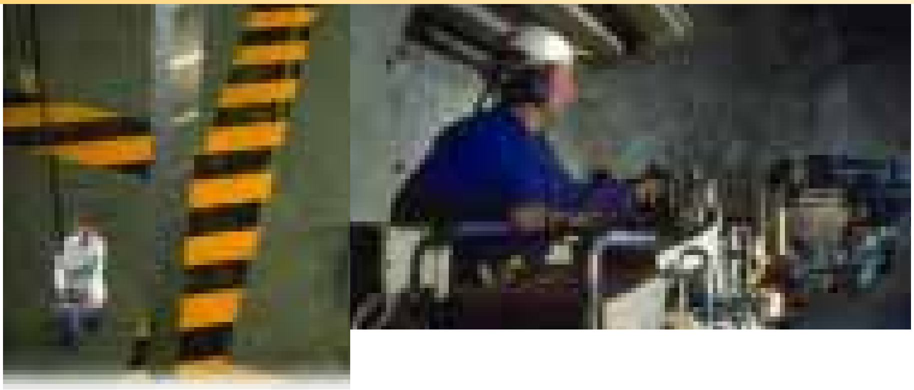
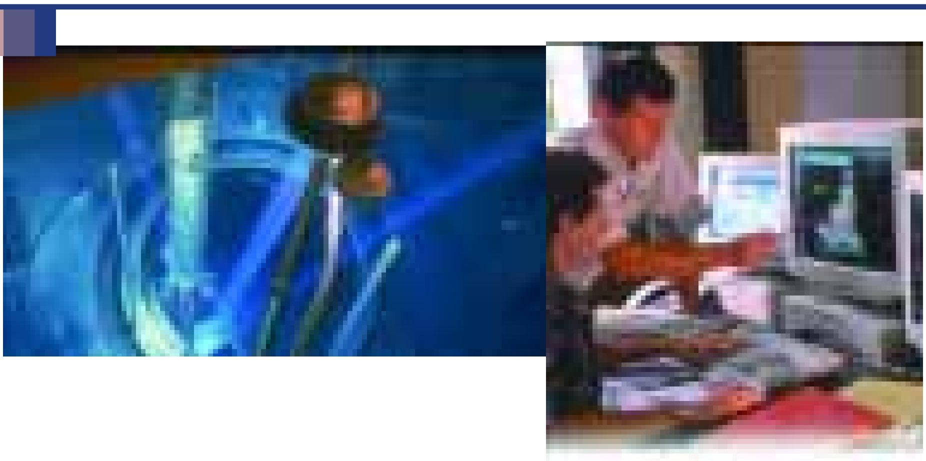
The nuclear power cycle

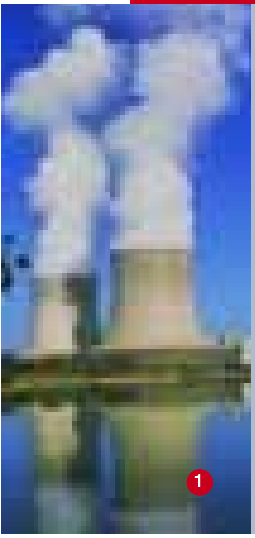
AREVA





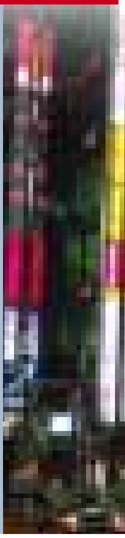
Nuclear power around the world

Close to 360,000 megawatts of installed capacity



Fifty years after the first nuclear reactor come on-line, nuclear power is fourth among the world's primary energy sources, after oil, coal and gas. In 2002, there were 441 reactors in operation worldwide. The United States led the world with 104 reactors and an installed capacity of 100,000 MWe, or more than one fourth of global capacity. Electricity from nuclear energy represents 78% of the production in France, 57% in Belgium, 46% in Sweden, 40% in Switzerland, 39% in South Korea, 34% in Japan, 30% in Germany, 30% in Finland, 26% in Spain, 22% in Great Britain, 20% in the United States and 16% in Russia. Worldwide, 32 reactors are under construction, including 21 in Asia.

(Source: 2002 Nuclear Power Statistics, International Atomic Energy Agency)



Security of supply and cost-competitiveness

Fossil fuels produce 75% of the world's energy today. At current rates of consumption, oil will run out in 40 years, natural gas in 56 years and coal in 197 years*. Moreover, 80% of the known oil routes are in the Middle East and 50% of the future gas routes pass through politically unstable regions. All of these considerations argue in favor of greater energy diversity, and nuclear power definitely has a role to play. In fact, between the uranium deposits being mined in various locations around the globe and existing uranium inventories, long-term security of supply is guaranteed for nuclear power.

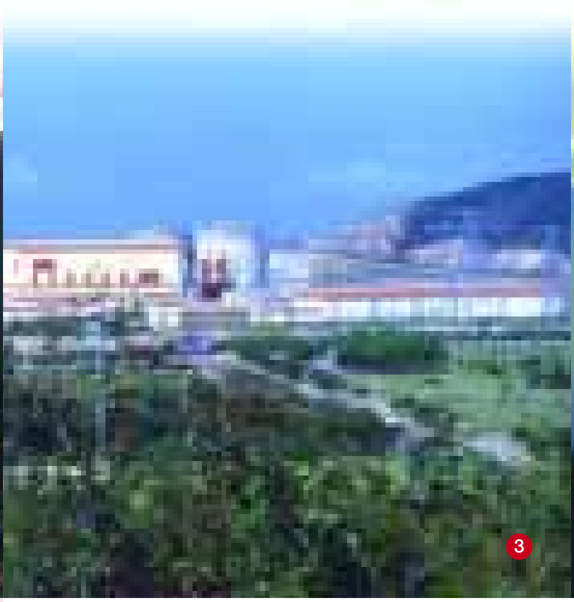
For countries without fossil fuel resources, nuclear power also avoids costly energy imports. It is quite cost-competitive, including in deregulated markets, and even compared with momentarily low-cost fossil fuels. But most of all, nuclear power ensures stable energy prices over the long term, regardless of the ups and downs of oil prices, because the raw energy material is a only a small percentage of the nuclear kilowatt-hour cost. When environmental impacts are internalized in fossil fuel prices, through carbon taxes, carbon sequestration, or other methods, nuclear power will inevitably come out ahead.

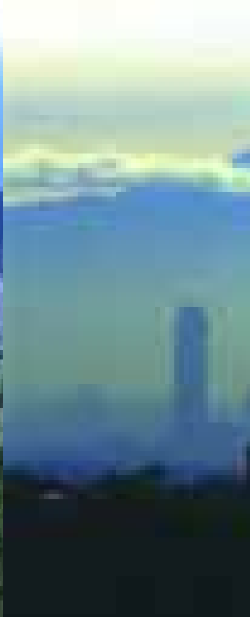
INSIGHT

Units of measure

Just as energy may be expressed in joules (J) or British thermal units (Btu) in physics, the unit of measure for electricity is the kilowatt-hour (kWh). The unit used when referring to a country's energy consumption is the metric ton of oil equivalent (toe). For example, 1 metric ton of coal = 0.667 toe and 1 megawatt-hour (MWh) = 0.077 toe. The nuclear MWh is equal to 0.26 toe. This means that a thermal power plant would have to burn 0.26 metric tons of oil to generate the MWh of electricity produced by a nuclear power plant.

**Source: "Worldwide Energy, Status and Outlook"]– Les Éditions de Physique, available in French from the French Ministry of Economy, Finance and Industry*





A CLOSER LOOK

The world's population will probably reach 10 billion people in this century, and the demand for electricity will increase more than 80% from 2000 to 2020. Meeting these colossal requirements will require every energy source available.

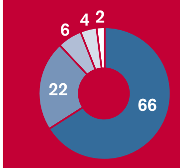
① *Saint Laurent des Eaux nuclear power plant, France.*

② *City of Tokyo, Japan.*

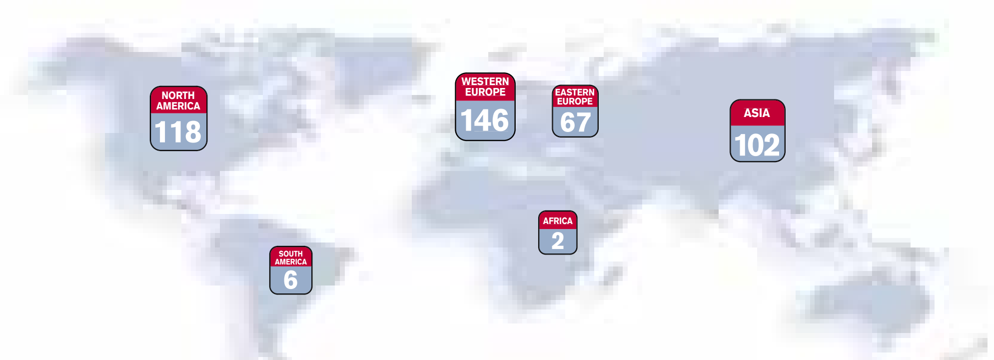
③ *Daya Bay nuclear power plant, China.*

④ *Pollution over Mexico City.*

Breakdown by reactor type
(installed capacity)



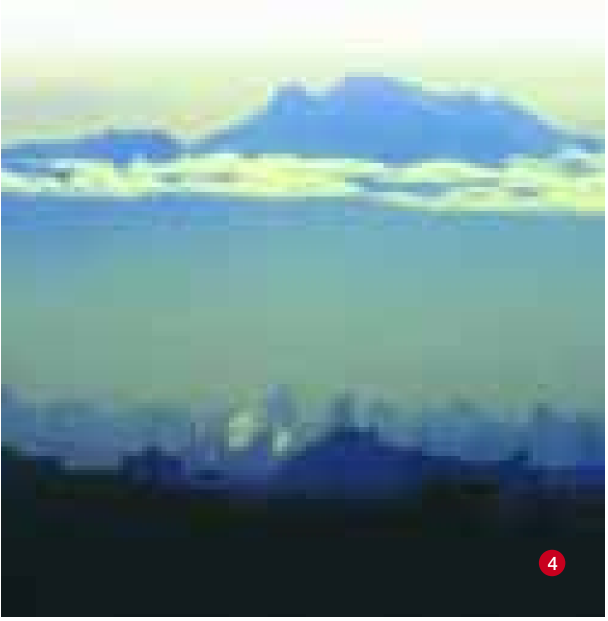
- ■ **PWR** (including VVER) PRESSURIZED WATER REACTORS
- ■ **BWR** BOILING WATER REACTORS
- ■ **CANDU-AGR** HEAVY WATER AND GAS-COOLED REACTORS
- ■ **RBMK** WATER AND GRAPHITE REACTORS
- ■ **OTHER REACTORS**



Number of reactors by region Source IAEA - 2002

441 reactors in service worldwide

Pressurized water reactors (PWR) are by far the most common worldwide, at about 66% of all operating reactors, followed by boiling water reactors (BWR). Heavy water reactors (Candu) and gas-cooled reactors (AGR) account for 6% of the total. The Soviet-era RBMK reactors represent 4% of the total.



INSIGHT

The greenhouse effect
The greenhouse effect occurs when some of the sun’s energy is trapped in the earth’s atmosphere. This occurs naturally, mainly due to the presence of water vapor in the air. Without it, the average temperature on the earth’s surface would be -18°C (-40°F) instead of the current 15°C (59°F). That difference of 33°C (99°F) is what makes life on earth possible. But human activity generates ever increasing amounts of gas that remain in the atmosphere for a long time, heightening the natural greenhouse effect. The result is global warming. In the previous century, the earth’s average temperature rose 0.6°C (1.08°F). The leading offenders are carbon dioxide (CO_2), methane, nitrous oxide and fluorinated gases.

