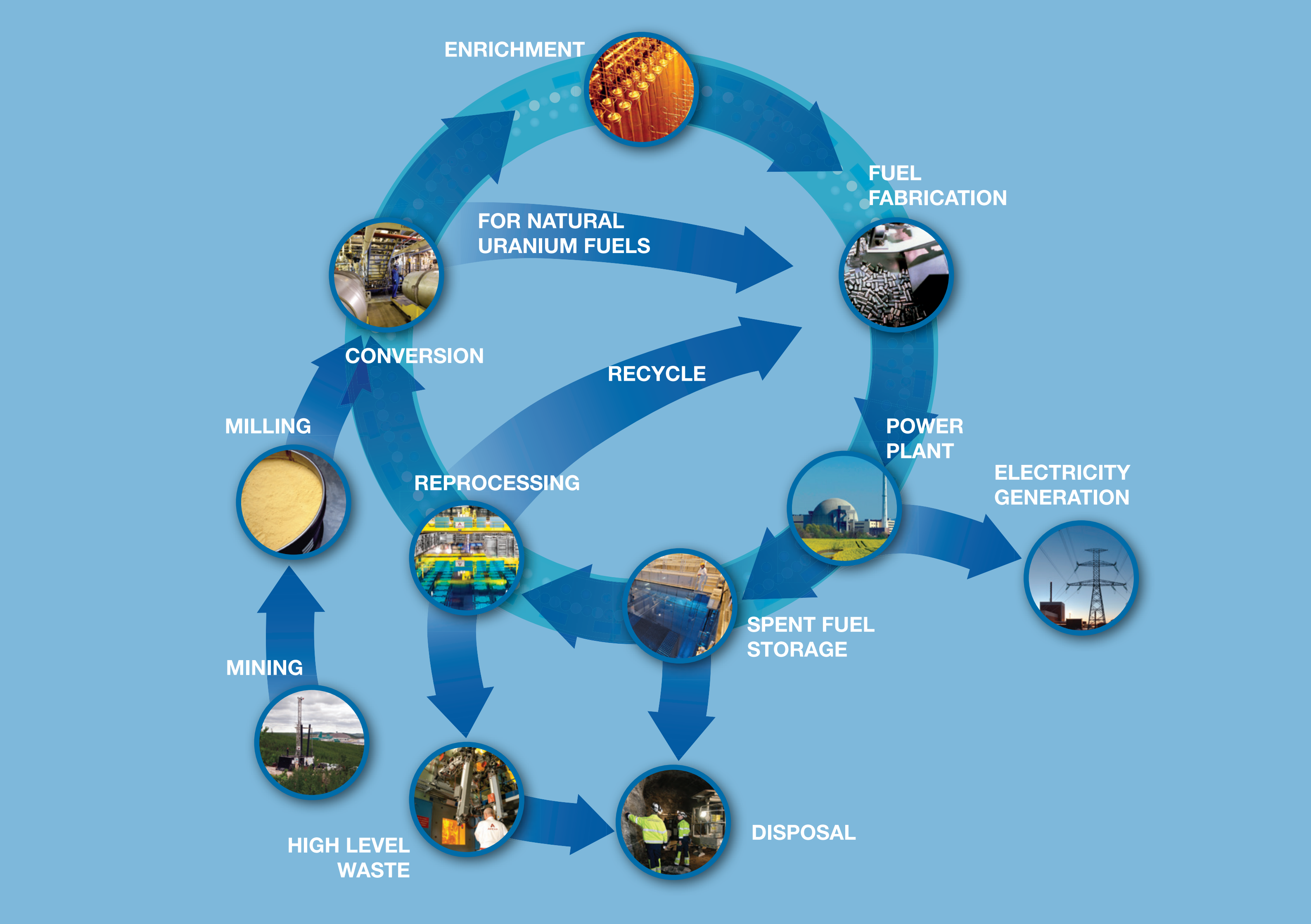
THE NUCLEAR FUEL CYCLE

IAEA
International Atomic Energy Agency


ENRICHMENT
FUEL FABRICATION
FOR NATURAL URANIUM FUELS
CONVERSION
RECYCLE
MILLING
POWER PLANT
ELECTRICITY GENERATION
REPROCESSING
SPENT FUEL STORAGE
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THE NUCLEAR FUEL CYCLE

