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About 20% of the UK's electricity supplies come from nuclear power stations. Many of these power stations are approaching the ends of their working lives. What are the future prospects for nuclear power?

A nuclear future?

GCSE key words
Nuclear energy
Nuclear fission
Isotopes
Radioactive decay

France, which has only small reserves of fossil fuels, produces 75% of its electricity using nuclear power.

Namibia in southern Africa is the biggest producer of uranium ore.

The nuclear industry starts with uranium mines. Uranium is the fuel for most nuclear power stations (some use plutonium), and uranium-rich minerals are found in many parts of the world, including Namibia, Canada and Russia. Uranium is the heaviest element found in nature — its atomic number is 92 — and it is a concentrated store of energy (see Box 1).

Natural uranium consists almost entirely of two isotopes, ^{235}U and ^{238}U, with different numbers of neutrons in their atomic nuclei. Both are radioactive, and so they gradually decay away. However, their half-lives are very long, so their stored energy is released only very slowly.

FAST REACTIONS

The nuclear reactor at the heart of every nuclear power station is designed to speed up the release of energy from uranium. It makes use of the fact that atoms of ^{235}U can be split in a process called **nuclear fission**, releasing much more energy than simple radioactive decay.

Here's how fission works (see Figure 1). A single neutron strikes the nucleus of a ^{235}U atom. The neutron is absorbed, but the nucleus is now highly unstable, and it splits in two. In the process, two or three neutrons are released. Energy is released during fission, some in the form of gamma radiation, and some as the kinetic energy of the particles which fly apart at high speed.

The next trick is to establish a **chain reaction**. If, on average, just one of the neutrons released by one nucleus goes on to split another nucleus, and so on, we have an ongoing chain reaction, releasing energy at a steady rate. The uranium gets hot. If *more* than one neutron goes on to cause further fission, the reaction escalates out of control, and we have a nuclear explosion. The design of reactors in power stations makes this impossible.

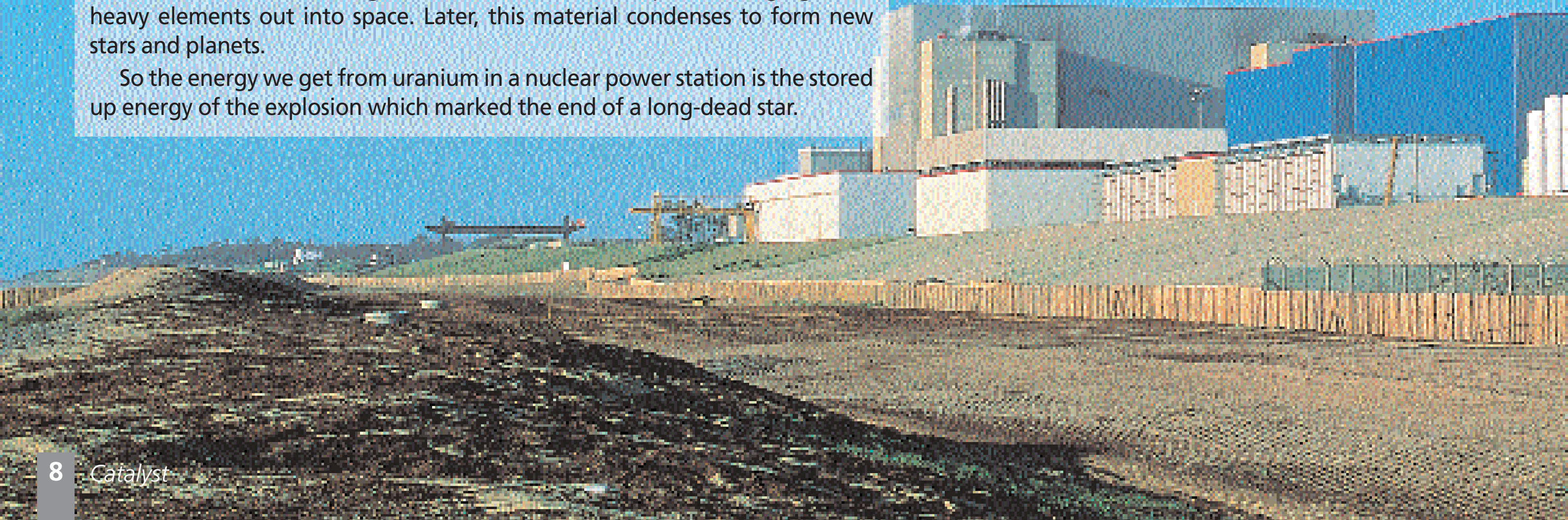
The daughter nuclei formed when a ^{235}U nucleus splits are highly radioactive, and release more energy as they decay. However, they do not decay entirely during the lifetime of the reactor, so the material inside the reactor core is dangerously radioactive. This is one of the big problems with nuclear power.

