

Learning more about

plutonium

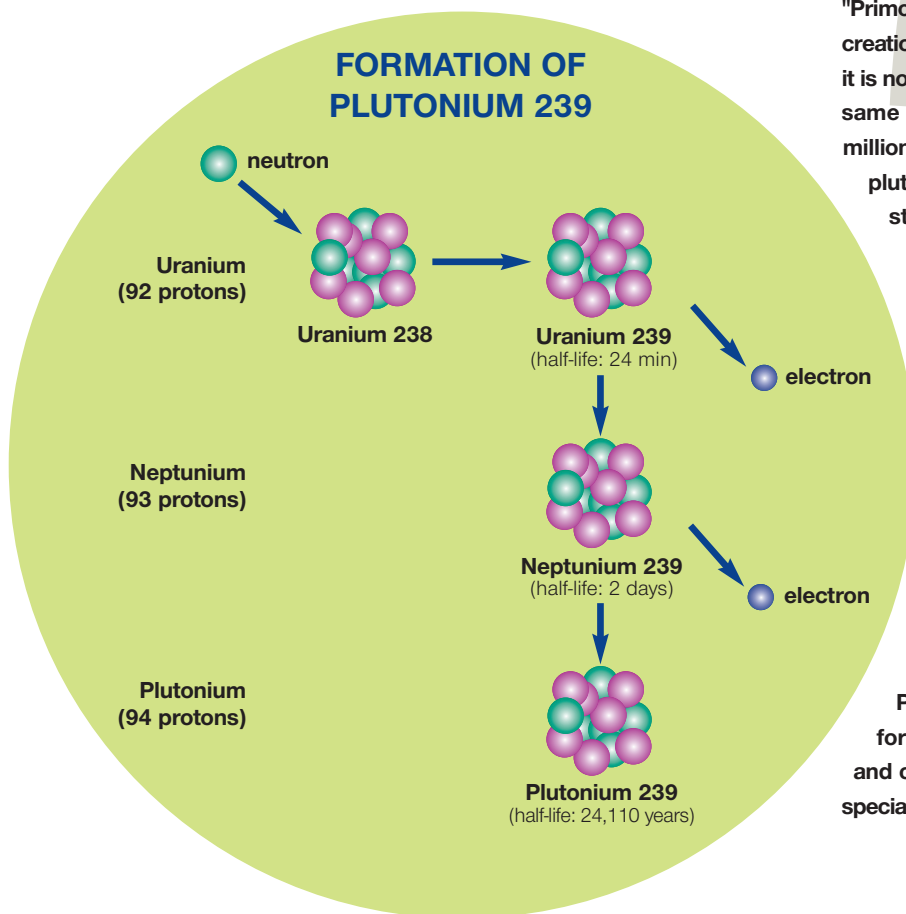
What is plutonium?

Plutonium (PU) is a hard white metal that looks like iron. It melts at 640° Celsius, turns into plutonium oxide when exposed to air and can catch fire. Plutonium is called a “radioelement” because it is radioactive. Like all other atoms, it consists of a nucleus made of neutrons and protons and of electrons. Since the plutonium nucleus has 94 protons, plutonium occupies the 94th position on the periodic chart of universal elements.

Though the plutonium nucleus always has 94 protons, the number of neutrons varies by isotope. There are fifteen plutonium isotopes, ranging from plutonium 232 (94 protons and 138 neutrons) to plutonium 246 (94 protons and 152 neutrons).

The plutonium isotopes most widely used in the commercial nuclear industry are plutonium 239, 240 and 241. Due to excess material, the plutonium nucleus is unstable. Equilibrium is restored through a reaction that releases particles and emits rays. This reaction is called radioactivity.

Where does plutonium come from?



"Primordial" plutonium 239 was formed during the creation of the universe. With a half life of 24,110 years, it is now long gone. Only plutonium 244, formed at the same time, remains in trace amounts due to its 83 million year half-life. Today, infinitesimal quantities of plutonium are still forming naturally as cosmic rays strike uranium 238 in the earth's crust.

Most of the plutonium present on earth today was formed artificially. It is created through a nuclear reaction that converts uranium used in nuclear fuel.

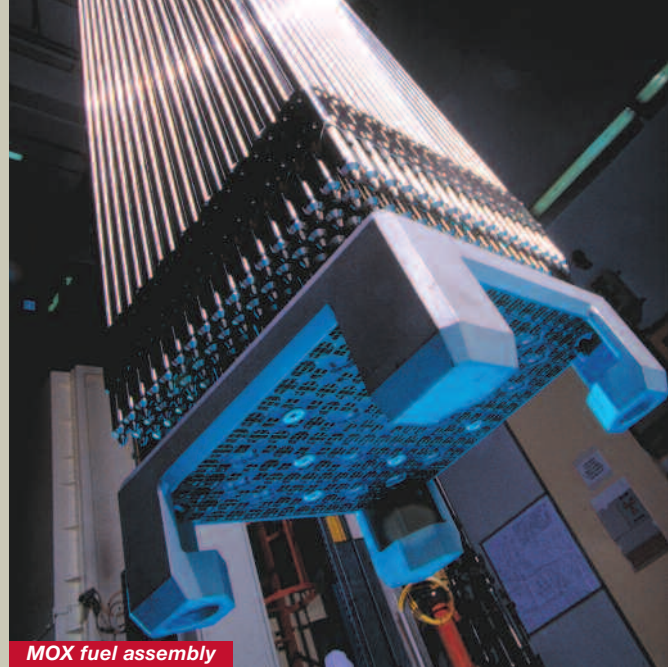
During the reaction, uranium 238 captures a neutron and transforms into uranium 239. The uranium 239 loses an electron in turn and transforms into neptunium 239. The neptunium 239 undergoes the same process, transforming into plutonium 239.

