different types of radiation

Radioactive decay is not the only factor to take into account when working out the time scale for decommissioning. Other safety factors are also important. **Conventional safety** includes assessing the structural stability of the reactor containment and support structures over the time period proposed. **Environmental factors** include consideration of the impact of radionuclides leaching into the environment and possible ways in which accidental releases of radioactive elements could occur.



	Element	Half-life
α	uranium-238	$4.5 \times 10^9$ years
β	thorium-234	24.5 days
β	protactinium-234	1.14 minutes
α	uranium-234	$2.33 \times 10^5$ years
α	thorium-230	$8.3 \times 10^4$ years
α	radium-226	1590 years
α	radon-222	3.825 days
α	polonium-218	3.05 minutes
β	lead-214	26.8 minutes
β	bismuth-214	19.7 minutes
α	polonium-214	$1.5 \times 10^{-4}$ seconds
β	lead-210	22 years
β	bismuth-210	5 days
α	polonium-210	140 days
	lead-206	stable

Figure 4 Decay chain for uranium-238

## BOX 2 RADIOACTIVE DECAY

Radioactive decay is the process by which an unstable isotope changes into another isotope of a different element, or into a less energetic form of the same isotope by emitting alpha, beta or gamma radiation. If the decay product is also unstable, decay continues until a stable product is reached.

The rate of decay of a particular radionuclide is constant. The time taken for a quantity of a radionuclide to decay to half its original mass is called the **half-life** and is characteristic of that particular radionuclide. For example, the half-life of radium is about 1600 years, so 1 g of radium decays to 0.5 g in 1600 years and to 0.25 g in 3200 years. Of course the radium does not disappear — it changes into its daughter products. The total mass does not change appreciably, for the loss in mass in the form of alpha and beta particles is negligible.

Figure 4 shows the radioactive series for uranium and the way it changes to eventually become stable lead. Throughout the decay process, all the products remain in equilibrium with each other. The half-lives of the radioactive elements vary over a wide range: some are only fractions of a second while others are thousands of years.

## BOX 3 IT'S NOT ALWAYS BEST TO WAIT

Radioactive decay may not always work to the decommissioners' advantage. Decommissioning a plutonium-contaminated laboratory, for example, is best carried out as soon as possible after the facility is shut down. This is because the plutonium decay chain (Pu-241 has a half life of 13.2 years) proceeds via a long-lived high-energy gamma emitter called americium-241 (which has a half life of 458 years). Over time this will build up, making decommissioning a more hazardous operation the longer it is left.

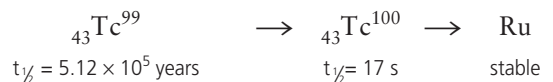
Table 1 Advantages and disadvantages of deferring decommissioning

Advantages	Disadvantages
Radiation doses to decommissioning workers are reduced	Need to retain knowledge of the plant over a long period
Opportunity to develop better or improved dismantling technologies	Need to maintain the facility in a safe and secure condition
The cost is deferred	Need to keep money available for a long time

Some advantages and disadvantages of deferring decommissioning are shown in Table 1.

## ACCELERATING THE DECAY PROCESS

Imagine if, instead of it taking hundreds or thousands of years for long-lived radionuclides to decay naturally, the decay process could be accelerated. Scientists, particularly in France and the US, are attempting to do just that using linear accelerators to bombard the radionuclides with neutrons and transmute them into non-radioactive elements. For example, long-lived technetium-99 will absorb a neutron to become technetium-100 which undergoes complete radioactive decay to stable ruthenium within minutes.



Making the transmutation process work is technically very challenging and requires difficult chemical separations of the nuclides before it can begin. However, the goal of eliminating the radiological hazard from nuclear waste, just like the original alchemist's dream of transmuting base metals to gold, continues to spur on this type of research.

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An unstable isotope is called a **radionuclide**.

● Find out about radioactivity on the BBC Bitesize website at: <http://www.bbc.co.uk/schools/gcsebitesize/physics/radioactivity/index.shtml>



Workers underneath the main part of the Windscale advanced gas cooled reactor removing parts that might be contaminated

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