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INTRODUCTION

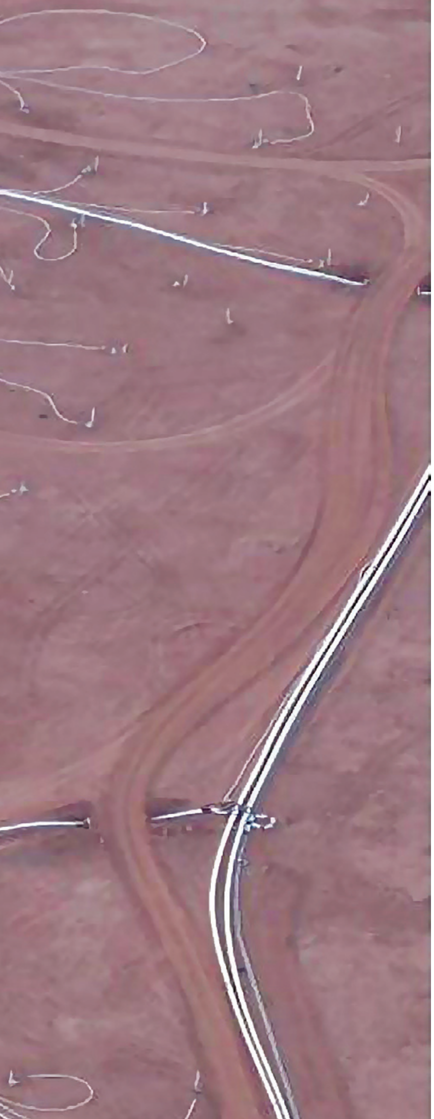
The various activities associated with the production of electricity from nuclear power reactors are referred to collectively as the nuclear fuel cycle.

The cycle starts with the mining of uranium and ends with the disposal of nuclear waste.

The raw material for today's nuclear fuel is mainly uranium. It must be processed through a series of steps to produce an efficient fuel for generating electricity. Spent fuel also needs to be taken care of for recycling or disposal.

The nuclear fuel cycle comprises the 'front end', i.e. preparation of the fuel, the 'service period' in which fuel is used during reactor operation to generate electricity, and the 'back end', i.e. the safe management of spent nuclear fuel including reprocessing and recycling, and disposal.

If spent fuel is not reprocessed, the fuel cycle is referred to as 'open' or 'once-through' fuel cycle; if spent fuel is reprocessed, and recycled, it is referred to as 'closed' nuclear fuel cycle.

