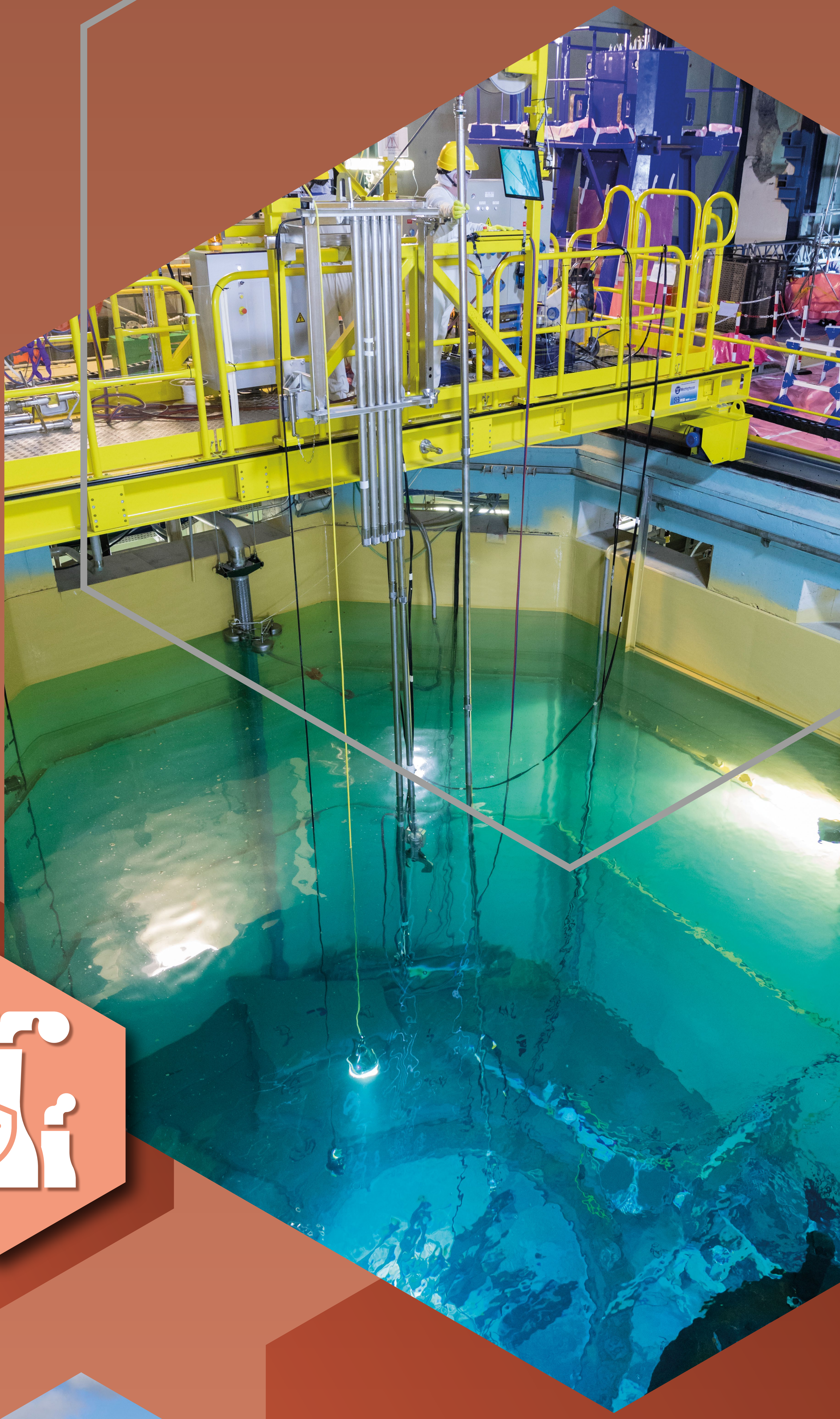
ARE NUCLEAR POWER PLANTS SAFE?



7.1 Design: ASN and IRSN Communications Departments - May 2022
Graphic design and production: www.kazoar.fr - Pictograms: Freepik, Kazoar – Photos: Philippe Dureuil/Médiathèque IRSN, Laurent Zylberman/Graphix-Images/ Médiathèque IRSN

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IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

ARE NUCLEAR POWER PLANTS SAFE?