Plutonium is separated from used fuel in the form of a nitrate through a series of mechanical and chemical processing operations performed in a specialized facility. It is then converted into oxide (PuO₂).

How is **plutonium** used?

There are two known commercial applications for plutonium:

- pacemakers, batteries used aboard satellites and space probes and similar applications makes use of the heat released by plutonium 238;
- electric power generation by nuclear reactors, which makes use of plutonium's fissile properties.

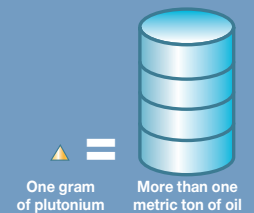


MOX fuel assembly



An energy-rich material

The fission of one gram of plutonium produces more energy than burning one metric ton of oil. Plutonium is formed through neutron capture by the uranium fuel used in all nuclear reactors. The main fissile isotopes of plutonium, plutonium 239 and plutonium 241, have fissile properties similar to uranium 235 used in nuclear power generation.



Capturing the value of plutonium through treatment and recycling

Used fuel is removed from the reactor core after three years of residence and undergoes treatment to recover the energy-rich materials it still contains.

The used fuel comprises:



After treatment, the recovered plutonium is recycled into mixed oxide fuel, or "MOX". The mixture consists of uranium oxide powder (93-95%) and plutonium oxide powder (5-7%). The powders are crushed, blended and compacted to form cylindrical pellets. The pellets are sintered in a very high temperature furnace and loaded into zirconium alloy tubes called fuel rods. The rods are bundled together into a metal structure, forming fuel assemblies. The reactor core, which comprises a number of such fuel assemblies, can use fresh MOX fuel instead of enriched uranium fuel.



MOX pellet press



Plutonium recycling offers major advantages

- A nuclear reactor with 30% MOX fuel consumes as much plutonium as it produces, helping to stabilize inventories of nuclear materials by minimizing the amount of plutonium that nuclear power plants produce.
- It reduces the long-term toxicity of final waste.
- It conserves enriched uranium.

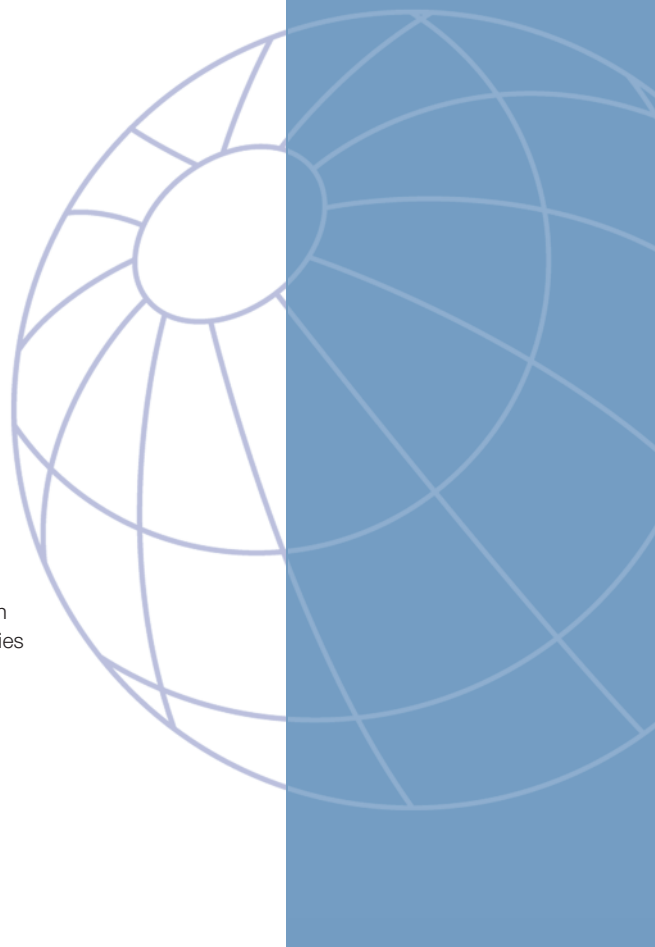
MOX around the globe



MOX has been used commercially for many years in European light water reactors. Currently, 36 European reactors in Germany, Switzerland, Belgium and France are operating with MOX fuel. In France, EDF has loaded MOX fuel into 20 of the 28 reactors technically capable of receiving this fuel type. In Japan, the utilities plan to load 16 to 18 of their reactors with this type of fuel.

MOX for peace: converting defense plutonium into civilian electric power.