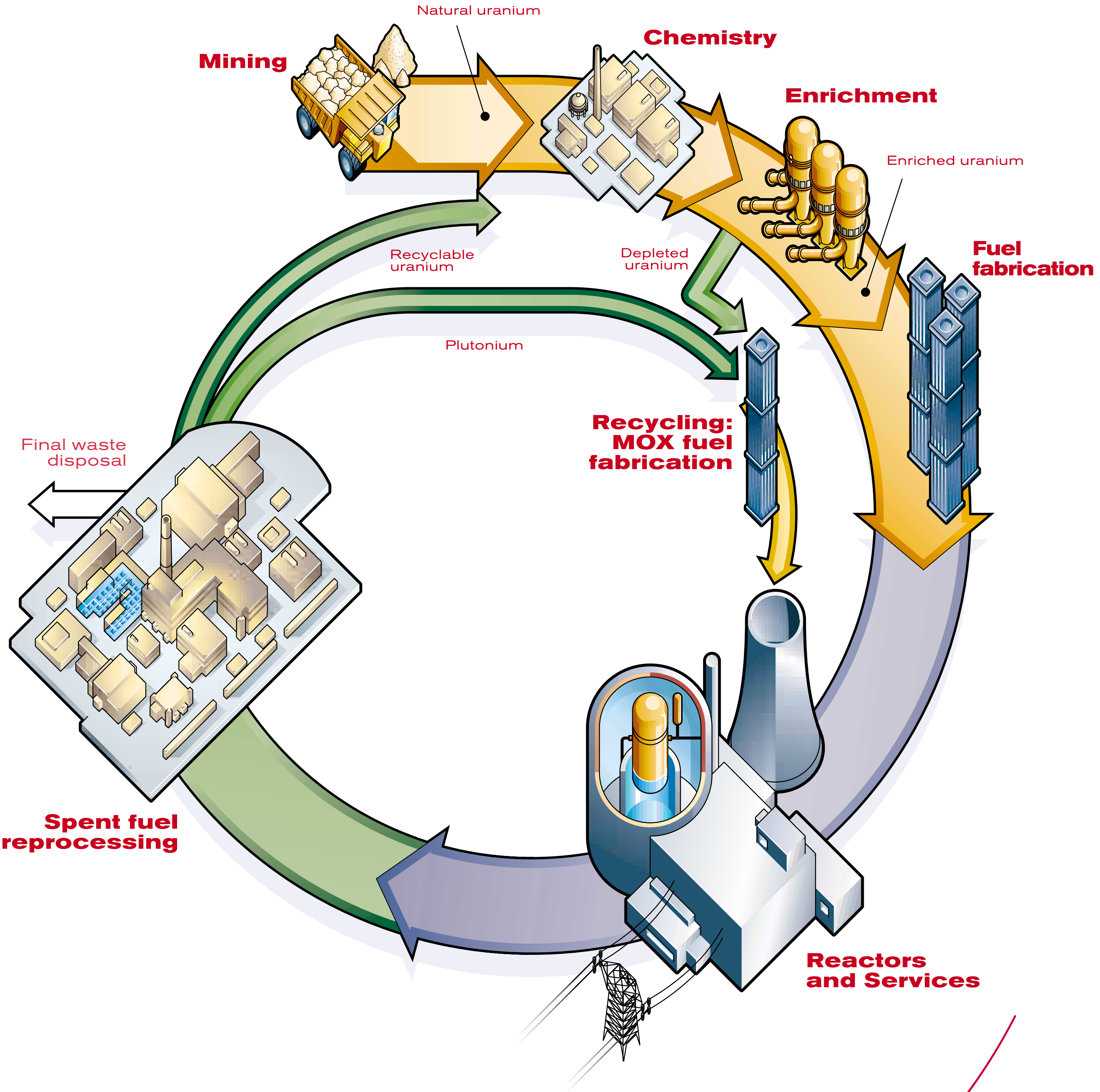
Combating the greenhouse effect

Global warming is caused by the greenhouse effect, a problem that demands the world’s attention. Originally a natural phenomenon, it is on the rise mainly due to human activity. What can be done to check this problem? Reduce our greenhouse gas emissions by encouraging energy conservation and promoting the use of non-emitting renewable energies and nuclear power. In France, for example, the country’s reliance on nuclear power has resulted in a carbon dioxide (CO2) gas emission rate that is 10 times lower than that of Germany, where nuclear power represents only 30% of electricity production, and 13 times lower than that of Denmark, which has no nuclear power program. Globally, if nuclear power plants were replaced by coal-fired plants, carbon dioxide emissions would increase by 2.3 billion tons per year.

The nuclear power cycle

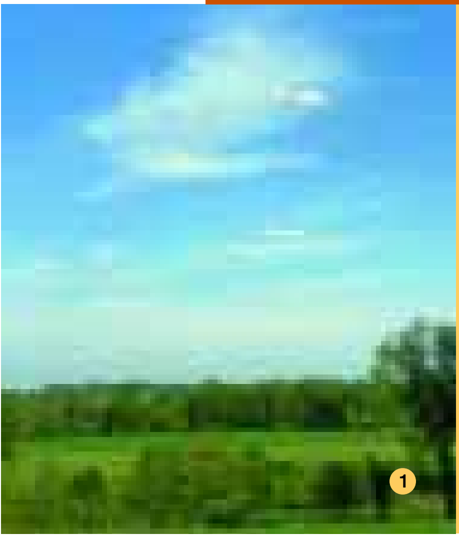
AREVA offers customers technological solutions for nuclear power generation backed by worldwide expertise in the energy business.

Nuclear power is already an effective answer to the planet's critical challenges created by the production of greenhouse gases. AREVA has developed a mature product and service offering for this clean, efficient and forward-looking energy that respects the interests of future generations.


Natural uranium
Mining
Chemistry
Enrichment
Enriched uranium
Fuel fabrication
Recyclable uranium
Depleted uranium
Plutonium
Recycling: MOX fuel fabrication
Final waste disposal
Spent fuel reprocessing
Reactors and Services

Uranium exploration

Searching for uranium on five continents



In its purest state, uranium is a hard, gray, very dense metal. It is never found in its native metal form, but rather in the form of ore. Uranium is relatively abundant in the earth's crust, at 3 grams per ton on average, but only large concentrations can be mined economically. The prospector's job involves searching the globe for new reserves to ensure long-term uranium supplies.

Uranium is a metallic element that is 1,000 times more abundant than gold in the earth's crust. It can be found in every type of terrain, especially granitic rock.

Tried and true exploration techniques plus radioactivity measurements

Uranium exploration uses the same prospecting methods used for most metal-bearing deposits: geological and geophysical surveys, soil and water chemistry, test drilling, etc. Uranium deposits can also be detected with radioactivity measurements, especially gamma radiation measurements using Geiger-Muller and scintillation counters. Usually, exploration starts with a very wide field selected for geological considerations, and then narrows gradually to areas with "anomalies", or significant indications of mineable ore bodies. Initially, prospectors use airplanes or helicopters. When a particular location shows promise, the ground crew digs or drills boreholes for samples. Increasingly detailed surveys are conducted on smaller and smaller surface areas. If the deposit is economically attractive, the next stage is to mine the ore body.

Canada, site of the some of the world's highest grade deposits

Uranium exploration activities in numerous countries have led to the discovery of deposits representing excellent long-term security of supply.

➜ In Canada's Saskatchewan province, the McClean Lake, Midwest, Cigar Lake and McArthur River deposits discovered from 1981 to 1988 are some of the highest grade uranium deposits in the world, at 20 to 200 kg of uranium per ton of ore – 10 to 100 times higher than reserves mined before their discovery.

A CLOSER LOOK

In honor of the planet Uranus

The uranium element was discovered in 1789 by Klaproth and named in honor of the planet Uranus, which had just been discovered by the astronomer Herschel.

Not only are the ore grades very high, but the deposits are some of the world's largest, with McArthur River alone representing some 180,000 metric tons of recoverable reserves. These deposits, and the geologic challenges of their location, will require real feats of technology to be economically mined.

➜ Exploration is also being conducted in Niger, Kazakhstan and Australia, and several deposits are under development or in production.

1. *Heliborne prospecting.*
2. *Uranium ore.*
3. *Test drilling.*
4. *Prospecting camp in Kazakhstan.*

Uranium mining

Using mining techniques specific to each deposit

①

AREVA produces 7,200 metric tons of uranium concentrates a year, drawing on the complete repertoire of mining techniques for its open pit and underground operations.

Special mining methods were developed to mine the high grade uranium deposits in Canada.

Open pit and underground mining operations

Most uranium deposits are mined using well-established metal mining methods. The ore bodies are accessed through open pits when they are close to the surface or through an access shaft and winze when they are deep. A variety of conventional techniques are used to mine the ore. Miner exposure to gamma radiation and radon gas released by the rock and ore dust is minimized by proper worksite design, particularly the extensive use of ventilation. Mine personnel are monitored, wearing individual dosimeter badges to verify that exposure is below regulatory limits, and benefitting from close medical supervision.

Exceptional techniques for exceptional deposits

Some of the Canadian deposits are so high-grade – up to 200 kg uranium per metric ton of ore, versus less than 10 kg elsewhere – that mining personnel cannot enter the jobsite. Special techniques must be used instead. An innovative hydraulic mining method was developed for the Cigar Lake deposit in Canada. Underground pipes of liquid coolant are used to freeze the ground. The frozen rock is broken apart with a high-pressure water jet and the slurry containing the ore is collected and pumped away from the production area. The operation is completely automated, and no miner comes into direct contact with the very high-grade ore.

Another mining technique that eliminates the need for personnel in the work area, mainly for economic reasons, is in-situ leaching via boreholes. This technique is suited to certain low-grade uranium deposits, such as the Muyunkum deposit in Kazakhstan, where a pilot project is in progress. The concept consists of dissolving, or "leaching", the uranium directly in the deposit by injecting an acidic or alkaline solution and pumping the resulting slurry to the surface. This technique eliminates the need to dig large quantities of ore containing only small amounts of uranium.

A CLOSER LOOK

Mining reclamation

When all mining activity ceases, mine sites undergo reclamation. This involves site stabilization, regrading and replanting, all of which are performed under the oversight of government agencies.

The main purpose of reclamation is to ensure public health and safety and environmental protection over the very long term. But reclamation also serves to integrate the site into the surrounding landscape and to render it useful for other activities through partnerships with local communities and economic development actors. Many reclaimed mine sites are now used for agriculture and forestry, and some open pit mines have been converted into lakes. Former mine sites that have undergone such treatment in France include sites in the Limousin region and in the Languedoc-Roussillon region. AREVA is currently performing site reclamation in Gabon and in Wyoming and Texas in the United States.

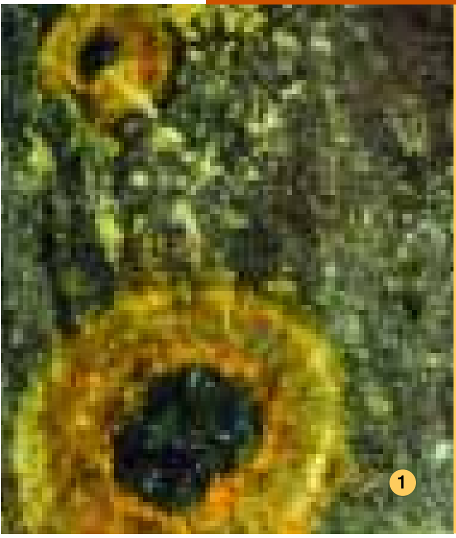
① *Cominak underground mine, Niger.*

② *Freeze barrier, McArthur, Canada.*

③ ④ *Tail mine during operations and after reclamation, Vendée, France.*

Uranium ore processing

Concentrating raw uranium into yellowcake



Once the uranium has been mined and brought to the surface, it must be separated from the rock and cleaned of impurities as much as possible. This concentration step is performed next to the mine to avoid unnecessary shipping of large quantities of ore over long distances.

The uranium-bearing rock, or ore, is crushed and milled to a fine powder in facilities close to the mine. Then it goes through a series of chemical processing steps, which may vary from one facility to the next, depending on the characteristics of the ore.

The overall process is similar in most cases.

→ The uranium contained in the ore is dissolved with an alkaline or acidic solution.

→ Then the uranium solution is separated from the tailings.

→ Finally, the uranium is precipitated as magnesium, sodium or ammonium uranate or as uranium peroxide. Dried uranium concentrates are usually bright yellow and powdery in appearance, hence the name “yellowcake”. Yellowcake is 75% uranium, or 750 kg per metric ton. Though the generic term yellowcake is still widely used in the industry, the concentrates are more often than not converted into U_3O_8, which has a uranium content of more than 80%, and are sold in that form.

A CLOSER LOOK

McClean, a uranium mill scaled for the North American deposits

The McClean mill processes ore mined from the McClean Lake and Cigar Lake deposits in Canada. Modular in design, the mill's currently licensed operating capacity of 3,000 metric tons of uranium per year could be doubled or even tripled to make it one of the world's largest ore concentration mills.

A CLOSER LOOK

Continuous monitoring of environmental impacts

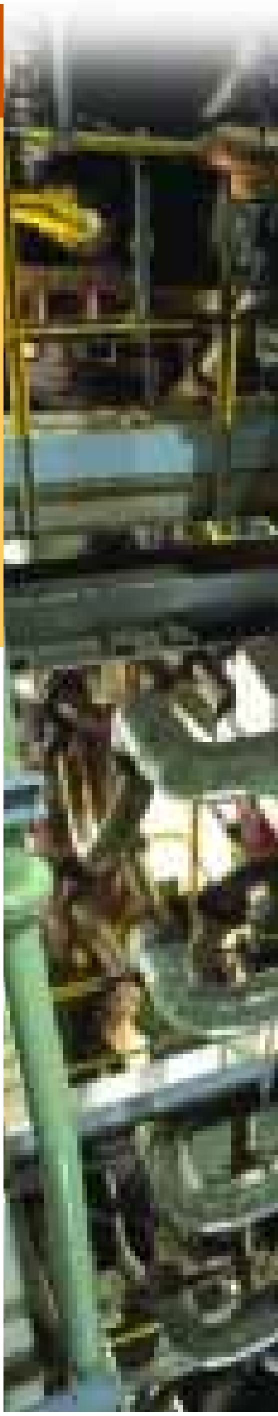
Programs are in place to reduce the environmental impacts associated with mine sites, including liquid effluent treatment stations and gaseous effluent filtration. In 2001, more than 200,000 analyses were performed at all of the group's sites. The results of these environmental analyses have been widely released via regularly published newsletters.