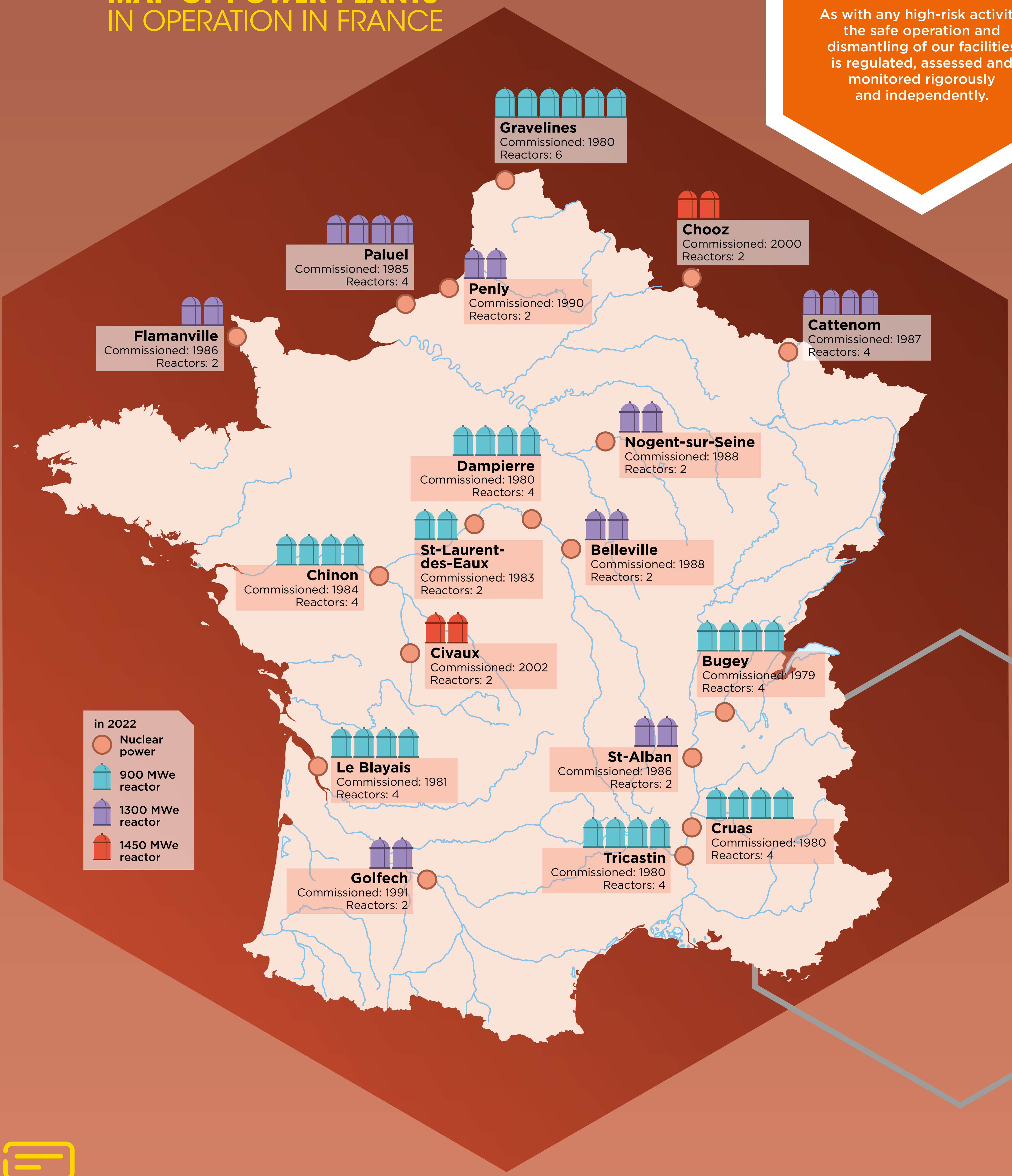
NUCLEAR POWER **IN FRANCE**

Worldwide, more than 440 nuclear reactors generate around 10% of the world's electricity. This figure reaches 30% in Europe and over 75% in France, which has **56** pressurised water nuclear **reactors** commissioned between the late 1970s and early 2000s.