The United States and the Russian Federation have selected French MOX technology for their non-proliferation program to reduce surplus defense plutonium inventories by using them to make fuel for power generation.



Origin of the name Plutonium

The elements uranium and neptunium, discovered before plutonium, owe their names to the planets Uranus and Neptune. By analogy, plutonium acquired its name in 1942 in reference to Pluto, the next planet in our solar system after Uranus.

Radioactive half-life of plutonium

Radioactivity is produced when an element returns to equilibrium. An element gradually transforms into a more stable element through a process of "radioactive decay". The "half-life" is the time required for half of the atoms of an unstable element to be transformed.

Plutonium isotopes have a wide range of half-lives:

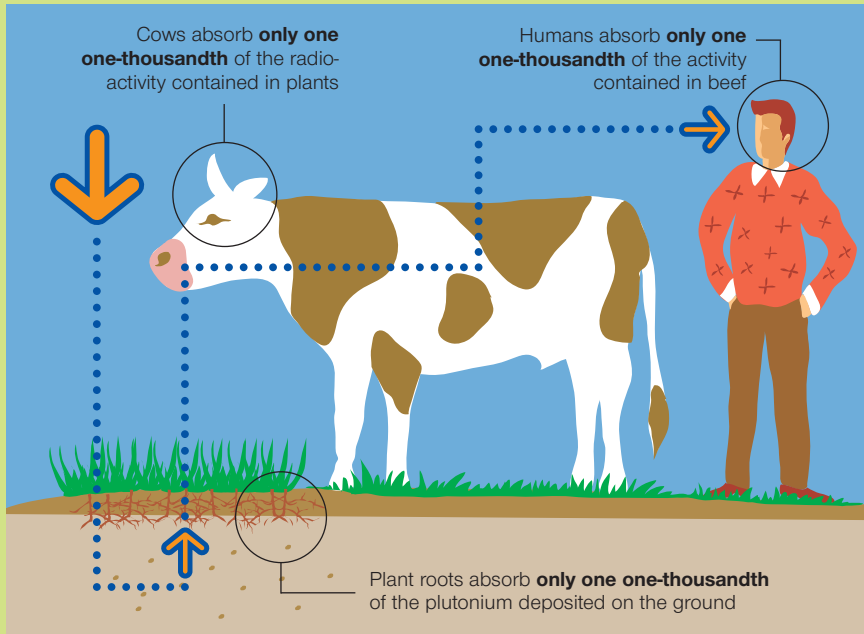
Pu 236	2,85 years
Pu 241	14,4 years
Pu 238	87 years
Pu 240	6 600 years
Pu 239	24 110 years
Pu 242	380 000 years



A little history

In 1934, Irène and Frédéric Joliot-Curie (Nobel Prize 1935) were the first to demonstrate that radioactive elements could be created artificially. In December 1940, **Glenn Theodore Seaborg** (Nobel Prize 1951) and his team discovered plutonium by "bombarding" a uranium 238 target at the University of California at Berkeley. In 1941, Seaborg discovered plutonium 239, first used to develop the atomic bomb. Since then, research has focused on the peaceful uses of plutonium, such as electric power generation.

Very little plutonium in the environment



Plutonium oxide **does not migrate easily** into the food chain

Plutonium is a heavy metal. It does not disperse easily in air or water. The plutonium found in the environment has three main sources: fallout from nuclear weapons testing conducted before 1973, when the treaty banning atmospheric testing was signed; the return to earth of failed plutonium-powered satellites; and, to a much lesser extent, the commercial nuclear power industry. Once deposited on the ground, plutonium does not migrate easily into the food chain. Humans are therefore rarely exposed to its toxicity.

Plutonium toxicity



The main source of plutonium toxicity is its radioactivity. Radioactivity is caused by the release of alpha particles and neutrons, and it varies by isotope. When plutonium enters the body, it irradiates contaminated organs. In an accident involving plutonium, the radioelement can be inhaled or ingested through a wound or enter the bloodstream and spread to the lungs, liver and bones. Depending on its chemical form (oxide, nitrate), plutonium

remains in these organs for some time before being eliminated in the urine. Extreme safety measures are employed for plutonium handling (glove boxes, leak-proof cells, etc.), making internal contamination highly improbable. Very few people have ever been contaminated, and no significant side effects were observed in scientific studies of such cases. However, cancer has been observed in animals after ingestion of large doses of plutonium.

All over the world, AREVA provides its customers with solutions for carbon-free power generation and electricity transmission. With its knowledge and expertise in these fields, the group has a leading role to play in meeting the world's energy needs.

Ranked first in the global nuclear power industry, AREVA's unique integrated offering covers every stage of the fuel cycle, reactor design and construction, and related services. In addition, the group is developing a portfolio of operations in renewable energies. AREVA is also a world leader in electricity transmission and distribution and offers its customers a complete range of solutions for greater grid stability and energy efficiency.

Sustainable development is a core component of the group's industrial strategy. Its 75,000 employees work every day to make AREVA a responsible industrial player that is helping to supply ever cleaner, safer and more economical energy to the greatest number of people.

www.aveva.com