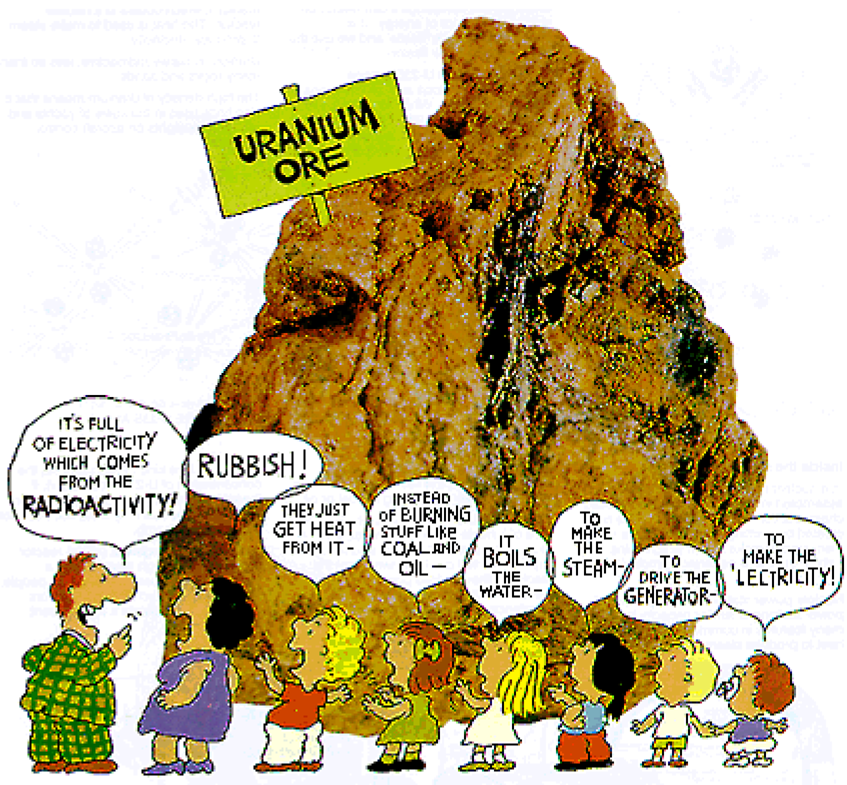
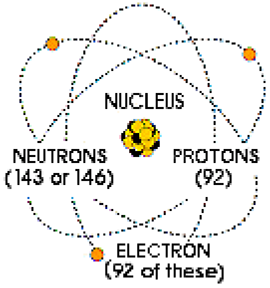
WHAT IS URANIUM?

How does it work?



- Uranium is a very heavy (dense) metal which can be used as an **abundant source of concentrated energy**.
- It **occurs in most rocks** in concentrations of 2 to 4 parts per million and is as common in the earth's crust as tin, tungsten and molybdenum. It occurs in seawater, and could be recovered from the oceans if prices rose significantly.
- It was **discovered in 1789** by Martin Klaproth, a German chemist, in the mineral called pitchblende. It was named after the planet Uranus, which had been discovered eight years earlier.
- Uranium was apparently **formed in super novae** about 6.6 billion years ago. While it is not common in the solar system, today its radioactive decay provides the **main source of heat inside the earth**, causing convection and continental drift.



- The **high density** of uranium means that it also finds uses in the keels of yachts and as counterweights for aircraft control surfaces (rudders and elevators), as well as for radiation shielding.
- Its melting point is 1132°C. The **chemical symbol** for uranium is U.

The Uranium Atom

On a scale arranged according to the increasing mass of their nuclei, uranium is the heaviest of all the naturally-occurring elements (Hydrogen is the lightest). Uranium is 18.7 times as dense as water.

Like other elements, uranium occurs in slightly differing forms known as 'isotopes'. These isotopes (16 in the case of uranium) differ from each other in the number of particles (neutrons) in the nucleus. 'Natural' uranium as found in the earth's crust is a mixture largely of two isotopes: uranium-238 (U-238), accounting for 99.3% and U-235 about 0.7%.