NUCLEAR SAFETY

As with any high-risk activity, the safe operation and dismantling of our facilities is regulated, assessed and monitored rigorously and independently.

MAP OF POWER PLANTS IN OPERATION IN FRANCE



DEBATE FOR OR AGAINST NUCLEAR POWER PLANTS?

Those in favour of nuclear power put forward the following arguments:

- It ensures that the electricity produced is competitively priced;
- It is an energy source that emits virtually no CO_2;
- The safety of nuclear facilities is subject to strict requirements;
- Incidents are reported and analysed so that lessons can be learned.

Opponents respond as follows:

- Nuclear operations have already caused serious accidents despite the controls in place;
- These accidents have contaminated the environment and led to health hazards;
- The cost of decommissioning facilities and disposing of nuclear waste is a cause for concern;
- Some waste will have to be stored for thousands of years, raising the question of safety and of the transmission of knowledge and skills to future generations.

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ARE NUCLEAR POWER PLANTS SAFE?

NUCLEAR FISSION AND ITS RISKS

The word atom comes from the Greek *atomos*, meaning "cannot be divided". However, atoms can be broken. This phenomenon, known as nuclear fission, produces intense heat that can be converted into electricity in a nuclear power station! But this process involves risks: the chain reaction could become a runaway reaction, dispersing radioactive atoms known as fission products, for example.