BOX 1 THE ENERGY OF STARDUST

Uranium has been here since the Earth formed. But how did it get here? Uranium atoms were present in the cloud of dust and gas from which the solar system formed. They have their origins in a massive stellar explosion — a supernova — which occurred billions of years ago.

When massive stars die, they collapse inwards, causing enormously high pressures and temperatures. In these conditions, medium-sized atoms such as iron and nickel are forced together and merge (fuse) to form atoms of the heaviest elements, including uranium. The star then explodes, flinging these heavy elements out into space. Later, this material condenses to form new stars and planets.

So the energy we get from uranium in a nuclear power station is the stored up energy of the explosion which marked the end of a long-dead star.



Sizewell nuclear power station in Suffolk. Below is Sizewell A, an advanced gas-cooled reactor, and on the right, with the white dome, is Sizewell B, the UK's first pressurised water reactor.

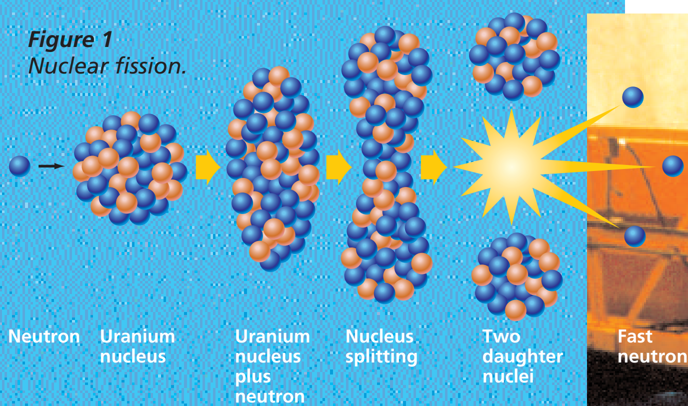


Figure 1 Nuclear fission.

CORE STRUCTURE

The core of a nuclear reactor is quite complex (see Figure 2).

- The **fuel** is in the form of rods. These can be withdrawn and replaced when they are spent.
- A **moderator**, such as graphite or water, helps to slow down the neutrons, so that they interact more with the uranium nuclei. Without moderation, they would mostly escape from the core.
- **Control rods**, made of boron or cadmium, absorb neutrons to keep the chain reaction at the desired level. In an emergency they drop into the core automatically.
- The **coolant**, water or carbon dioxide, carries the heat out of the core.

The coolant is used to generate high-pressure steam, just as in a coal or gas-fired power station. The steam turns turbines, which cause generators to spin and produce electricity.

Positioning a fuel rod crane over the reactor core of a US nuclear power station. To the right of the crane is the new fuel rod ready for insertion. The top of the reactor core is covered with 10 m of water to protect workers from radioactivity.