1. *Uranium ore.*
2. *Crushing mill in the McClean ore processing facility, Canada.*
3. *Yellowcake.*
4. *Environmental monitoring at the McClean site, Canada.*

Uranium conversion

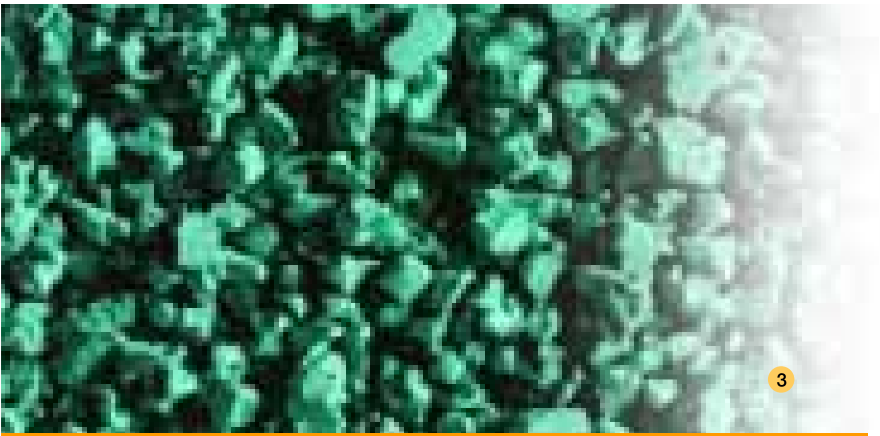
Converting yellowcake into useful compounds through uranium chemistry

Uranium cannot be used as such in nuclear power reactors, even in the form of concentrated yellowcake, because it does not contain enough of the isotope that fissions. Before the natural uranium can be enriched in that isotope, it must first undergo chemical transformations so that it can become a gas. To do this, refined yellowcake must be converted into uranium hexafluoride (UF_6).



From UF_4 to UF_6

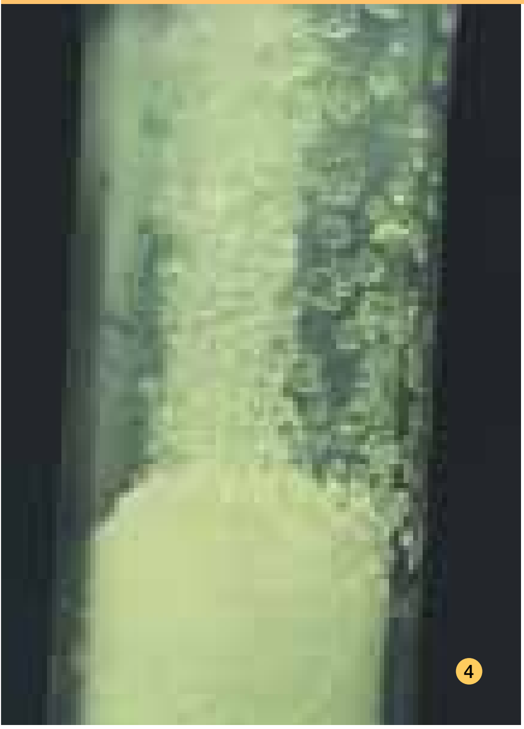
Uranium concentrates must be converted to achieve the levels of purity required for nuclear fuel fabrication. Conversion is generally done in two phases. First, the mine concentrates are purified and converted into uranium tetrafluoride (UF_4) at the Comurhex-Malvési plant near Narbonne, France. For the second phase, the UF_4 is shipped to the Comurhex-Pierrelatte plant at the Tricastin site in the Drôme department, where it is converted into uranium hexafluoride (UF_6). This product can go from the solid state to the liquid state or the gaseous state through slight variations in temperature. At 65°C (149°F), the UF_6 is a gas, which is perfectly suited to enrichment by gaseous diffusion or gas centrifuge, the next step in the fuel cycle. The Comurhex-Pierrelatte plant is one of the few plants in the world that can convert uranium from reprocessed spent fuel. The reprocessed UF_6 can then be enriched and used to make more fuel.



A CLOSER LOOK

Uranium chemistry and fluorine chemistry

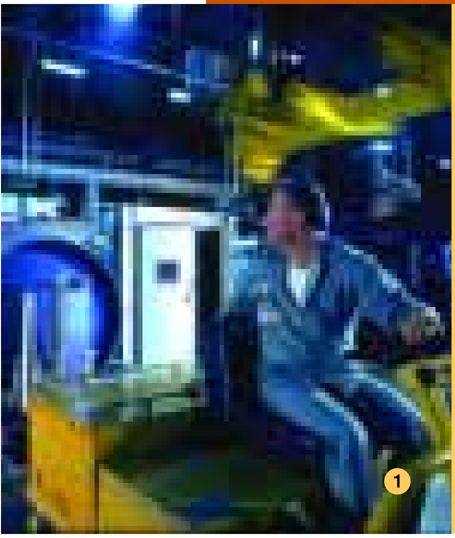
The Comurhex plant at Pierrelatte is not just a uranium converter: it is also Europe's leading producer of fluorine, a product it uses in the conversion process. The site's non-uranium bearing fluorine derivatives are marketed to the electronics and automobile industries.



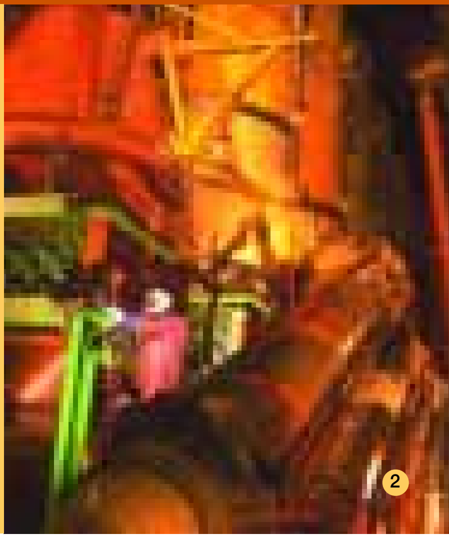
1. *Sampling station, Comurhex-Malvési plant.*
2. *Flame reactor, Comurhex-Pierrelatte plant.*
3. *Uranium tetrafluoride (UF_4), Comurhex-Malvési plan.*
4. *Uranium hexafluoride crystals (UF_6), Comurhex-Pierrelatte conversion plant.*

Uranium enrichment

Increasing uranium 235 concentrations



Uranium consists mainly of two isotopes, one with an atomic weight of 235, the other with an atomic weight of 238. Uranium 235 is far less abundant in the natural state than uranium 238, at only 0.7%, or 7 kg per metric ton. Most nuclear reactors use fuel containing from 3 to 5% of uranium 235. Enrichment involves increasing uranium 235 concentrations to produce a material that can be used in nuclear reactors. Two enrichment processes are currently used on a production scale: gaseous diffusion and gas centrifuge.

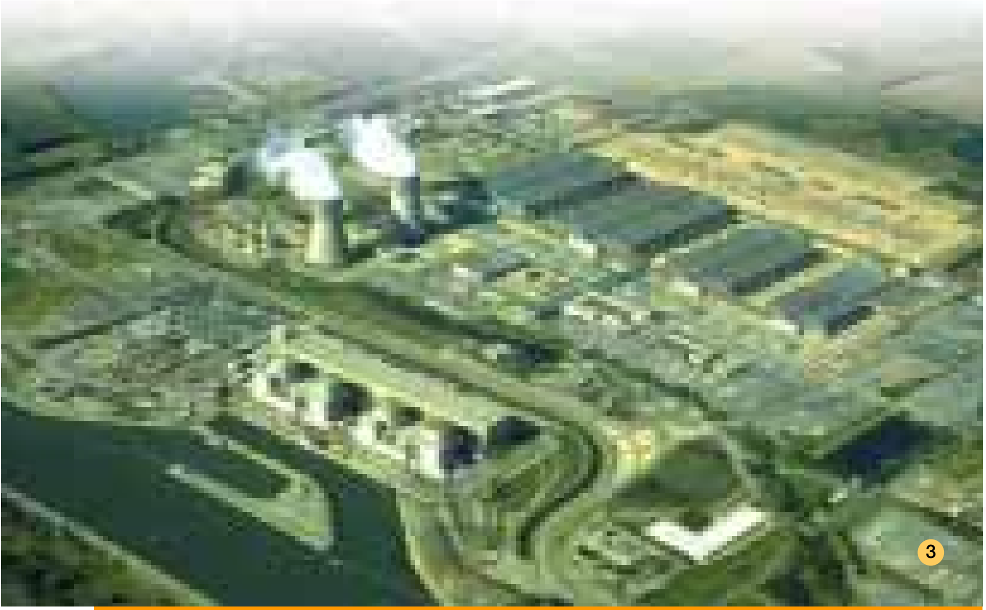


Gaseous diffusion

The gaseous diffusion enrichment process exploits the difference in weight between the U^{235} and U^{238} isotopes to enrich the product. First, the isotopes are combined with fluorine to form uranium hexafluoride (UF_6), which is brought to the gaseous stage at moderate temperatures and pressures. The lightest molecule of the UF_6 gas – U^{235} – is also the fastest moving. When the gas is confined, this molecule strikes the walls of the confined space more frequently than the heavier U^{238} molecule. If the wall is porous, the lightest molecules will cross through the pores more often than the heavier ones, giving a gas that is richer in U^{235} on the other side. This isotope sorting process is done inside a diffuser. The UF_6 gas is pushed through porous tubes called diffusion barriers by a compressor. The depleted gas returns to the preceding diffusion stages, while the enriched gas is sent to the following diffuser. Because the unit enrichment factor is very low, the process must be repeated 1,400 times at the Eurodif gaseous diffusion plant to achieve the enrichment levels required by the customer. The plant can be configured for varying power levels and customer requirements, whether for 100 kg or several tons, or for assays of 1 to 5% U^{235}. Heat is released to the atmosphere through two cooling towers. When operating at full power, the plant consumes almost 3,000 MWe. It is capable of supplying the enriched uranium requirements of one hundred 900 MWe reactors. The plant services France's *Electricité de France* and some forty other power companies around the world.

Gas Centrifuge

Through the agreement signed with the European nuclear consortium Urenco on November 24, 2003, AREVA has access to centrifuge technology and is building a new plant based on this technology at the Tricastin site in France. The plant will ensure continued supply of enrichment services to operating reactors around the world for the next forty years.



A CLOSER LOOK

Basic functions of a centrifuge

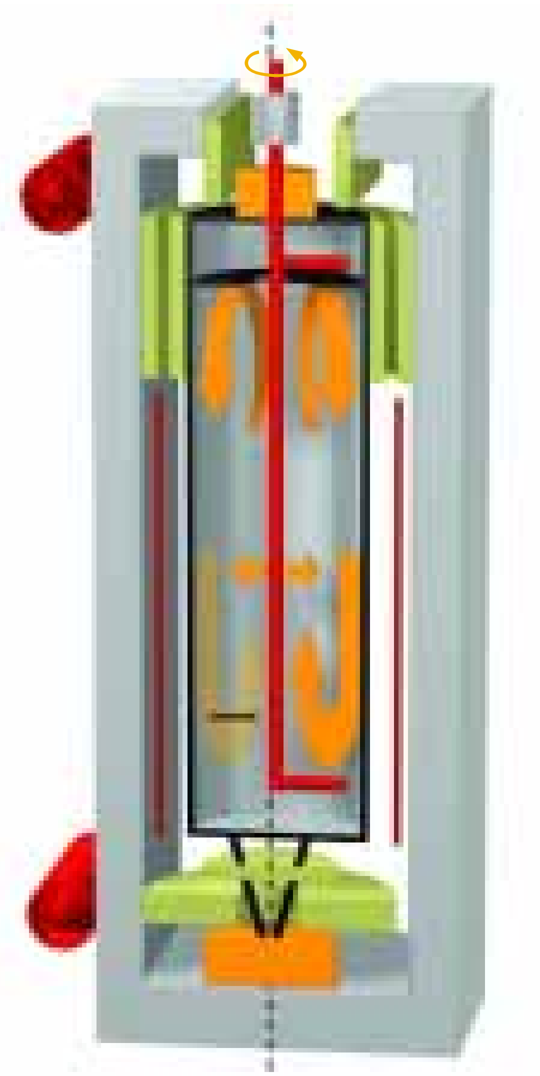
➜ A long cylinder spins in a vacuum at very high speeds inside a sealed housing. The cylinder, or "bowl", is made of high-strength metals or a carbon fiber composite, depending on the version of the machine. The mechanical properties of the composite have boosted machine yields 5 to 10 times.

➜ Uranium in the form of hexafluoride (UF_6) is fed into the system, as it is in the gaseous diffusion process.

➜ The centrifugal force of the machine throws the heaviest particles to the cylinder walls, effectively separating them from the lighter isotope.

➜ Physical mechanisms cause the gas to flow axially, increasing isotopic separation. The gas enriched in the lighter isotope, located closer to the center of the bowl, flows towards the top of the machine, while the gas with the heavier isotope flows towards the bottom. The enriched and depleted products are recovered at either end of the machine.

Cutaway of a centrifuge



① *Heat chamber in the receiving-shipping-monitoring building. Eurodif's enrichment plant in France.*

② *Eurodif's enrichment plant in France.*

③ *A series of diffusers.*

Fuel fabrication

A high-precision process

The core of a light water reactor consists of millions of small enriched uranium pellets packaged in fuel assemblies. Extremely exacting fabrication processes are followed to achieve the requisite levels of performance and safety.