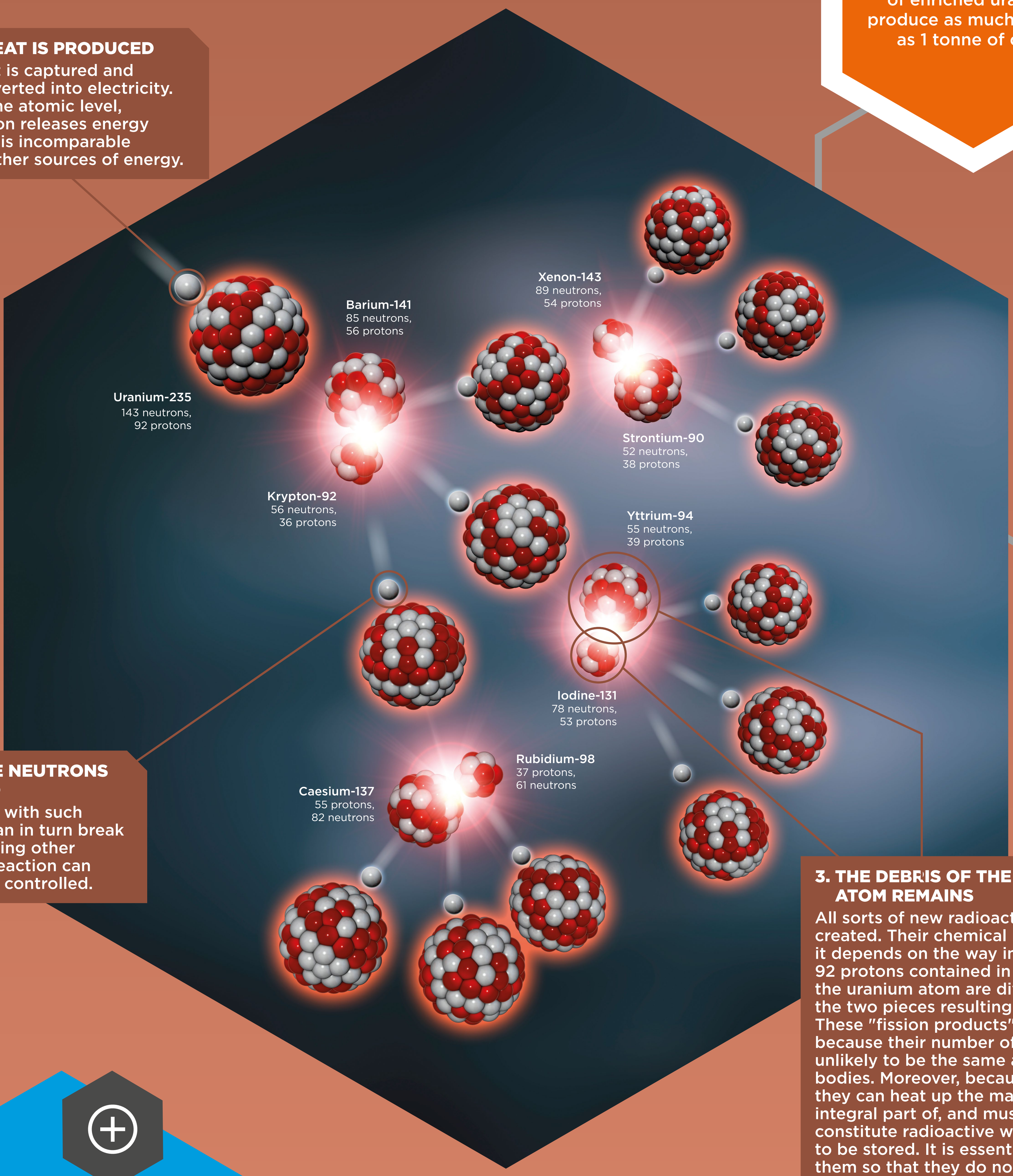
THE CASE OF URANIUM-235

When a uranium-235 nucleus is bombarded by a neutron, it can break. Nuclear fission of an atom always generates three phenomena:

EQUIVALENCE

10 grams of enriched uranium produce as much energy as 1 tonne of coal.

1. HEAT IS PRODUCED
Heat is captured and converted into electricity. At the atomic level, fission releases energy that is incomparable to other sources of energy.



2. TWO OR THREE NEUTRONS ARE RELEASED
They are projected with such energy that they can in turn break other nuclei, releasing other neutrons: a chain reaction can occur that must be controlled.

3. THE DEBRIS OF THE ORIGINAL ATOM REMAINS
All sorts of new radioactive bodies are created. Their chemical nature is random: it depends on the way in which the 92 protons contained in the nucleus of the uranium atom are divided between the two pieces resulting from the break. These "fission products" are radioactive because their number of neutrons is unlikely to be the same as that of natural bodies. Moreover, because they radiate, they can heat up the material they are an integral part of, and must be cooled. They constitute radioactive waste that will have to be stored. It is essential to contain them so that they do not escape into the environment.

In the case of an atomic bomb,
the aim is to set off an uncontrolled chain reaction to produce maximum damage.

In a nuclear power plant, however, control rods and borated water absorb neutrons to control the chain reaction.

A LITTLE HISTORY

1938
Discovery of nuclear fission by German chemist Otto Hahn and his assistant Fritz Strassmann, with the contribution of an Austrian physicist, Lise Meitner.

1948
Commissioning of the Zoé installation, France's first experimental reactor.

1956
In France, at Marcoule, commissioning of the first French reactor (G1) to experimentally produce electricity. Natural uranium graphite gas reactor (UNGG).

1977
Commissioning of reactor No.1 at the Fessenheim power plant in Alsace, the first pressurised water reactor (PWR) in a vast programme that would include 58 reactors.

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ARE NUCLEAR POWER PLANTS SAFE?

HOW A NUCLEAR POWER PLANT WORKS

In principle, a nuclear reactor can be compared to **a gigantic pressure cooker.** The steam created by the heat of nuclear fission drives a turbine which, thanks to the alternator, produces electricity.

THE PEOPLE IN CONTROL

Operators control the plant's operation using thousands of sensors. They activate valves and pumps.