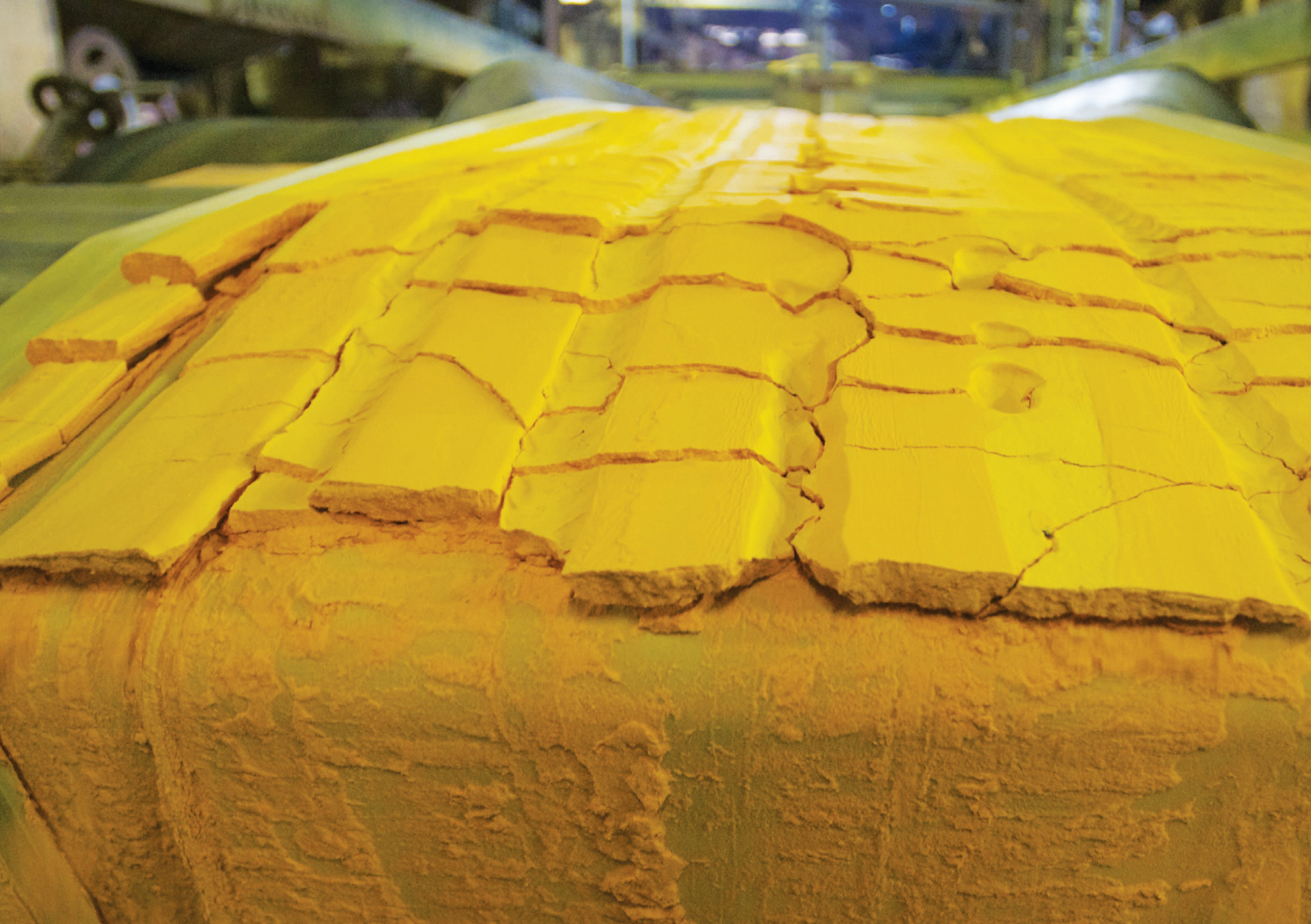


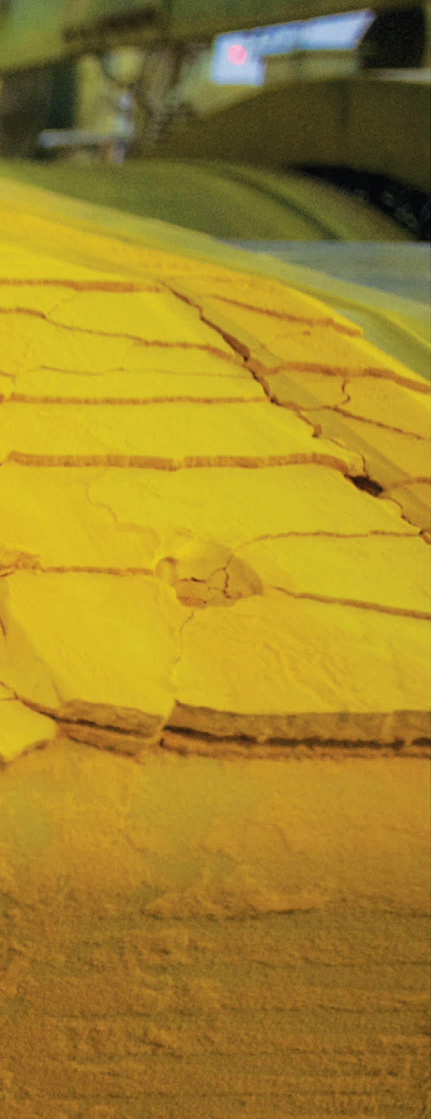
URANIUM MINING

Uranium is a common metal that can be found throughout the world. It is present in most rocks and soils, in many rivers and in sea water. Uranium is about 500 times more abundant than gold and about as common as tin.