"Fuel rods" filled with uranium pellets...

Once it has been defluorinated, the U^{235}-enriched uranium in the form of oxide powder is ready to deliver energy.

First, the powder is pressed under very high pressure into small cylindrical pellets weighing ten grams. Then the pellets are "sintered", or fired in a furnace like industrial ceramics.

The pellets are ground with a diamond-coated grinding wheel and inspected for size and density. Then they are inserted into long metal tubes of zirconium alloy, which are filled with helium and hermetically sealed. The sealed tube constitutes one "fuel rod". Zirconium was chosen because it is transparent to neutrons, meaning that it does not slow the nuclear reaction in the reactor core.

In addition to holding the pellets in the optimum configuration for the desired nuclear reaction, the fuel rods serve as the primary containment barrier. They must withstand severe thermal and mechanical stresses while preventing the release of radioactive products.

For a 900 MWe pressurized water reactor, each fuel rod contains about 300 uranium pellets.

...bundled together in "assemblies"

The fuel rods are bundled together into "assemblies", or fuel elements that make up the reactor core. Each assembly contains 264 fuel rods.

The assemblies also have guide tubes to insert control rods, which are used to control the chain reaction, and a center tube for instrumentation.

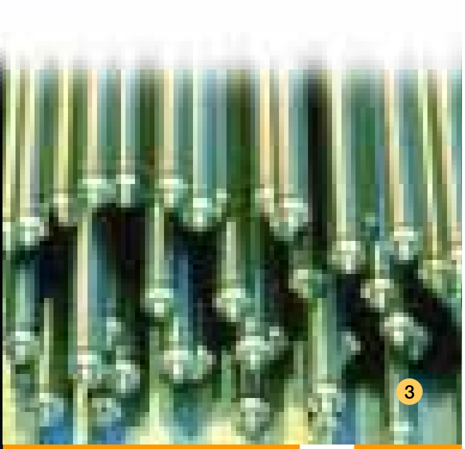
The structural components that hold the fuel rods together are also made out of low-absorbent materials that do not slow the nuclear reaction and thus conserve fuel.

① *Visual inspection of UO_2 pellets.*

② *Fuel assembly handling.*

③ *Exceptionally corrosion-resistant M5™ alloy.*

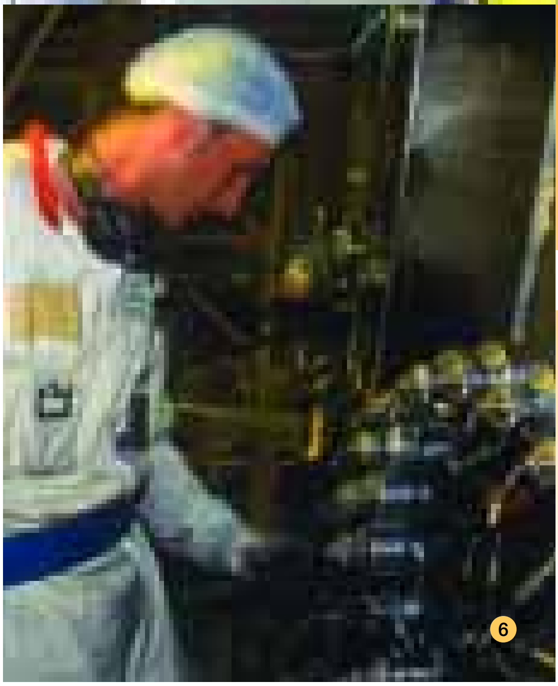
④ *Visual inspection of a fuel skeleton.*



A CLOSER LOOK

Continuous improvement of nuclear fuel performance

Research efforts have focused primarily on tube materials and on the composition of the ceramic constituting the fuel pellet. The resulting fuel achieves better performance in the reactor, making higher burnups possible. This means that more electricity can be produced with the same amount of material.



A CLOSER LOOK

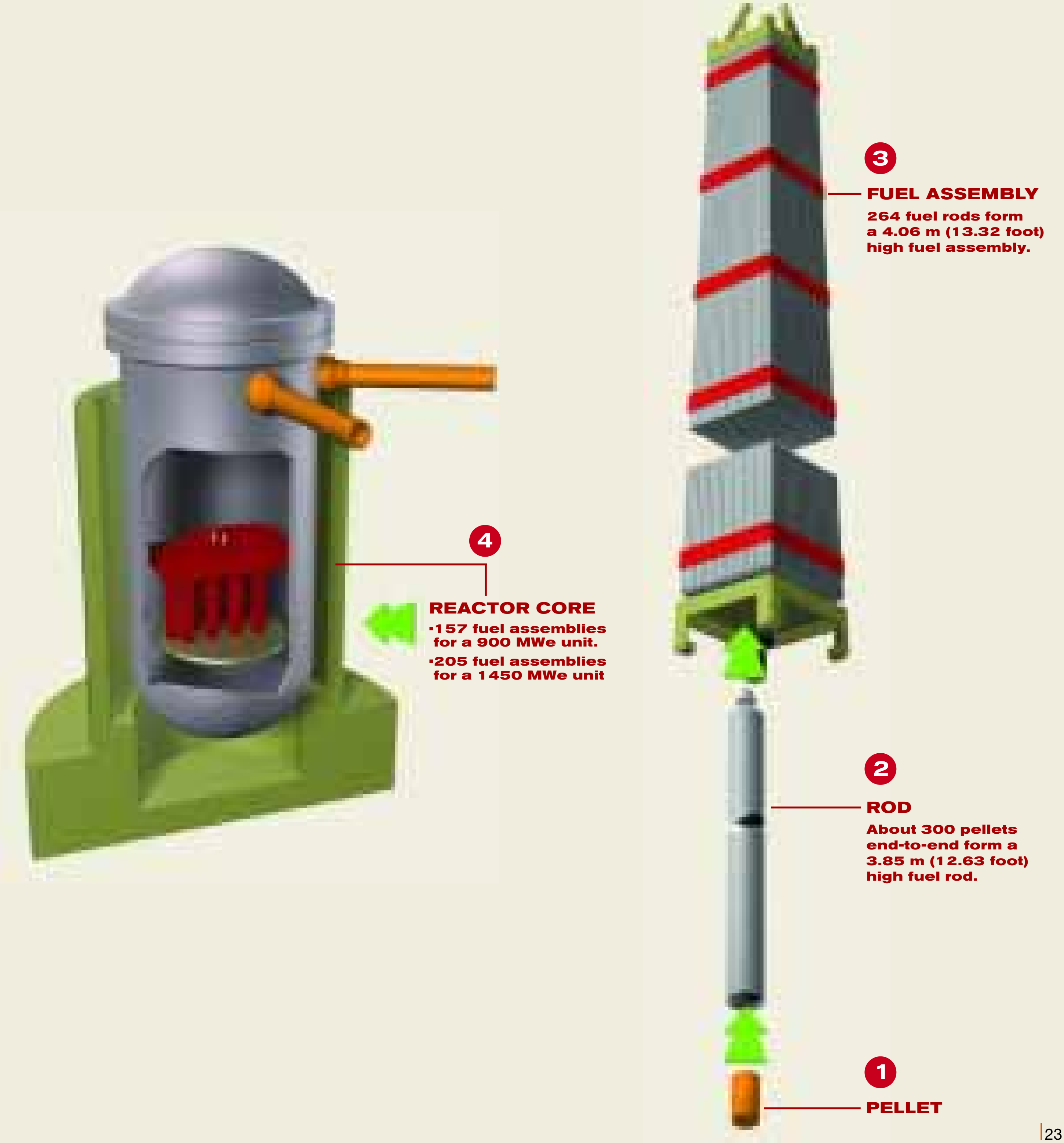
Protecting personnel and the environment

All fuel cycle operations involve the handling and use of relatively radioactive products, and this requires shielding and protection. The type and level of protection depend on the characteristics of the products in question and on their radioactivity levels. But the same protection principle applies at every stage of the process: under no circumstances shall operating personnel or members of the public be exposed to radiation doses that are detrimental to their health.

⑤ *Pelleting line downstream from the pellet press.*

⑥ *Wearing a dosimeter badge during contact maintenance.*

Simplified diagram of a pressurized water reactor core



FUEL ASSEMBLY

264 fuel rods form
a 4.06 m (13.32 foot)
high fuel assembly.

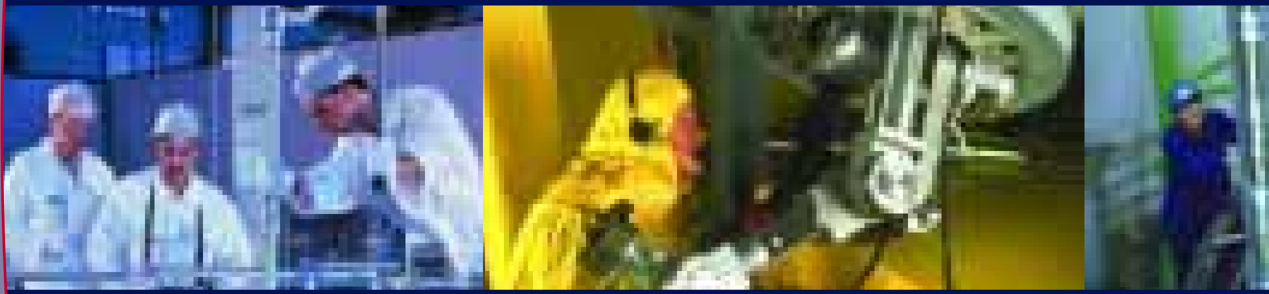
REACTOR CORE

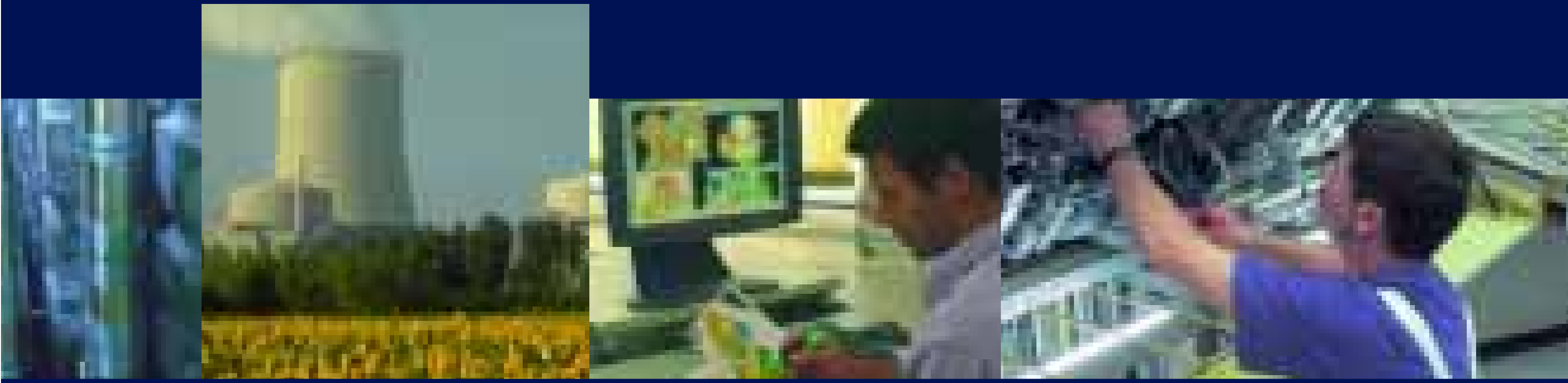
- 157 fuel assemblies for a 900 MWe unit.
- 205 fuel assemblies for a 1450 MWe unit

ROD

About 300 pellets
end-to-end form a
3.85 m (12.63 foot)
high fuel rod.

PELLET





Reactor design

From the reactor to the nuclear power plant...

Nuclear reactors are used to produce and control the intensity of a fission chain reaction. The considerable energy released by this reaction is used in a "nuclear steam supply system" (NSSS), where water is converted into steam. Inside the nuclear power plant, the motive force of the steam activates a turbine, generating electricity. The steam exiting the turbine is reconverted into water in a "condenser", which cools it with seawater or river water, or by cool air in concrete "cooling towers". The water is returned to the nuclear reactor, where it is once again converted into steam, closing the cycle.