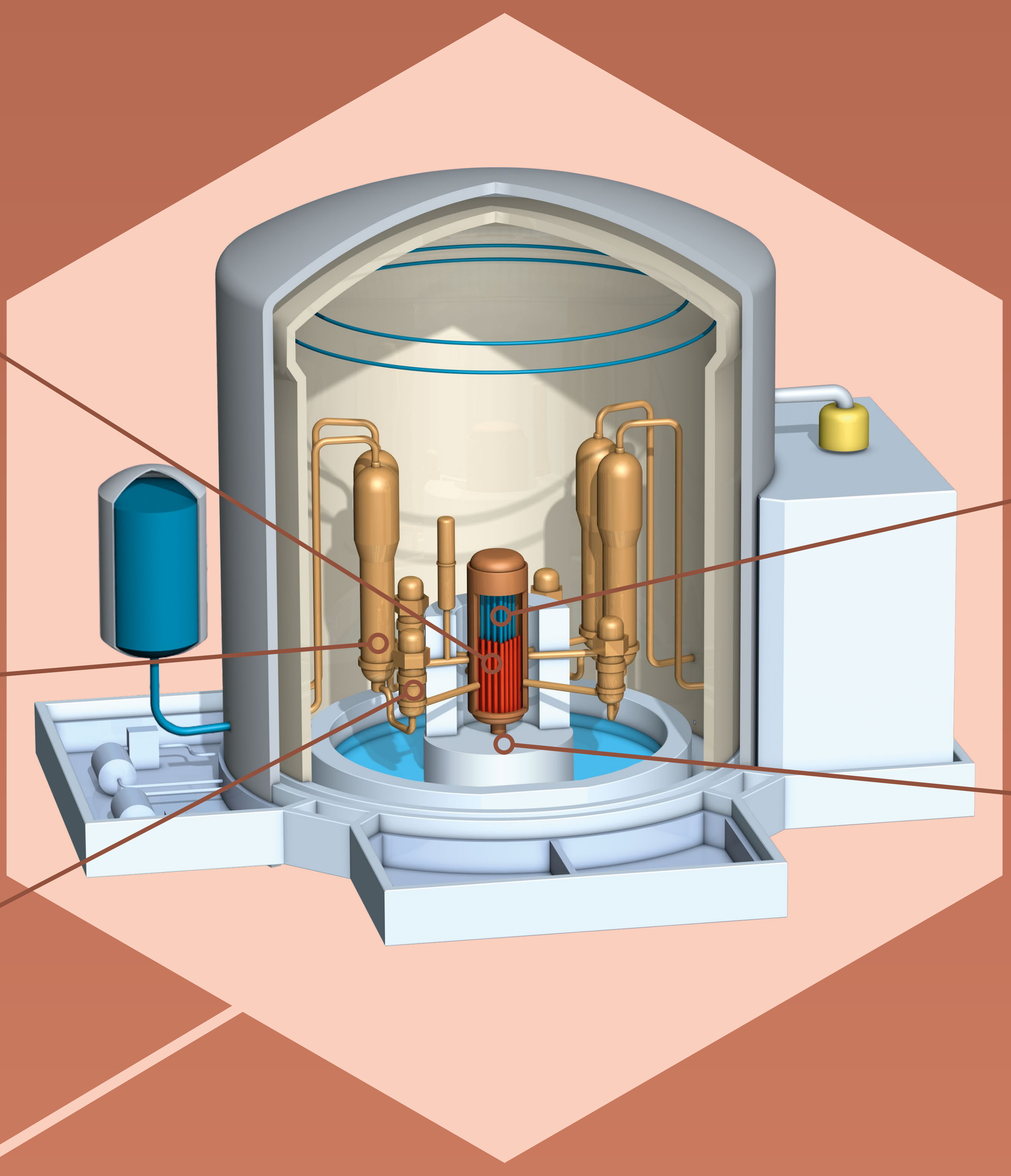
COOLING EVEN DURING SHUTDOWN

The fission products continue to release a lot of heat, even when the reactor is shut down and the chain reaction has almost completely stopped.

NUCLEAR FUEL
The fuel is placed in a steel pressure vessel filled with water. Every second, billions of atoms break, releasing enormous amounts of energy. This heat energy heats up the water in the reactor coolant system to a temperature of over 300°C and a pressure of 150 bars.

STEAM GENERATOR
The hot water in the coolant system heats the water in the secondary system, which is transformed into steam.

REACTOR COOLANT PUMPS
They circulate the water in the reactor coolant system.