There are three ways to mine uranium: open pit mines, underground mines and in situ leaching where the uranium is leached directly from the ore.

The largest producers of uranium ore are Kazakhstan, Canada and Australia. The concentration of uranium in the ore could range from 0.03% up to 20%.





URANIUM MILLING

Milling is generally carried out close to a uranium mine. The mined uranium ore is crushed and chemically treated to separate the uranium.

The result is ‘yellow cake’, a yellow powder of uranium oxide (U_3O_8). In yellow cake the uranium concentration is raised to more than 80%.

After milling, the yellow cake concentrate is shipped to a conversion facility.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FLUORINE
HYDROGEN

CONVERSION

Natural uranium consists primarily of two isotopes, 99.3% is ^{238}U and 0.7% is ^{235}U. The fission process by which heat energy is released in a nuclear reactor, takes place mainly in ^{235}U. Most nuclear power plants require fuel with ^{235}U enriched to a level of 3–5%.

To increase the ratio of ^{235}U against ^{238}U, uranium must be enriched. Since enrichment happens in gaseous form, yellow cake is converted to uranium hexafluoride gas (UF_6) at a conversion facility.

UF_6 gas is filled into large cylinders where it solidifies. The cylinders are loaded into strong metal containers and shipped to an enrichment plant.

ENRICHMENT

Uranium hexafluoride gas is enriched in ^{235}U by introducing the gas in fast-spinning cylinders ('centrifuges'), where heavier isotopes are pushed out to the cylinder walls.

Uranium can also be enriched using older technology (gaseous diffusion) by pumping UF_6 gas through porous membranes that allow ^{235}U to pass through more easily than heavier isotopes, such as ^{238}U. Research and development activities are ongoing to enrich ^{235}U vapor by laser techniques.


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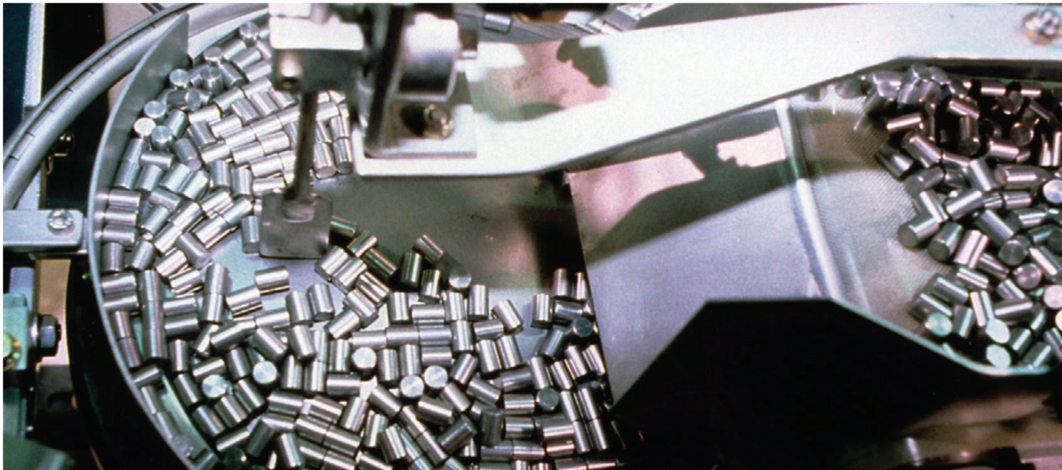
FUEL FABRICATION

Solidified enriched uranium hexafluoride (UF_6) is converted into uranium oxide (UO_2) pellets, by pressing and sintering (baking) UO_2 at temperatures of over 1400°C to achieve high density and stability. The pellets are cylindrical and are typically 8–15 mm in diameter and 10–15 mm long.