① *Ling Ao nuclear power station in China.*

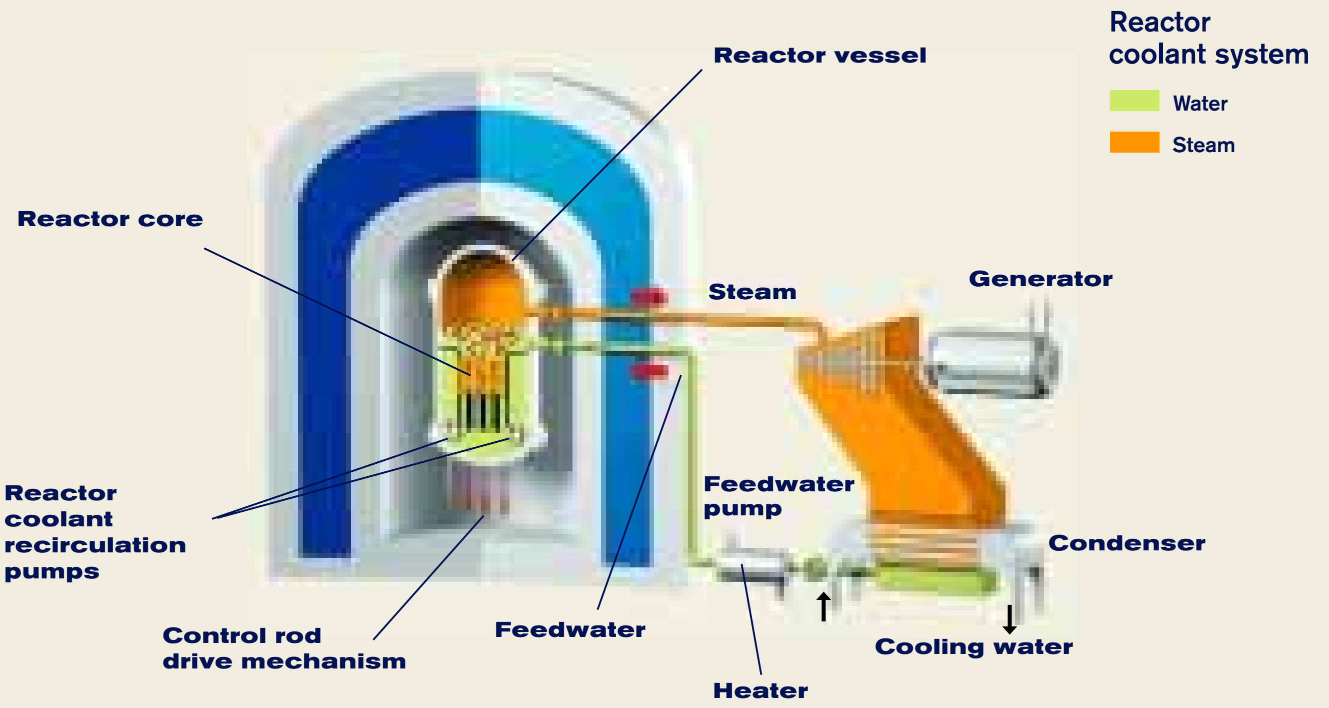
"Ordinary" or "light" water reactors

Light water reactors include boiling water reactors (BWR) and pressurized water reactors (PWR). The second reactor type is by far the most prevalent worldwide, at 66% of all operating reactors. In both reactor types, the fuel core is contained in a vessel, where the self-sustaining fission chain reaction heats the fuel assemblies. Water enters the bottom of the vessel and heats up through contact with the fuel.

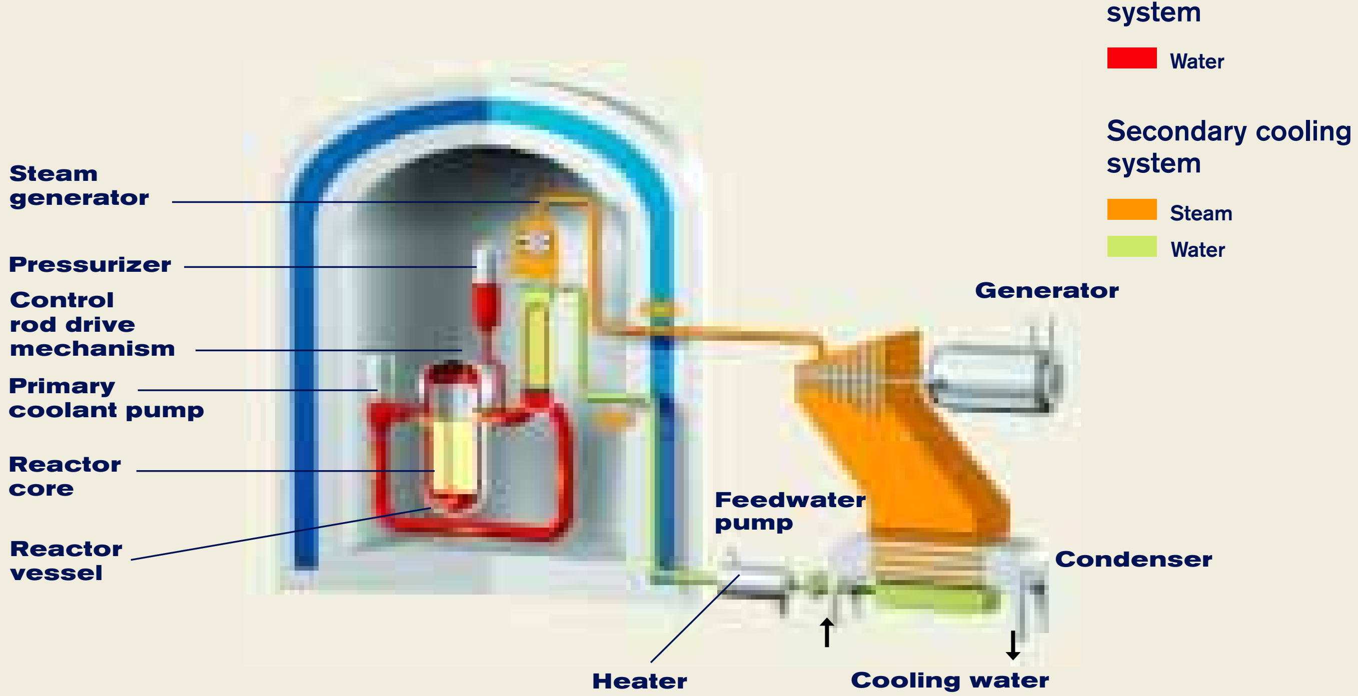
➜ In BWRs, the water starts boiling, turning into steam inside the reactor vessel. Recirculating pumps force water that hasn't vaporized back into the reactor core, accelerating natural circulation. The steam is routed through steam pipes to the turbine. The reactor containment building prevents the release of radioactive products in the event of core damage.

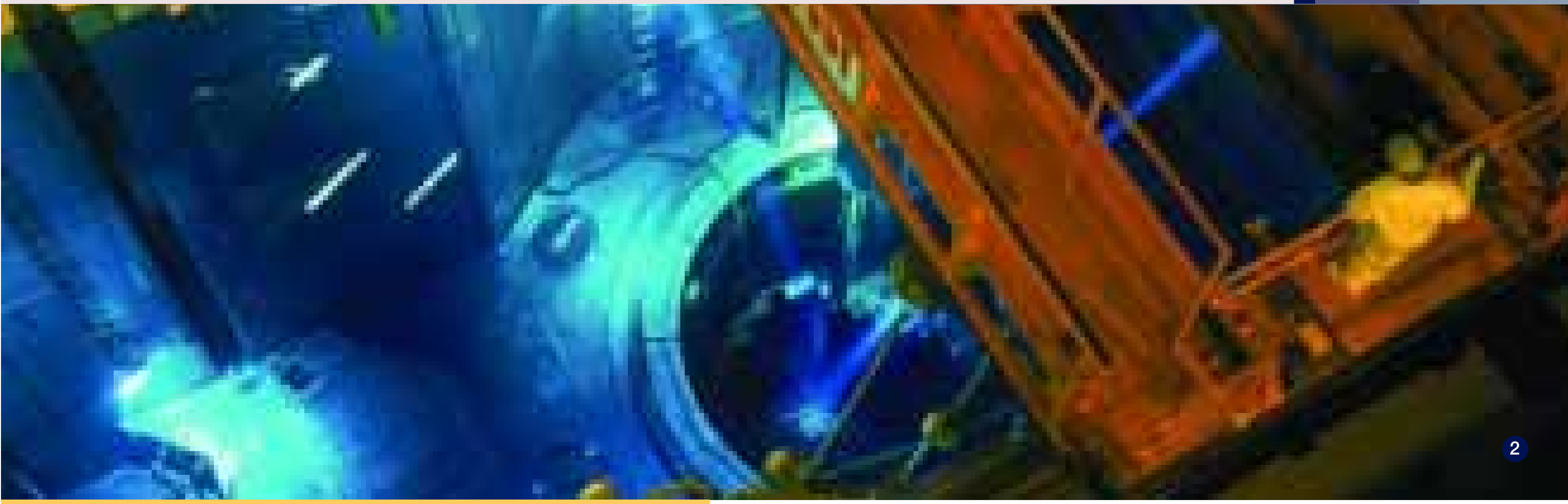
➜ In PWRs, the fuel assemblies in the core heat water, or "primary coolant", which is pressurized to prevent it from boiling and keep it in liquid form. Hence the name pressurized water reactor. The coolant is not sent directly to the turbine. Instead, it is circulated by "primary coolant pumps" inside a closed loop that goes from the reactor core to a large "steam generator" (SG). It is the steam generator that transmits heat from the primary coolant to the much less pressurized "secondary coolant", causing it to boil. The steam produced by the secondary coolant is routed to the turbine.

Boiling water reactor (BWR) concept



Pressurized water reactor (PWR) concept





Fission and the chain reaction: fundamental mechanisms of nuclear power

Fission and the chain reaction are triggered deliberately in nuclear power plants to produce and use energy in the form of heat.

Atoms

All matter is made of atoms. All atoms have the same structure: most of its weight is concentrated in the nucleus, which consists of protons and neutrons, while most of the volume is taken up by electrons that orbit around the nucleus. The protons and electrons are electrically charged. Each proton carries a positive charge and each electron carries a negative charge. Neutrons are not electrically charged. Every atom has as many protons as electrons, which means every atom is electrically neutral. A chemical element may have variations as to the number of neutrons that make up the nuclei of its atoms. In that case, several isotopes of that element are said to exist.

The remarkable properties of uranium 235

The uranium 235 atom is not very abundant in natural uranium, but it is the only natural isotope that is highly reactive to neutrons. When a neutron strikes it, it splits into two smaller atoms, throwing off neutrons and releasing energy in the process. This is known as fission.

The fission reaction produces large amounts of energy

When a uranium 235 atom fissions, each of the neutrons it throws off can strike another uranium 235 atom, causing it to fission and release more energy and neutrons, which in turn can strike yet more atoms, and so on. This is the “chain reaction”. The chain reaction ripples from one atom to the next at very high speed, accumulating considerable energy in the process.

② *Loading fuel into the Civaux-1 reactor in France.*

③ *Control rod drive mechanisms.*

④ *Engineering the EPR.*

The European Pressurized Water Reactor (EPR)

The EPR is a pressurized water reactor that uses moderately enriched (up to 5%) uranium oxide fuel or mixed oxide fuel (MOX). Its net electrical output is in the range of 1,600 MWe. Advantages of the EPR are:

- Major gains in performance including greater than 90% availability and lower operating costs, translating into greater cost-competitiveness and electricity that is 20% cheaper than gas-generated power.
- Significant safety improvements: the probability of a core meltdown, already infinitesimal with the PWR, is a factor of 10 lower with the EPR. But if such an event were nevertheless to occur, there would be no significant impact outside the power plant due to the extremely rugged containment building surrounding the reactor.
- An answer to sustainable development concerns: by design, the EPR generates more electricity from a given quantity of fuel, thus conserving uranium resources (-15%) and generating less waste (-15%).

Fast neutron reactors

In fast neutron reactors, there is no need to slow the neutrons, as the name suggests. The coolant is either a liquid metal (often sodium) or an inert gas (helium). The fuel for this reactor contains plutonium, a manmade element that is fissile like uranium 235. The fast neutron reactor core also contains uranium 238. Though U^{238} is not fissile and therefore does not contribute to the chain reaction, it converts into plutonium when it absorbs a neutron. As a result, these reactors produce more plutonium than they consume when operated in breeder mode, greatly increasing energy recovery from uranium resources. When operated in burner mode, these reactors are especially well suited to radioactive waste incineration.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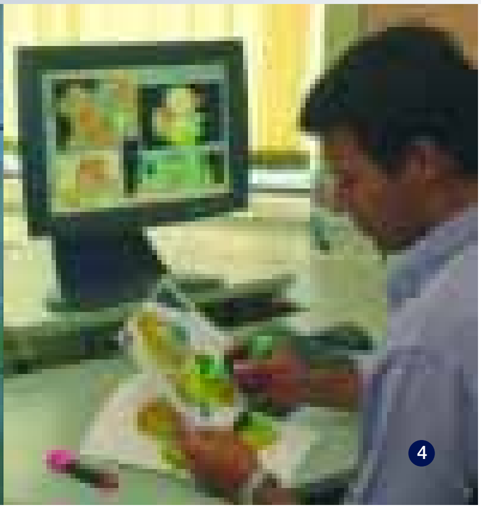
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INSIGHT

Controlling the nuclear reaction
To adjust the intensity of the self-sustained fission reaction, the number of available neutrons is controlled. This involves inserting neutron-absorbing rods into the reactor core in a controlled manner. When completely inserted, the control rods stop the nuclear reaction altogether. This can be done quickly for an emergency shutdown.

Heavy water reactors*

In this reactor type, heavy water is the moderator. Canada has championed its development with the Candu reactor. Heavy water presents the advantage of absorbing fewer neutrons than ordinary water, so it can use natural uranium, instead of enriched uranium, as fuel, thus saving a step. Heavy water can also be used as a coolant, since its other physical properties are close to those of ordinary water.