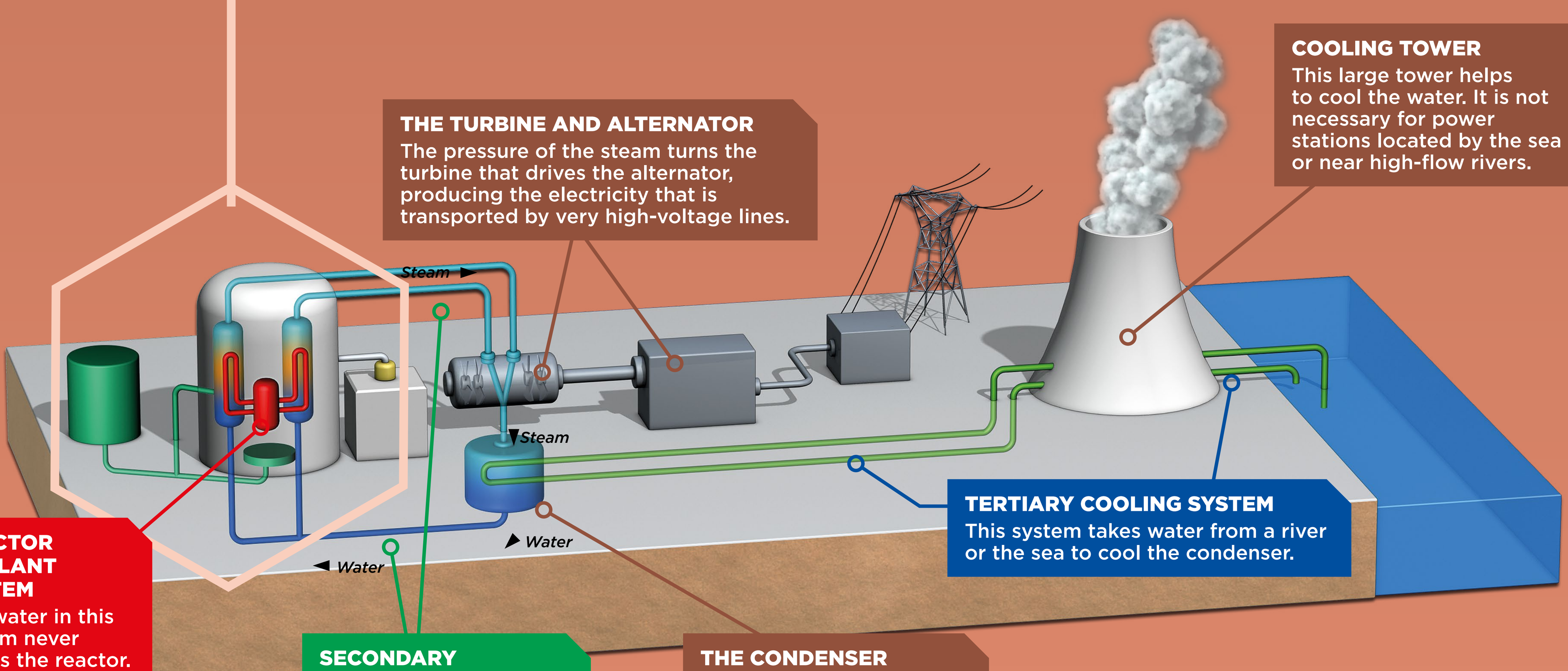


REGULATION
The heat produced by the fuel is regulated notably by the control rods. This makes it possible to adapt electricity production to consumer demand.

THE REACTOR PRESSURE VESSEL
With its 20-cm thick steel, it confines the 40 tonnes of nuclear fuel contained in metal tube assemblies filled with uranium oxide pellets.

THE TURBINE AND ALTERNATOR
The pressure of the steam turns the turbine that drives the alternator, producing the electricity that is transported by very high-voltage lines.

COOLING TOWER
This large tower helps to cool the water. It is not necessary for power stations located by the sea or near high-flow rivers.



TERTIARY COOLING SYSTEM
This system takes water from a river or the sea to cool the condenser.

REACTOR COOLANT SYSTEM
The water in this system never leaves the reactor.

SECONDARY COOLING SYSTEM
The water in this system changes state, passing successively between liquid and gaseous forms.

THE CONDENSER
After passing through the turbine, the steam is cooled, transformed back into liquid and returned to the steam generator for a new cycle.