They are packed in long metal tubes to form fuel rods, which can withstand high temperature and pressure. The fuel rods are then grouped in 'fuel assemblies' for introduction into a nuclear reactor.

The same process is used to fabricate mixed oxide fuel (MOX), composed of uranium and plutonium oxides.

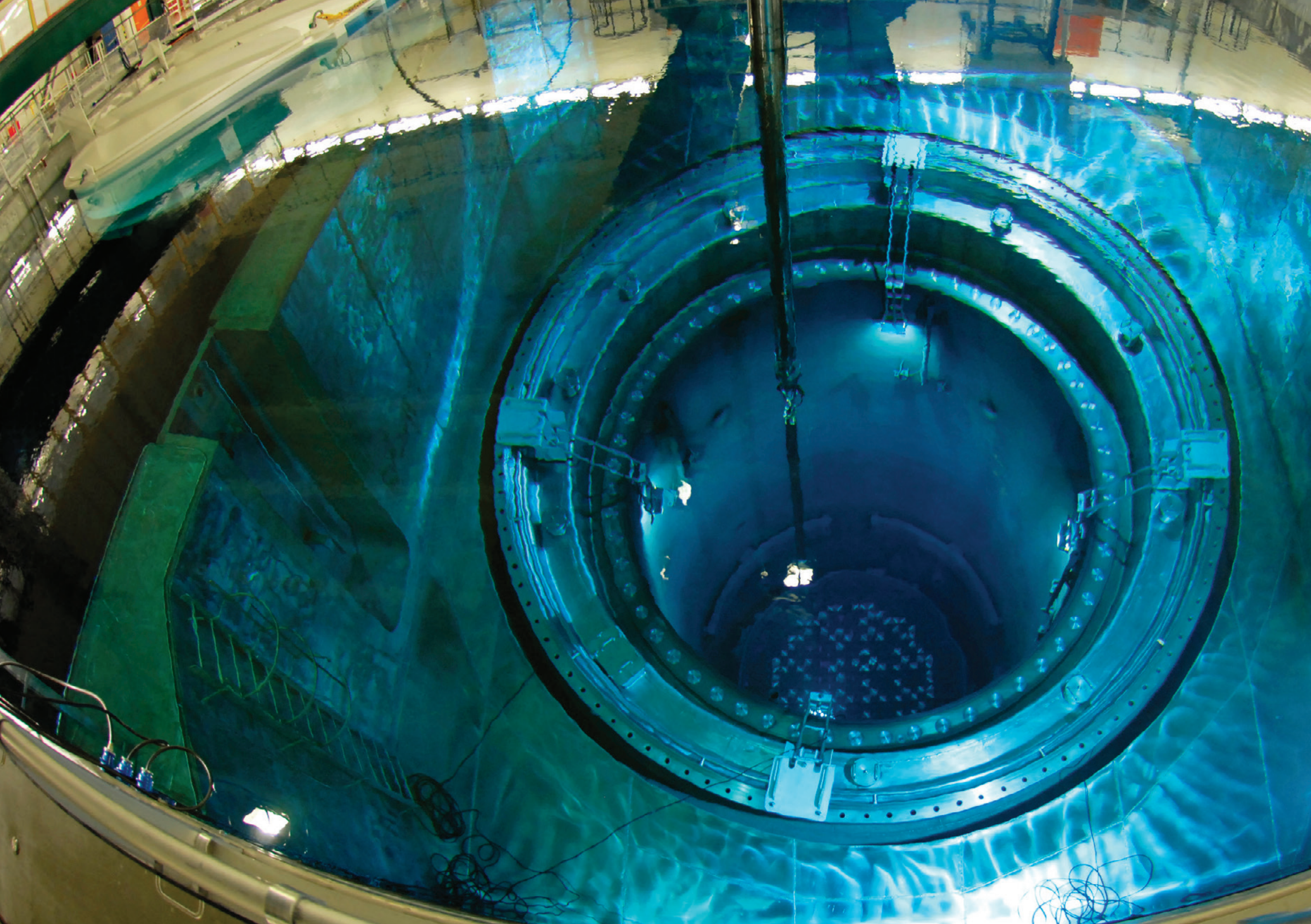


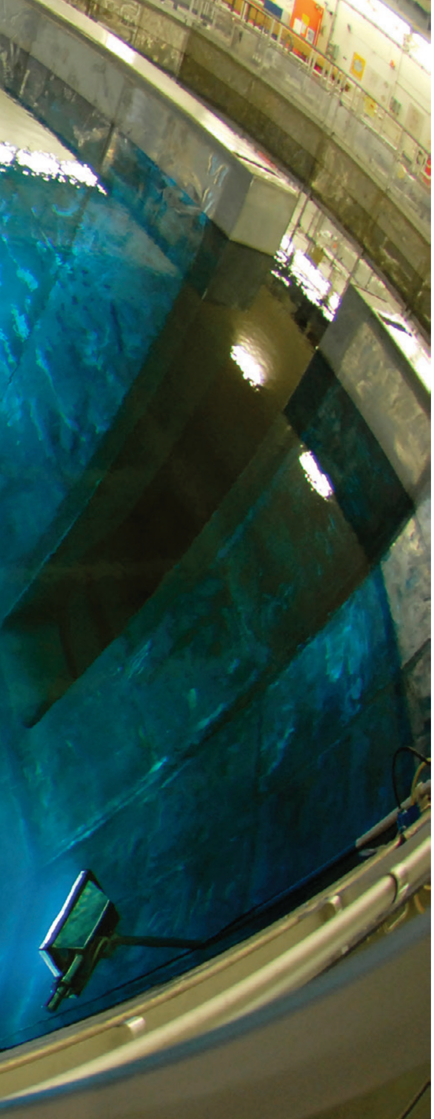
ELECTRICITY GENERATION

Once the fuel is loaded inside a nuclear reactor, controlled fission can occur. Fission means splitting of fissile radionuclides (e.g. ^{235}U and ^{239}Pu). The splitting releases energy that is used to heat water and produce high pressure steam. The steam turns a turbine connected to a generator, which generates electricity.

The fuel is used in the reactor for 3–6 years. About once a year, part of the fuel is unloaded and replaced with fresh fuel.

Controlled fission results in production of several elements, such as plutonium that can be recycled, and others, which are waste.