*D_2O is a combination of oxygen and deuterium (a heavy hydrogen atom) and is commonly called "heavy water", as distinguished from ordinary water, commonly called "light water".

INSIGHT

The area of the nuclear reactor containing the heat-producing fuel is called the "core". Several systems come into play for a successful self-sustained fission chain reaction in the reactor core.

Moderator and coolant
Neutrons are released at a very high speed when uranium 235 atoms fission. But their interaction with new uranium 235 atoms, producing new fissions, is much easier if the neutrons are slow. This is why neutrons are "moderated", or slowed, to promote the chain reaction.
In boiling water reactors (BWR) and pressurized water reactors (PWR) – representing the majority of the world's installed nuclear generating capacity – the moderator is simply the water flooding the reactor core. It's like billiard balls: when the ball hits another ball weighing the same amount, it slows down rapidly, but it rebounds if it hits a wall or a larger ball. Similarly, light-weight neutrons must strike light atoms to slow down. The hydrogen atoms in the water are perfect for this.
In other reactors, the moderator and the coolant are one and the same water.
In reactors that use helium as a coolant, graphite is the moderator because its carbon atoms are light enough to play this role. In fast neutron reactors, there is no moderator and the coolant can be either a liquid metal (e.g. sodium) or a gas (helium).

Using fuel in the reactor core

Producing heat, generating electricity

The reactor core consists of fuel assemblies arranged in a precise configuration. For a 900 MWe light water reactor, the core is 72.7 metric tons of enriched uranium. This fuel will undergo a series of transformations until it is "spent", and must be regularly replaced.

Gradual transformation of the fuel

A fuel assembly can remain in the reactor core for up to five years. During that time, uranium fission supplies the heat needed to generate electricity. But the fuel also undergoes a series of transformations that gradually reduce its performance:

➜ the uranium 235 content diminishes as a result of fission;

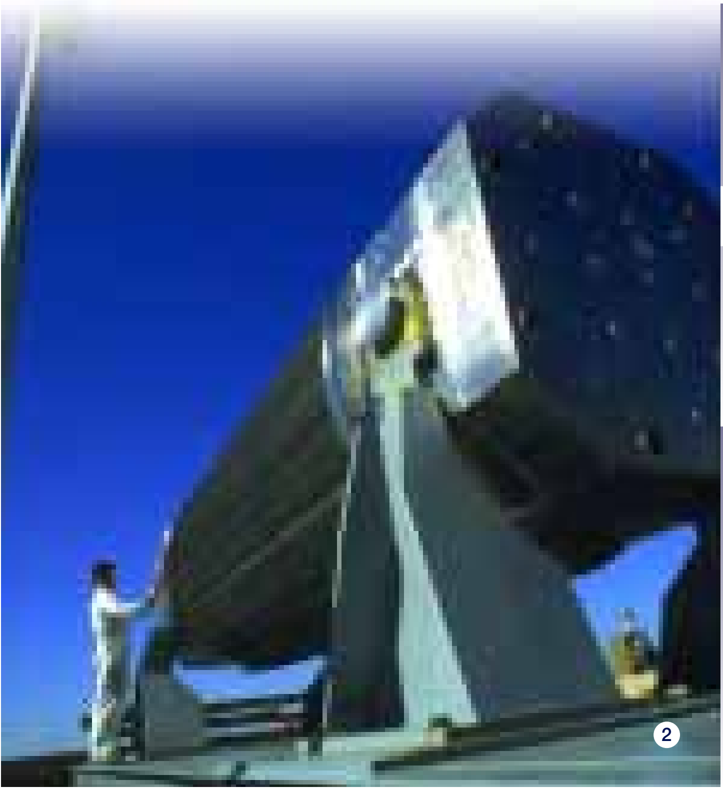
➜ plutonium is formed from neutron capture by uranium 238 atoms and begins to fission, producing energy just like uranium 235;

➜ fission of uranium 235 and plutonium results in fission products. Neutron capture also produces other, so-called minor actinides, such as neptunium, americium and curium. It is these products that constitute the final waste from the nuclear reaction, because they cannot be recycled, unlike the other products. They also slow down the chain reaction, earning them the name "poisons".

When the fuel is too spent to sustain the nuclear reaction and produce energy efficiently, it must be removed from the reactor core and replaced with fresh fuel. The spent fuel still contains a high proportion of recyclable energy materials. Spent fuel is more radioactive than fresh fuel and requires special handling. Before the energy-rich materials are recovered from the spent fuel, the unloaded assemblies are placed in pools next to the reactor for "cooling". Water is an effective barrier to radiation and also cools the assemblies, which continue to produce heat for a while. The radioactivity of the fuel decreases significantly after this temporary storage period, and the fuel can then be shipped to the La Hague reprocessing plant

① *Fuel assemblies in the reactor core.*

② *Spent fuel shipping cask.*



A CLOSER LOOK

Spent fuel transport: safety first

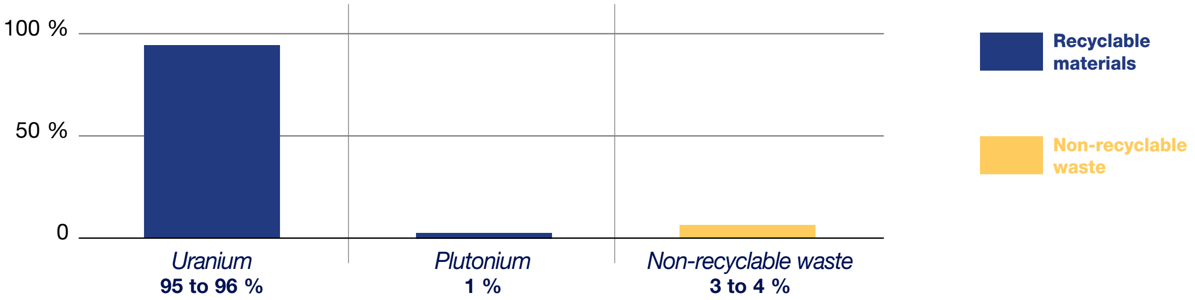
Very rigorous packaging and transportation standards apply to radioactive materials at every stage in the fuel cycle. To transport spent fuel from the power plant to the reprocessing plant, rugged shipping “casks” weighing close to 100 metric tons are used. The casks are designed for absolute nuclear and industrial safety, whether the fuel is to be transported by road, by rail or by sea. Every year, close to five new cask concepts are developed and 3,000 multinational shipments are completed worldwide.

A CLOSER LOOK

Preserving the environment and anticipating regulations

Safety requirements and the “ALARA” principle (“as low as reasonably achievable”) are factored into the design of nuclear fuel cycle facilities from the beginning. This applies to radiation doses, which remain below regulatory limits, effluent types and volumes (liquid and gaseous releases, effluent treatment), operating requirements, and many other aspects.

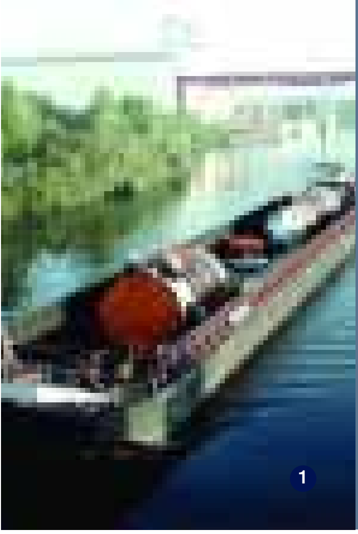
Composition of a spent fuel assembly



Fresh fuel contains about 3% U^{235} and 97% U^{238}. After a certain amount of time in the reactor core, the same fuel still contains 1% U^{235} and 95% U^{238}, as well as 1% plutonium and about 3% non-recyclable waste (fission products and minor actinides). Thus, “spent” fuel is actually almost 97% recyclable, with materials recoverable through reprocessing and recycling.

Manufacturing reactor equipment

Equipping nuclear power plants



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AREVA offers the industry a full range of manufacturing capabilities for nuclear power plant equipment and components. Its employees design and manufacture components for more than 90 reactors around the globe. And its technological skills and capabilities continue to be enriched by operating feedback from more than 1,500 reactor years of nuclear power plant operations.

Number 1 worldwide in nuclear components

Two main entities manufacture nuclear components. One is the Chalon/St. Marcel plant in the Burgundy region of France, which is totally dedicated to nuclear power and manufactures heavy equipment for the nuclear island. The other is the Jeumont plant in northern France, which designs and manufactures moving mechanical parts for the nuclear island, including reactor coolant pump sets and control rod drive mechanisms, along with their spare parts (motors, shafts, gaskets and hydraulic systems for primary coolant pumps). St. Marcel and Jeumont supply these components to nuclear power plants in France as well as in Belgium, Great Britain, the People's Republic of China, the Republic of Korea, South Africa, Sweden, Switzerland and the United States. Both plant sites are equipped with large-scale resources and are recognized for their unparalleled products and absolute quality. Their certifications under ASME, ISO 9001, RCC-M and French pressurized water reactor regulations attest to their compliance with the highest quality standards.

The Chalon/St. Marcel plant, center of the NSSS production line

Chalon/St. Marcel manufactures reactor vessels, vessel heads and internals, steam generators, pressurizers and their components for electric utilities in France and around the world in complete compliance with applicable requirements and regulations. The plant is involved in nuclear equipment design at several levels. Upstream, it adapts engineering design data to meet production and quality control requirements. Downstream, it prepares stress reports.

Production capacity unmatched in Europe

Since it was founded in 1975, close to 500 large components have been manufactured at the Chalon/St. Marcel plant for power stations the world over. The plant's annual production capacity is more than two 4-loop PWR power plants. That means two reactor vessels, eight steam generators, two pressurizers and related components such as accumulators, auxiliary heat exchangers, internals and supports, as well as 18 to 20 replacement steam generators.

Large-scale resources

The plant's 35,800 m^2 (385,348 ft^2) of covered facilities are located on a 35-hectare (86-acre) site next to a dock on the Saône River, facilitating component transport by river to the Mediterranean. The site is also close to major European rail and road networks. More than 50% of the staff consists of engineers and high-level. It is supported by a first-rate engineering department with calculation resources and skills in the areas of finite elements, fatigue studies and fracture mechanics, and a technology center for development of welding and non-destructive examination techniques.

① *Barge with 900 MWe reactor vessel, vessel head, steam generator and pressurizer headed for Ling Ao 1 nuclear power plant in China.*

② *Bird's eye view of the Chalon/Saint Marcel plant.*

③ *Heavy equipment assembly building.*


4

Technical expertise and proven experience: the Jeumont plant

For more than a century, the Jeumont plant has been designing, manufacturing and maintaining electrical equipment and mechanical components for thermal power production. Design, production, testing and maintenance of reactor coolant pump sets and control rod drive mechanisms are all performed on a single site. Today, plant personnel are working on orders for more than 110 reactors.

Designing and manufacturing high-performance products

The plant is the only manufacturer of complete reactor coolant pump sets, and has manufactured more than 220 of them to date. The pump sets circulate primary coolant between the reactor and the steam generator in the three cooling loops of a 900-1,000 MWe reactor or the four cooling loops of a 1,300 to 1,450 MWe reactor. They are an important factor in the availability and safety of nuclear power plants. To accommodate increasing power plant sizes and the need for high inertia, the plant designed the reactor coolant pump sets with controlled leak-off shaft seals that now equip 900 MWe, 1,300 MWe and 1,450 MWe reactors. The teams also bring their pump expertise to designs of next generation reactors.

Continuously improving spare parts manufacturing

Drawing on its store of lessons learned as an original equipment manufacturer and supplier of maintenance and repair services for control rod drive mechanisms and reactor coolant pump sets, the plant specializes in the supply of spare parts incorporating continuous improvements at the design and manufacturing level.

A CLOSER LOOK

Impressive testing resources ensuring equipment safety and reliability

The Jeumont plant has two test loops for reactor coolant pump sets, three test loops for shaft seals, and two cold test loops and one hot test loop for control rod drive mechanisms.

A CLOSER LOOK

Control rod drive mechanisms: guaranteed reliability

A control rod drive mechanism is a completely airtight electromagnetic cylinder installed on the upper portion of the reactor vessel head. It provides three essential functions:

➜ inserting and removing control rods into the reactor core,

➜ maintaining the control rod in the required position, and

➜ letting the control rods drop by gravity into the reactor core for an emergency shutdown.

The Jeumont plant supplies L106 series control rod drive mechanisms and will also supply mechanisms for the next generation of reactors.

A few figures…

➜ One 1,450 MWe reactor vessel + vessel head: 432 metric tons and 14 meters high.

➜ One 1,300 MWe steam generator: 460 metric tons and 22 meters high.

➜ One 1,300 MWe pressurizer: 117 metric tons and 13.5 meters high.

➜ 129 kilometers of tubing in a single 1,450 MWe team generator.

➜ One reactor coolant pump set: 110 metric tons and 8 meters high. 220 pump sets manufactured to date and more than 400 serviced.

➜ One control rod drive mechanism: 180 parts and 6.5 meters high. 4,500 drive mechanisms manufactured to date and 5,000 inspected.