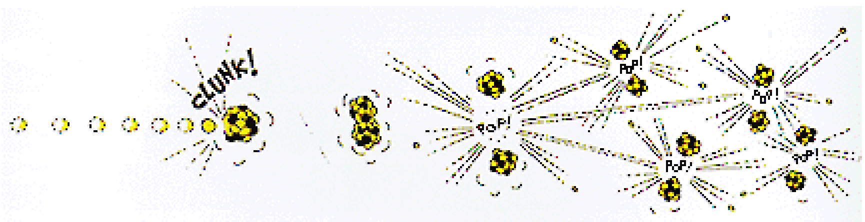
The isotope U-235 is important because under certain conditions it can readily be split, yielding a lot of energy. It is therefore said to be 'fissile' and we use the expression 'nuclear fission'

Meanwhile, like all radioactive isotopes, it decays. U-238 decays very slowly, its half-life being the same as the age of the earth (4500 million years). This means that it is barely radioactive, less so than many other isotopes in rocks and sand. Nevertheless it generates 0.1 watts/tonne and this is enough to warm the earth's core.

Energy from the uranium atom

The nucleus of the U-235 atom comprises 92 protons and 143 neutrons (92 + 143 = 235). When the nucleus of a U-235 atom captures a neutron it splits in two (fissions) and releases some energy in the form of heat, also two or three additional neutrons are thrown off. If enough of these expelled neutrons cause the nuclei of other U-235 atoms to split, releasing further neutrons, a fission شchain reactionص can be achieved. When this happens over and over again, many millions of times, a very large amount of heat is produced from a relatively small amount of uranium.

It is this process, in effect "burning" uranium, which occurs in a nuclear reactor. The heat is used to make steam to produce electricity.



Inside the reactor

In a nuclear reactor the uranium fuel is assembled in such a way that a controlled fission chain reaction can be achieved. The heat created by splitting the U-235 atoms is then used to make steam which spins a turbine to drive a generator, producing electricity.

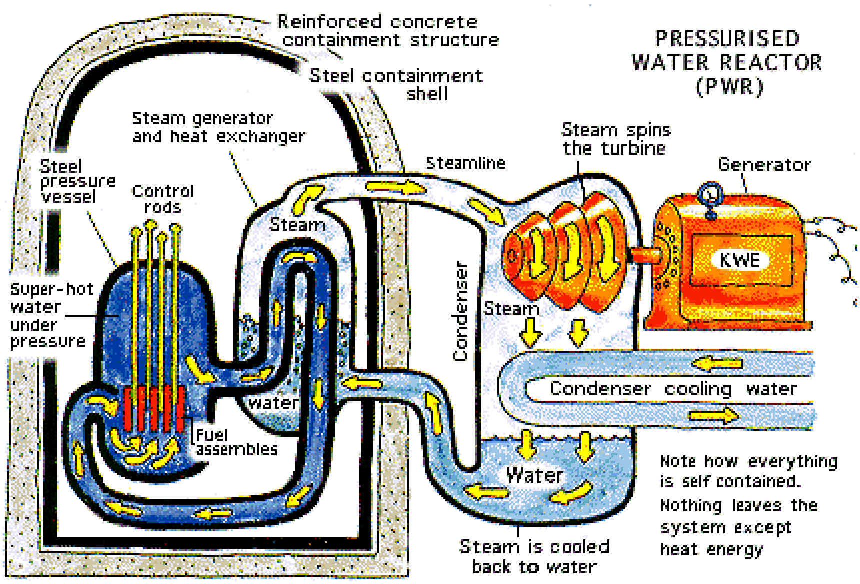
Nuclear power stations and fossil-fuelled power stations of similar capacity have many features in common. Both require heat to produce steam to drive turbines and generators. In a nuclear power station, however, the fissioning of uranium atoms replaces the burning of coal or gas .

The chain reaction that takes place in the core of a nuclear reactor is controlled by rods which absorb neutrons and which can be inserted or withdrawn to set the reactor at the required power level.