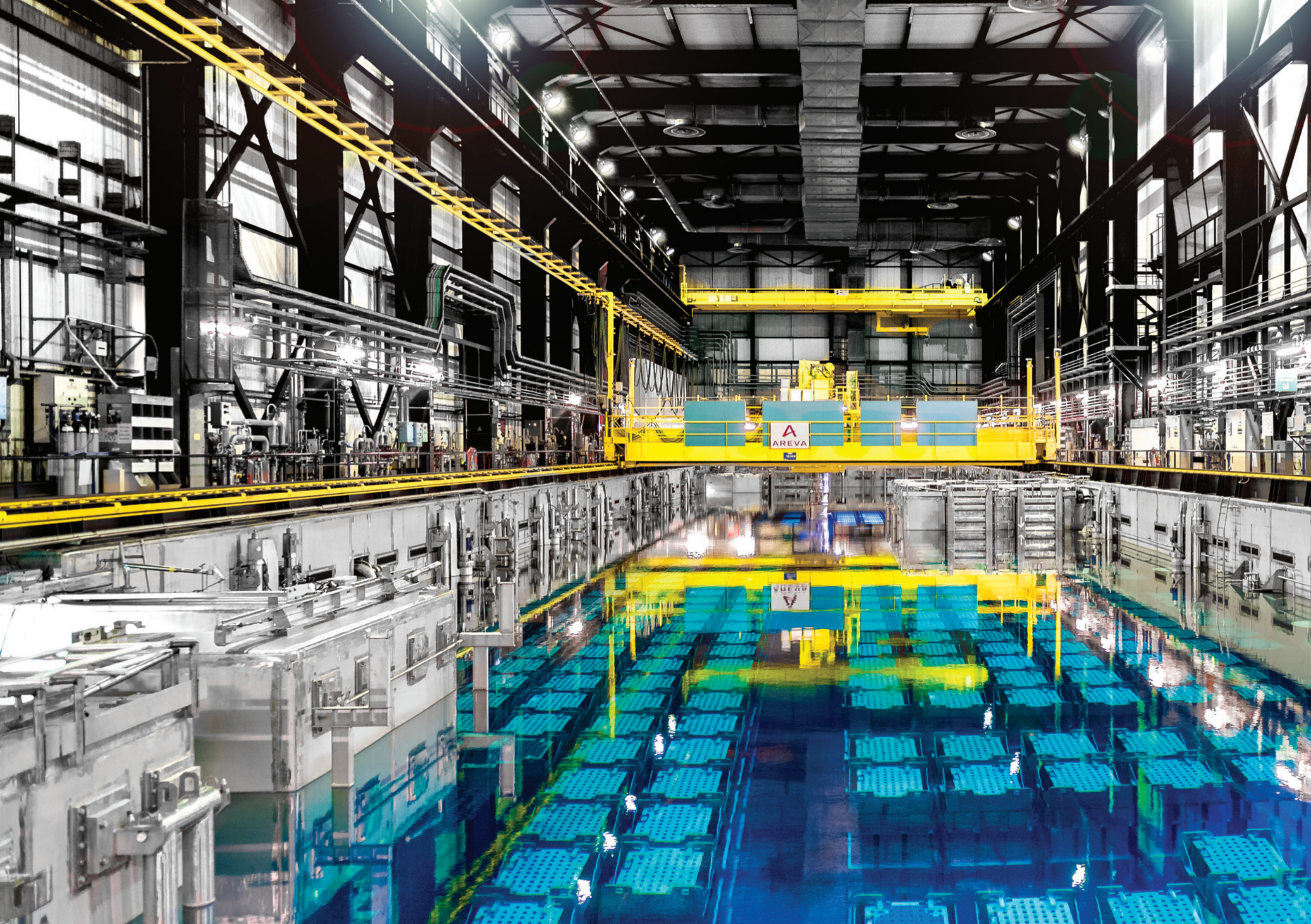


SPENT FUEL STORAGE

The spent fuel assemblies removed from the reactor are very hot and radioactive. Therefore, the spent fuel is stored in the reactor pool, where water provides both cooling and radiation shielding.

After a few years, spent fuel can be transferred to an interim storage facility. This facility can involve either wet storage, where spent fuel is kept in water pools, or dry storage, where spent fuel is kept either in casks or in canisters.

Both the heat and radioactivity decrease over time. After 40 years in storage, the fuel‘s radioactivity will be about a thousand times lower than when it was removed from the reactor.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REPROCESSING AND RECYCLING

The spent fuel contains uranium (96%), plutonium (1%) and high level waste products (3%). The uranium, with less than 1% fissile ^{235}U and the plutonium can be reused. Some countries chemically reprocess usable uranium and plutonium to separate them from unusable waste.

Recovered uranium from reprocessing can be returned to the conversion plant, converted to UF_6 and subsequently re-enriched to fabricate new fuel.

Recovered plutonium, mixed with uranium, can be used to fabricate MOX fuel.

SPENT FUEL AND HIGH LEVEL WASTE DISPOSAL

Spent nuclear fuel and high level waste can be safely disposed of deep underground, in stable rock formations such as granite or clay, thus eliminating the health risk to people and the environment. The first disposal facilities will be in operation in the mid-2020s.

Waste will be packed in long-lasting containers and buried deep in the geological formations chosen for their favourable stability and geochemistry, including limited water movement. These geological formations have stability over hundreds of millions of years, far longer than the waste is hazardous.

Fresh fuel assemblies in the core of
Novovoronezh-6 nuclear power reactor

IAEA
International Atomic Energy Agency

Department of Nuclear Energy

Vienna International Centre
PO Box 100, 1400 Vienna, Austria
www.iaea.org/ne
@IAEANE

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