④ *Machining building for primary coolant pump bodies.*

⑤ *Control rod drive mechanisms.*

⑥ *6 Digital lathe machining of seal parts.*

Reactor services

Nuclear power plant inspection and maintenance

Nuclear power plants are inspected and maintained after coming on line throughout their entire service life to ensure high levels of safety and technical performance at all times. These operations are performed during reactor outages for fuel reloading scheduled every 12, 18 or 24 months, depending on the reactor.

More than 3,000 people in France, Germany and the United States regularly bring the world's most comprehensive skills in PWR, BWR and VVER servicing to nuclear power plant operators in 30 countries. Services include inspection, routine service and maintenance, as well as component repair and replacement and facility and equipment upgrades. In every instance, work complies with applicable codes, standards and regulations in each country, as well as with the operator's requirements.

Non-destructive examinations and inspections

Regulatory compliance inspections are performed on all equipment in the nuclear steam supply system to verify that there are no material or structural defects. The inspections meet the requirements of the regulatory authorities as well as those of the operator. They are performed during power plant outages according to a pre-determined schedule defined by regulation. Most are performed robotically. In fact, the entire range of non-destructive examination methods is brought to bear: ultrasonic, eddy current, radiographic and liquid penetrant examinations; visual and camera inspections; seam tests, etc.

Nuclear measurements: a broad range of services

The nuclear measurement business designs and manufactures turnkey radiation measurement instrumentation and equipment. A wide range of services is offered, from tools for the analytical laboratory to radiological monitoring equipment to full-scale systems for industry. Three main markets are served:

- ➜ fundamental research in nuclear physics;
- ➜ analytical laboratories that measure radioactivity for environmental protection, health and safety; and
- ➜ the nuclear industry.

① *"Artur", a maintenance robot used to replace piping in high-radiation environments.*

② *Setting up the "Aramis" maintenance robot, used in steam generators.*

③ *Radiological monitoring equipment.*

4

5

Servicing, repairing, retrofitting

A variety of services are performed during reactor outages. Routine servicing occurs at each outage, while maintenance operations, such as component repair and replacement, are performed more infrequently throughout the reactor's service life.

Routine servicing

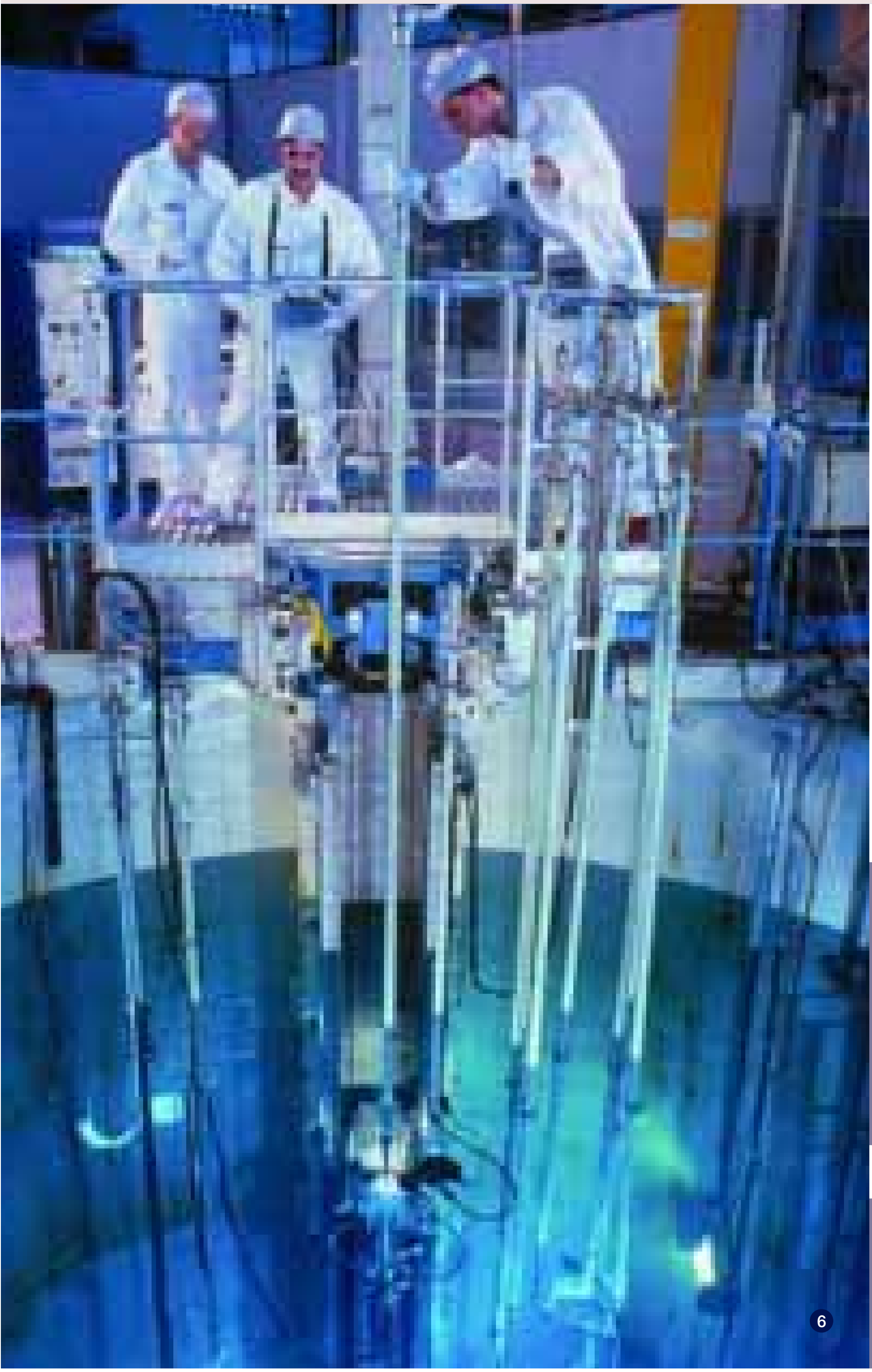
Routine servicing includes preparing the reactor vessel for a fuel reload, examinations of emergency backup equipment, and verification testing of mechanical equipment (valves, pumps, etc.), electrical equipment and the reactor control system.

Component repair and replacement

NSSS components may be repaired or replaced to ensure safe and efficient power plant operations throughout the reactor life cycle. This mostly concerns large equipment requiring the reactor constructor's special know-how and expertise.

Retrofitting

Given the long service life of nuclear power plants, during which time technology can evolve and safety requirements change, the reactor must periodically undergo retrofitting. This avoids equipment obsolescence by ensuring that only the most up-to-date technology is used, thus enhancing safety levels. Retrofitting concerns mechanical equipment as well as electrical systems and the reactor control system.



④ *Steam generator replacement at the Gravelines power plant in France.*

⑤ *Installing the Teleperm XS system for improved control at the Beznau nuclear power plant in Switzerland.*

⑥ *Operator training in fuel assembly repair at the CETIC training and qualification center (Chalon/Saône, France*

A CLOSER LOOK

Continuing operator training, process qualification

Operations inside the reactor building follow stringent procedures for operator training, process qualification and compliance with radiation protection requirements. All operating personnel and work processes are qualified by the plant operator according to regulatory standards. Methods used are validated in specialized facilities on full-scale mock-ups of reactor components that recreate the actual work environment. These tests also serve as training opportunities for operators and to verify operations before they are conducted in the power plant.

Spent fuel reprocessing

and recycling

Spent fuel reprocessing

Uranium, plutonium and fission products: separating, recycling and packaging spent fuel components

Spent fuel reprocessing is fundamentally sound waste management. It allows recyclable materials to be recovered and final waste to be packaged for disposal. Reprocessing is an efficient way to manage the back end of the fuel cycle. For France and other countries who believe in the optimum use of nuclear power, the decision to reprocess is completely consistent with the principles of sustainable development: to balance economic development with social welfare and environmental preservation.

The advantages of reprocessing are threefold:

➜ energy-rich uranium and plutonium representing 96% of the spent fuel's content can be recycled into MOX fuel;

➜ non-recyclable waste is more easily stored (temporarily) or disposed of (permanently) by isolating it, reducing its volume and packaging it appropriately;

➜ the long-term toxicity of the final waste can be divided by ten and its volume by five by packaging it according to precise, internationally accepted technical specifications, just like other industrial products.

Reprocessing at the La Hague plant

The La Hague reprocessing plant came on stream in 1966. Since then, it has been continuously upgraded to satisfy customer requirements and meet stringent environmental protection criteria. An example of this is the ACC hulls compaction facility, which started up in 2002. The culmination of a major research and development program, the facility compacts spent fuel hulls, end-fittings and dry active waste and packages them into standard containers. Three benefits accrue from this facility:

➜ waste volumes are divided by five;

➜ handling, transport and storage operations are optimized; and

➜ operations are more cost-effective.

The La Hague reprocessing plant is now dedicated mainly to light water reactor fuels. The plant services more than 20 utilities in Europe, including *Electricté de France*, and in Japan.

Nuclear engineering

The group's nuclear engineering activities originally focused on designing, building and starting up facilities for the back end of the fuel cycle.

This was extended by incorporating operating lessons learned in the design and construction of new nuclear facilities and in the optimization of existing facilities for the worldwide nuclear industry.

Today, the engineering business covers four areas:

- Process engineering: industrial scale-up of processes developed by the national research centers and applications development for existing processes.
- Project engineering: design, construction and start-up of industrial facilities.
- Engineering services: operator support for production facility upgrades and modifications.
- Engineering for nuclear cleanup and dismantling: operator support from decommissioning of the facility through cleanup and dismantling to final site restoration.

INSIGHT

Plutonium is created inside the reactor core

Plutonium is manmade. It forms during the nuclear reaction from uranium used as reactor fuel. During the reaction, the uranium 238 captures a neutron, transforming it into uranium 239. The uranium 239 transmutes in turn into neptunium 239. Half of the neptunium 239 is transformed into plutonium 239 every two days.

① *Dry unloading of spent fuel, La Hague spent fuel reprocessing plant, France.*

② *The La Hague, France, spent fuel reprocessing plant from above.*

③ *Plutonium conversion and packaging facility at the La Hague plant.*

Spent fuel reprocessing

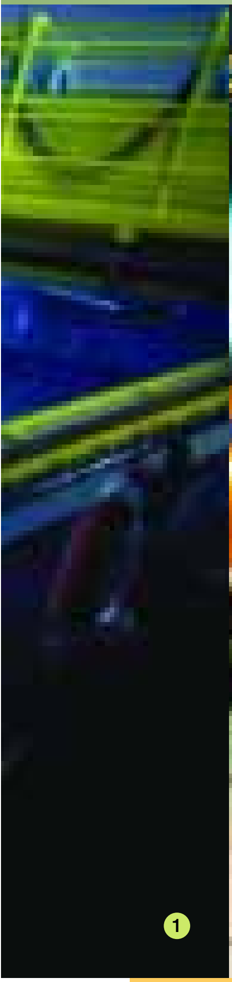
1. *Spent fuel storage pool at the La Hague, France, spent fuel reprocessing plant.*
2. *Operators using remote manipulators at the La Hague, France, spent fuel reprocessing plant.*
3. *Return of vitrified waste to Japan.*
4. *Transport of spent fuel shipping casks.*

A final destination for each separated product

After some time in the reactor pool, the spent fuel is stored in pools at the La Hague plant, where it will continue to cool for 5 to 8 years. Then the fuel is removed and sheared into pieces a few centimeters long so that the nuclear material inside can be extracted by dissolving it in acid. Solvents are used to separate the uranium, plutonium and fission products. The uranium is concentrated in the form of liquid nitrate and shipped either to the Comurhex plant at Pierrelatte for reconversion into UF_6, or to the TU_5 plant, also at Pierrelatte, for conversion into an oxide for later recycling. The plutonium is packaged in oxide form inside sealed containers for recycling into new MOX fuel (fuel made with a mixture of uranium and plutonium oxides). The waste is packaged by type and radioactivity in standard containers that have been approved by regulatory authorities in several countries.

Returning reprocessing products to the fuel owner

The customer companies that send their spent fuel to La Hague for reprocessing remain the owners of the fuel. The reprocessing contract provides for the return of non-reusable portions of the reprocessed fuel, packaged as final waste. The waste is returned to owners in special land-based or sea-based equipment.



A CLOSER LOOK

Remote handling and robotics

At the La Hague plant, operations may be divided into three phases: spent fuel receiving and storage prior to reprocessing, the actual reprocessing operation, and waste packaging. Due to the elevated radioactivity of spent fuel, stringent safety measures are taken to protect operating personnel and the environment. All operations, whether handling, mechanical or chemical, are performed remotely with remote manipulators or robotic control systems.

Radioactive materials transportation and storage: safety first

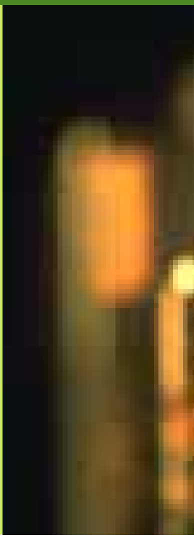
For the design and manufacture of special shipping casks, as for nuclear materials transportation and storage, AREVA tailors its solutions to its international customers' requirements. Personnel safety, transportation safety and environmental protection are put first at all times.