The fuel elements are surrounded by a substance called a moderator to slow the speed of the emitted neutrons and thus enable the chain reaction to continue. Water, graphite and heavy water are used as moderators in different types of reactors.

Because of the kind of fuel used (ie the concentration of U-235, see below), if there is a major uncorrected malfunction in a reactor the fuel may melt, but it cannot explode like a bomb.

A typical 1000 megawatt (MWe) reactor can provide enough electricity for a modern city of close to one million people. About 35 such nuclear reactors could provide Australia's total electricity needs.



Uranium and Plutonium

Whereas the U-235 atom is 'fissile', the U-238 atom is said to be 'fertile'. This means that it can capture one of the neutrons which are flying about in the core of the reactor and become (indirectly) plutonium-239, which is fissile. Pu-239 is very much like U-235, in that it fissions when hit by a neutron and this also yields a lot of energy.

Because there is so much U-238 in a reactor core (most of the fuel), these reactions occur frequently, and in fact about one third of the energy yield comes from "burning" Pu-239.

But sometimes a Pu-239 atom simply captures a neutron without splitting, and it becomes Pu-240. Because the Pu-239 is either progressively "burned" or becomes Pu-240, the longer the fuel stays in the reactor the more Pu-240 is in it.*

* The significance of this is that when the spent fuel is removed after about three years, the plutonium in it is not suitable for making weapons but can be recycled as fuel.

From uranium ore to reactor fuel

Uranium ore can be mined by underground or open-cut methods, depending on its depth. After mining, the ore is crushed and ground up. Then it is treated with acid to dissolve the uranium, which is then recovered from solution.

Uranium may also be mined by in situ leaching (ISL), where it is dissolved from the orebody in situ and pumped to the surface.

The end product of the mining and milling stages, or of ISL, is uranium oxide concentrate (U_3O_8). This is the form in which uranium is sold.

Before it can be used in a reactor for electricity generation, however, it must undergo a series of processes to produce a useable fuel.

For most of the world's reactors, the next step in making a useable fuel is to convert the uranium oxide into a gas, uranium hexafluoride (UF_6), which enables it to be enriched. Enrichment increases the proportion of the uranium-235 isotope from its natural level of 0.7% to 3 - 4%. This enables greater technical efficiency in reactor design and operation, particularly in larger reactors, and allows the use of ordinary water as a moderator.

After enrichment, the UF_6 gas is converted to uranium dioxide (UO_2) which is formed into fuel pellets. These fuel pellets are placed inside thin metal tubes which are assembled in bundles to become the fuel elements for the core of the reactor.

For reactors which use natural uranium as their fuel (and hence which require graphite or heavy water as a moderator) the U_3O_8 concentrate simply needs to be refined and converted directly to uranium dioxide.