US Department of Energy/SPL

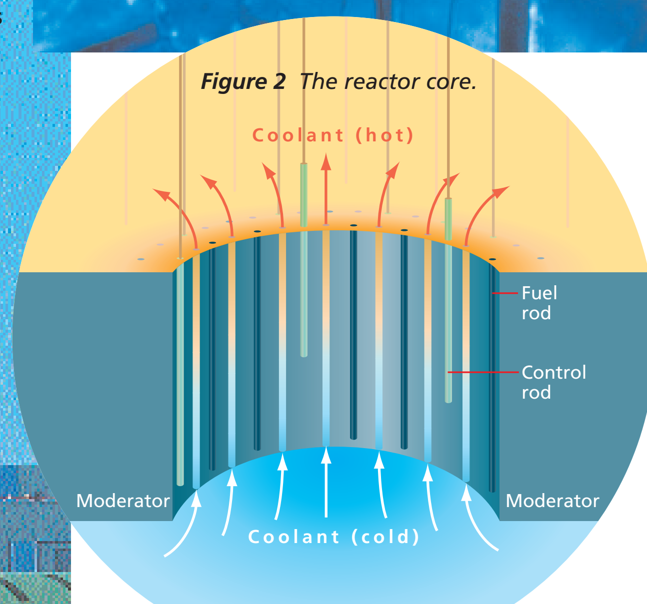


Figure 2 The reactor core.

In a nuclear reactor, some uranium atoms are transformed to even heavier elements such as plutonium and americium.

- **Explain why, when the Earth formed, there must have been a higher proportion of ^{235}U than there is today.**

Martin Bond/SPL

Table 1 The two most common isotopes of uranium. The most useful isotope, ^{235}U, makes up only 0.7% of mined uranium

Isotope	Number of protons	Number of neutrons	Proportion in natural uranium	Half-life (millions of years)
^{235}U	92	143	0.7%	710
^{238}U	92	146	99.3%	4500

US Department of Energy/SPL

***Left:** Decommissioning of a pressurised water reactor at Shippingport, USA. It was built in the 1950s and shut down in 1982. Here the wall from the reactor pit is being removed.*

ENVIRONMENTAL QUESTIONS

Nuclear power is being used increasingly, particularly in Europe and North America. One argument in favour of its use is that it does not produce greenhouse gases, unlike power stations which burn fossil fuels. So is nuclear power 'clean'?

Of course not. To appreciate the problems, we need to think about the complete fuel cycle, starting with mining. Uranium ore contains only a small percentage of uranium, and extracting it produces large volumes of radioactive waste. The uranium is then usually enriched, to increase the proportion of ^{235}U relative to ^{238}U. More waste results.

Once the fuel rods are spent, they must be removed from the core and replaced. The old rods are highly radioactive, and must be cooled in large tanks of water for several months before they can be taken away and stored. Sometimes the spent fuel is reprocessed; this is what happens at Sellafield in Cumbria. The idea is to extract any remaining ^{235}U and re-use it; plutonium is also separated, for use in reactors or bombs. The most hazardous waste products are concentrated, with the intention of storing them safely. However, no-one is sure how best to do this. The problem will be around for thousands of years, because of the long half-lives of the substances involved.

At the end of its life, a power station must be decommissioned. It is dismantled, and the most radioactive parts are taken away for safe storage. The site is eventually levelled and is unlikely to be fit for other uses for several decades.

PROLIFERATING CONCERNS

In practice, nuclear power stations have proved relatively safe. There have been some spectacular accidents — notably the fire at Chernobyl in the Ukraine in 1986, which resulted in thousands of deaths and illnesses. The UK's nuclear stations have been carefully operated, but many are now reaching the ends of their lives. Should they be replaced?

In fact, there is a glut of electricity, and prices have fallen. Most new power stations use natural gas (a fossil fuel), and nuclear power cannot produce electricity as cheaply as these. Are we being short-sighted, burning gas which is a non-renewable resource and which contributes to climate change?

Keep an eye on these questions. The government is developing an energy strategy for the next 20 years. Will it give the nuclear industry a new lease of life?

***David Sang** writes textbooks and is an editor of* CATALYST.

Answers to brine shrimp puzzle, page 6

Hidden word:

HERBIVORES