Spent fuel recycling

Making use of energy materials recovered through reprocessing


1

Reprocessing recovers fissile plutonium. Recycling plutonium into MOX fuel unlocks its significant energy potential. The uranium recovered during reprocessing is still about 1% U^{235}, some of which is recycled. The rest is stored in stable form and could be re-enriched if the market supports it.



One gram of plutonium 239 can generate as much electricity as more than one metric ton of oil. It is fissile. When used in MOX (a fuel made from a mix of uranium and plutonium oxides), plutonium plays the role that U^{235} plays in “fresh” fuel. Which is why plutonium recovered from spent fuel is used to make MOX fuel. Recycling into MOX:

➜ lowers waste volumes and toxicity levels, since the fuel’s highly radiotoxic plutonium content is consumed rather than disposed of; and

➜ conserves natural resources of gas and uranium.

MOX, a fuel with plutonium as the fissile material

The MELOX plant in southern France is the world leader in MOX fuel fabrication. MOX is made of 5-11% plutonium oxide mixed with depleted uranium oxide (UO2) from the TU2 plant at Pierrelatte. MOX fabrication uses much the same approach as for conventional nuclear fuel. Like enriched uranium fuel, MOX consists of pellets that are inserted into “fuel rods” to make fuel assemblies. The difference lies in the special nuclear and industrial safety requirements that apply to fabrication operations. The fuel is also comparable to enriched uranium fuel in terms of performance in the reactor. MOX has been used in Europe commercially for several years in light water reactors: since 1982 in Germany, 1985 in Switzerland and 1987 in France. Today, 35 European reactors are running on MOX fuel. In France, national utility *Electricité de France* uses MOX fuel in 20 of the 28 reactors technically capable of loading it. In Japan, power companies plan to load MOX fuel in 16 to 18 reactors. In the French case,


2

MOX assemblies make up 30% of the reactor core, with the remaining 70% consisting of enriched uranium fuel. AREVA's MOX fabrication technologies can also be used for disarmament programs, such as the bilateral weapons reduction agreement between the United States and Russia, which call for a portion of their surplus defense plutonium (68 metric tons) to be recycled into MOX fuel.

1 *MOX fuel fabrication building, Melox, France.*
Final inspection of the assembly.

2 *MOX pellet press.*

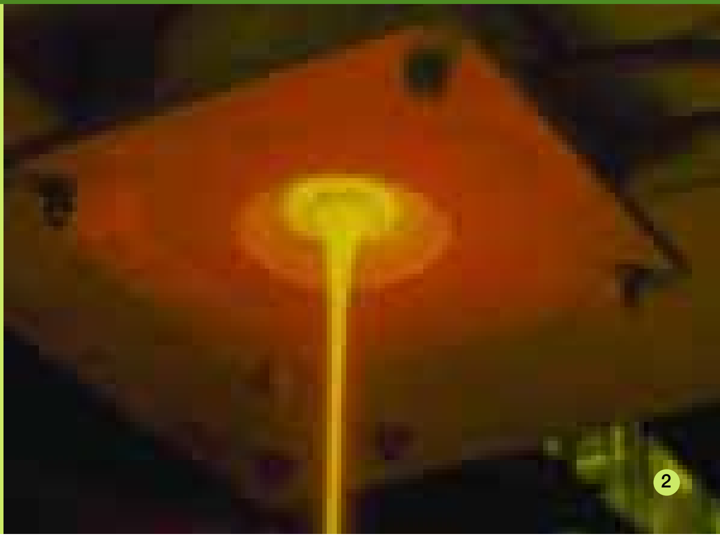
3 *MOX fuel assembly.*


3

Waste management

Standardized waste packages for different half-lives and activity levels

Low, medium and high level waste with varying half-lives is generated at each stage in the fuel cycle. Spent fuel reprocessing, which separates the fuel's different components, simplifies waste management by enabling use of packaging and disposal techniques specific to each waste type.



Waste isolated during reprocessing is packaged at the La Hague site “in line” – meaning as and when it is separated. Fission products, minor actinides and fuel structures are all packaged in "universal canisters" or standard waste containers.

Vitrification

Fission products, such as strontium and cesium, and minor actinides, such as neptunium and americium, are formed in the fuel when it is in the reactor. Once isolated, they concentrate practically all of the spent fuel’s radioactivity into a very small volume. These products are not recyclable, and thus constitute final waste. They are incorporated into molten glass and poured into stainless steel canisters. The sealed canisters are placed in air-cooled pits before return to the owner utility. Vitrified fission products have very long term integrity, are insoluble in water and resist corrosion by natural physico-chemical processes.

Compaction

Fuel structural components, which are also non-recyclable, are classified as medium level waste. They consist of sheared fuel "hulls" and end-fittings, which are compacted into “pancakes” and placed inside the same type of container as for vitrified waste. Standardizing waste containers facilitates handling, transportation and disposal operations.

Disposal

Waste packaging is designed for very high integrity under disposal conditions. The service life of a glass canister, for example, is from 100,000 to 10,000,000 years. Its exceptional characteristics and volume reduction factor facilitate waste storage, which may conceivably be used for several centuries using existing technologies.

A CLOSER LOOK

Reducing final waste volumes and toxicity levels

Waste and effluent volumes from spent fuel reprocessing have continually declined ever since commercial reprocessing operations began in 1966. Today, less than 0.5 m^3 of high and medium level waste is generated per metric ton of spent fuel reprocessed. Without reprocessing and recycling, spent fuel is treated as waste and disposed of as is, meaning that some 2 m^3 of high level waste needs to be buried. Reprocessing also slashes final waste toxicity to one-tenth initial levels. And even greater improvements are expected in the years ahead.

① *Standard waste containers for vitrified and compacted waste.*

② *Glass pour in a vitrification test facility.*

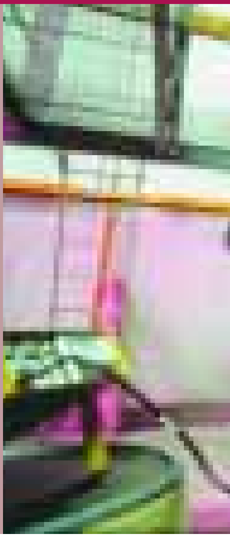
③ *High-pressure compactor.*

④ *Sheared fuel hulls before compaction.*

Nuclear cleanup and dismantling

A unique alliance of nuclear operators and decommissioning specialists

One day or another, all industrial facilities reach the end of their service life, regardless of the type of facility. Made obsolete by technological advances, they are shut down to make room for other modes of production. The owners of these facilities remain responsible for them and have a duty to take charge of their future. The goal is to remove residual pollution generated by past operations so that the site may ultimately be reused.



AREVA companies have been involved in decontamination and dismantling operations for more than twenty years, whether at their own nuclear fuel cycle facilities or at other sites in France and abroad.

By merging the experience of the nuclear operator with the know-how of companies specializing in various aspects of cleanup and dismantling, the AREVA group offers the nuclear industry unique expertise to support their cleanup and dismantling projects.

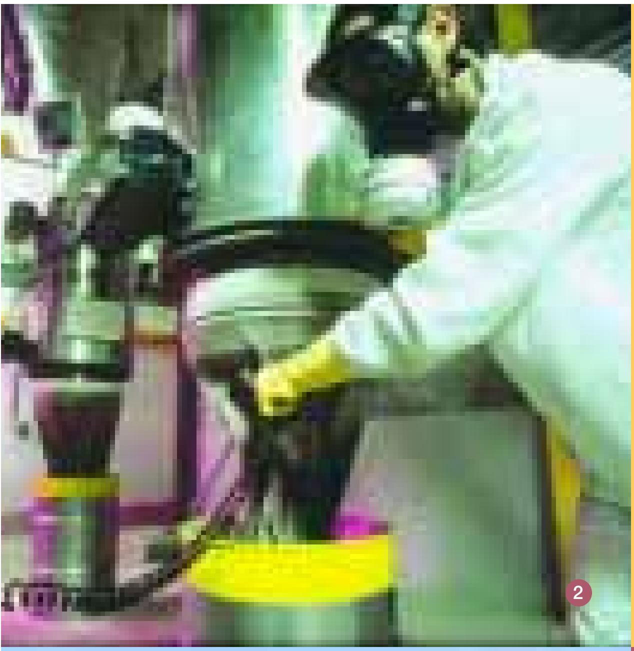
AREVA draws on synergies among its member companies to provide targeted services, from project planning and safety analyses, to licensing support, to cleanup and dismantling operations and waste management.

The group has successfully completed more than thirty nuclear facility dismantling projects to date. Now AREVA is offering its cleanup and dismantling know-how in projects around the world: Hanford (USA). Dounreay (Great Britain), Chernobyl (Ukraine), Brennilis (France) and the ballistic missile submarine Le Redoutable (France).

① *Decommissioning of the sodium-cooled fast reactor at Dounreay, Great Britain.*

② *Decommissioning activities at the Marcoule site, France.*

③ *Hanford site, USA.*



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The Marcoule facilities

The UP1 plant at Marcoule was France's first spent fuel reprocessing plant. A program to dismantle the plant began in 1998 with the goal of cleaning up the facilities to environmentally regulated status or for unrestricted use. The techniques of cleanup are largely well established, but their application to an entire site represents a major challenge. In fact, the Marcoule plant dismantling program is a world first in terms of scale.

The program is divided into three distinct projects:

Decommissioning

Nuclear materials are removed and the facilities are cleaned up.

Monitoring and dismantling

The most contaminated equipment is physically taken apart under containment specifically designed for residual activity levels.

Waste retrieval and packaging

Waste for which technical solutions or disposal methods were previously unavailable is sorted and repackaged to comply with long-term safety requirements.

3

A CLOSER LOOK

The Hanford site (USA)

The AREVA group is involved in several aspects of this large defense site cleanup program: cleanup of hot cells and pools, characterization and stabilization of radioactive waste, and supply of liquid effluent treatment systems.

INSIGHT

What happens during cleanup of a nuclear site?

Permits

→ Before the work begins, the project must be carefully defined. The nuclear operator establishes the decommissioning plan and describes safety measures to be taken. This information is submitted to the regulatory authorities. Each stage of the project is subject to a special permit.

Final shutdown

→ During this phase of the project, nuclear materials are removed and the facilities are decontaminated to a level consistent with safe dismantling operations. Final shutdown operations also help to reduce facility monitoring requirements until dismantling operations can begin.

Dismantling

→ Production equipment is removed and the area is decontaminated. Support facilities, such as effluent treatment and waste packaging facilities, are generally not shut down as they will continue to be used throughout the dismantling phase.

Site cleanup

→ When an entire plant site is undergoing decontamination and dismantling, it may also be necessary to clean up certain areas of the site, especially those used to store materials or waste during the operating period.

Glossary

Actinide

(see also “Transuranics”)
Chemical element whose nucleus contains more than 88 protons. In order, the actinides are actinium, thorium, protactinium, uranium and the transuranics. Neptunium, americium and curium are often called minor actinides.

Hulls

Pieces of metal tubing about 3 cm long resulting from the shearing of fuel rods containing nuclear power plant fuel in the reprocessing plant.

IAEA, International Atomic Energy Agency.

International organization under U.N. oversight whose role is to promote the peaceful use of nuclear power and to ensure that nuclear materials are not diverted for military purposes.

Isotope

Elements whose atoms have the same number of electrons and protons but a different number of neutrons. For example, uranium has three isotopes: U^{234} (92 protons, 92 electrons, 142 neutrons), U^{235} (92 protons, 92 electrons, 143 neutrons) and U^{238} (92 protons, 92 electrons, 146 neutrons). A given chemical element may therefore have several different isotopes, depending on the number of neutrons. All isotopes of the same element have the same chemical properties but different physical properties (in particular weight).

Plutonium

Element with atomic number 94 and symbol Pu. Plutonium 239, a fissile isotope, is produced in nuclear reactors from uranium 238.

Radioactivity

Emissions of electromagnetic waves and/or particles by a chemical element caused by a rearrangement of its nucleus. Emissions may be spontaneous (naturally occurring radioactivity of some unstable atoms) or induced (manmade radioactivity).

Reactor core

Area of a nuclear fission reactor consisting of the nuclear fuel and configured to promote the fission chain reaction.

Transuranics

(see also “Actinides”)
Chemical elements whose nuclei contain more protons than the uranium nucleus. The leading transuranics are, in ascending order, neptunium, plutonium, americium and curium.

Uranium

Chemical element with atomic number 92 and symbol U, with three natural isotopes: U^{234}, U^{235} and U^{238}. U^{235} is the only naturally fissile nuclide, a property that explains its use as an energy source.

Winze

Inclined passage used by personnel carriers and machinery to access underground mine substructures from the surface.

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AREVA is a worldwide expert in the energy field, with a strong industrial presence in over 40 countries. The group provides its clients with technological solutions for nuclear energy production and electricity transmission and distribution. AREVA also offers interconnect systems, principally in the telecommunications, computer and automotive markets.
The 75,000 AREVA employees are thus committed to the major challenges of the 21st century: access to energy for everyone, preservation of the planet and responsibility toward future generations.

www.areva.com

27/29, rue Le Peletier
F - 75433 Paris Cedex 09
Tel.: 33 (0)1 44 83 71 00
Fax: 33 (0)1 44 83 25 00

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