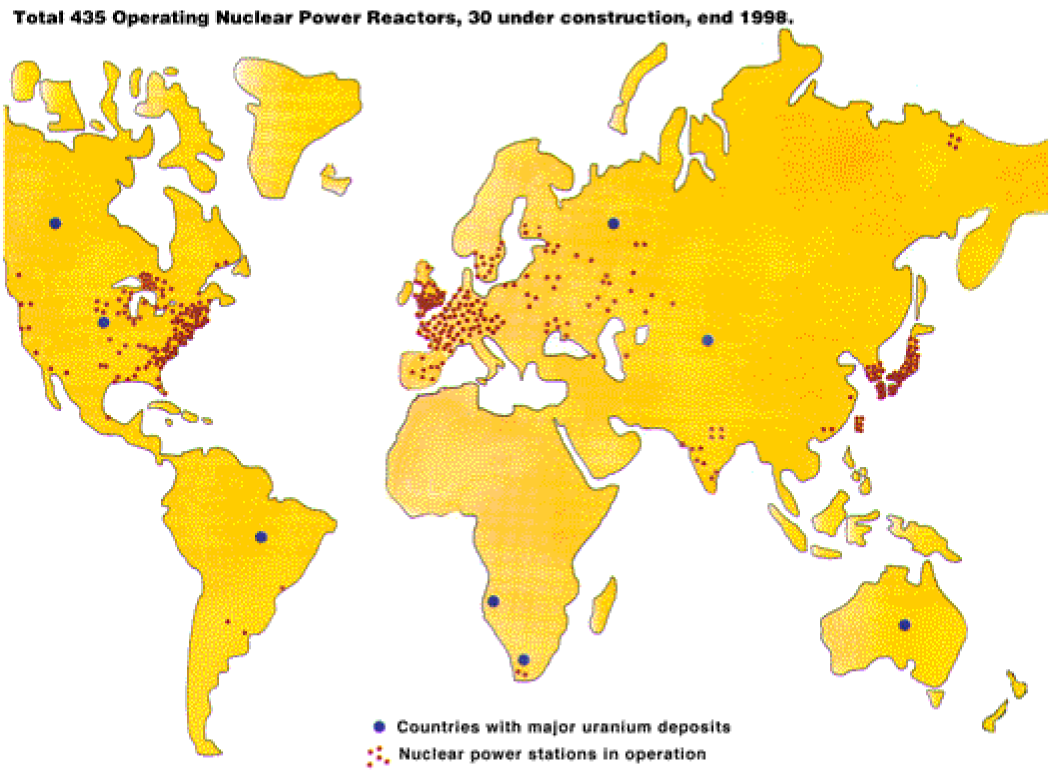
Spent reactor fuel is removed, stored, and then either reprocessed or disposed of underground (see Nuclear Fuel Cycle or Radioactive Waste Management in this series).

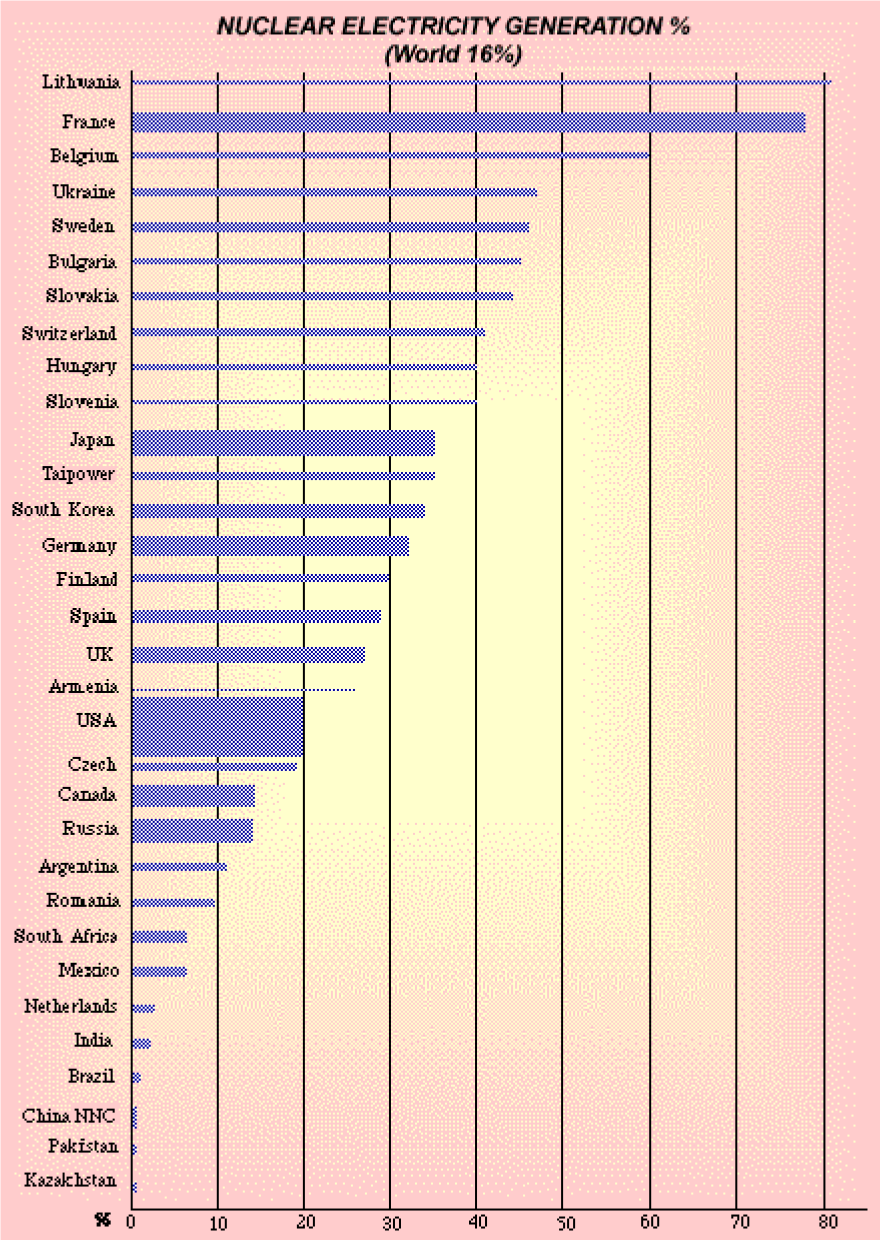
Who uses nuclear power?

Over 16% of the world's electricity is generated from uranium in nuclear reactors. This amounts to about 2400 billion kWh each year, as much as from all sources of electricity worldwide in 1960. In a current perspective, it is twelve times Australia's or

South Africa's total electricity production, five times India's, twice China's and 500 times Kenya's total.

It comes from over 430 nuclear reactors with a total output capacity of more than 350 000 megawatts (MWe) operating in 31 countries. A further thirty reactors are under construction, and another 70 are on the drawing board.





Belgium, Bulgaria, Finland, France, Germany, Hungary, Japan, South Korea, Lithuania, Slovakia, Slovenia, Sweden, Switzerland and Ukraine all get 30% or more of their electricity from nuclear reactors. The USA has over 100 reactors operating, with capacity of almost three times Australiaےs total, and supplying 20% of its electricity. The UK gets almost a quarter of its electricity from uranium.

Table of the World's Nuclear Power Reactors

Who has and who mines uranium?

Uranium is widespread in many rocks, and even in seawater. However, like other metals, it is seldom sufficiently concentrated to be economically recoverable. Where it is, we speak of an orebody. In defining what is ore, assumptions are made about the cost of mining and the market price of the metal. Uranium reserves are therefore calculated as tonnes recoverable up to a certain cost.

Australiaصs reasonably assured resources of uranium are 667,000 tonnes U recoverable at up to US$80/kg U (about three times the market شspotص price), Canada's are 326,000 tonnes U. Australiaصs reserves are about 28% of the worldصs total, Canada's 14%.

Although it has more than any other country, Australia is not the only one with major deposits. Others in order are: Kazakhstan (15% of world total), Canada, South Africa, Namibia, Brazil, Russia and USA (3%). Many more countries have smaller deposits which could be mined if needed.

Despite being so well-endowed with uranium reserves, political factors mean that Canada is well in front of Australia as the main supplier of uranium to world markets.

Uranium is sold only to countries which are signatories of the Nuclear Non-Proliferation Treaty, and which allow international inspection to verify that it is used only for peaceful purposes. Customer countries for Australia's uranium must also have a bilateral safeguards agreement with Australia. Canada has similar arrangements.

Australian exports in 2000-01 amounted to almost 10,000 tonnes of U_3O_8 valued at nearly A$500 million. This was about 24% of world mine production of uranium. Canada produced almost 13,000 tonnes of U_3O_8.

Other uses of nuclear energy

Many people, when talking about nuclear energy, have only nuclear reactors (or perhaps nuclear weapons) in mind. Few people realise the extent to which the use of radioisotopes has changed our lives over the last few decades.

Using relatively small special-purpose nuclear reactors it has become possible to make a wide range of radioactive materials (radioisotopes) at low cost. For this reason the use of artificially produced radioisotopes has become widespread since the early 1950s, and there are now some 270 "research" reactors in 59 countries producing them.

Radioisotopes
In our daily life we need food, water and good health. Today, radioactive isotopes play an important part in the technologies that provide us with all three. They are produced by bombarding small amounts of particular elements with neutrons.

In **medicine**, radioisotopes are widely used for diagnosis and research. Radioactive chemical tracers emit gamma radiation which provides diagnostic information about a person's anatomy and the functioning of specific organs. Radiotherapy also employs radioisotopes in the treatment of some illnesses, such as cancer. More powerful gamma sources are used to sterilise syringes, bandages and other medical equipment. About one in two Australians is likely to experience the benefits of nuclear medicine in their lifetime, and gamma sterilisation of equipment is almost universal.

In the **preservation of food**, radioisotopes are used to inhibit the sprouting of root crops after harvesting, to kill parasites and pests, and to control the ripening of stored fruit and vegetables. Irradiated foodstuffs are accepted by world and national health authorities for human consumption in an increasing number of countries. They include potatoes, onions, dried and fresh fruits, grain and grain products, poultry and some fish. Some prepacked foods can also be irradiated.

In the growing **crops** and breeding **livestock**, radioisotopes also play an important role. They are used to produce high yielding, disease and weather resistant varieties of crops, to study how fertilisers and insecticides work, and to improve the productivity and health of domestic animals.

Industrially, and in mining, they are used to examine welds, to detect leaks, to study the rate of wear of metals, and for on-stream analysis of a wide range of minerals and fuels.

There are many other uses. A radioisotope derived from the plutonium formed in nuclear reactors is used in most household **smoke detectors**.

Radioisotopes are used by police to fight crime, in detecting and analysing pollutants in the environment, to study the movement of surface water and to measure water runoffs from rain and snow, as well as the flow rates of streams and rivers.

Other reactors

There are also other uses for reactors. Over 200 small nuclear reactors power some 150 ships, mostly submarines, but ranging from icebreakers to aircraft carriers. These can stay at sea for long periods without having to make refuelling stops. The worldصs first nuclear powered container ship was built in Russia.

The heat produced by nuclear reactors can also be used directly rather than for generating electricity. In Sweden and Russia, for example, it is used to heat buildings and to provide heat for a variety of industrial processes such as water desalination.

Military weapons

Both uranium and plutonium were used to make bombs before they became important for making electricity and radioisotopes. But the type of uranium and plutonium for bombs is different from that in a nuclear power plant. Bomb-grade uranium is highly-enriched (>90% U-235, instead of about 3.5%); bomb-grade plutonium is fairly pure (>90%) Pu-239 and is made in special reactors.

Today, due to disarmament, a lot of military uranium is becoming available for electricity production. The military uranium is diluted about 25:1 with depleted uranium (mostly U-238) from the enrichment process before being used.

Australia's reactor
Australia has no nuclear reactors supplying electricity. However, it has a small (10 megawatt) old research reactor at Lucas Heights near Sydney which is due to be replaced by a more modern 20 megawatt unit in 2005.

The Australian Nuclear Science and Technology Organisation's HIFAR reactor has operated since 1958. Its main work is providing an intense source of neutrons for research teams studying physics and other properties of various materials. In addition, it produces a wide range of medical and industrial radioisotopes for Australian hospitals and industry. Some of these isotopes are exported to nearby South-East Asian countries and New Zealand.

To investigate:

- How did uranium and plutonium get their names?
- What other element associated with them was named similarly? (It is actually between U-238 and Pu-239!).
- When was the first nuclear reactor run?
- When was the first electricity made by commercial nuclear power plants?
- Which were the first three countries to have nuclear electricity?
- Which country has all its (14+) nuclear reactors running on natural (unenriched) uranium?
- What materials are used for control rods in a reactor core?
- Which countries are most actively expanding their nuclear generating capacity?

Appenndix: See UIC Physics of Uranium

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