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ARE NUCLEAR POWER PLANTS SAFE?

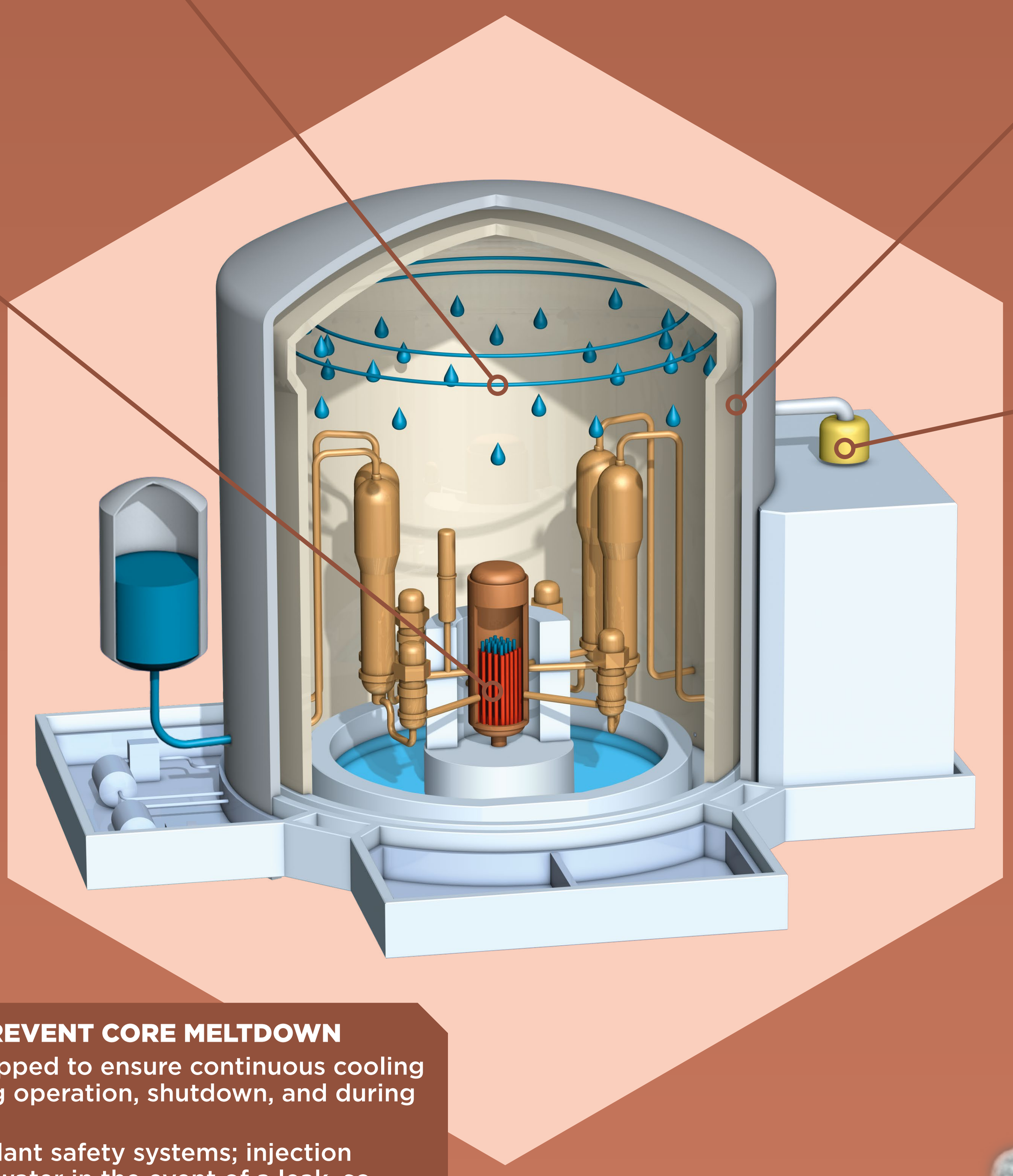
THE SAFETY **OF A NUCLEAR POWER PLANT**

Numerous mandatory **safety systems** are installed in a power plant to **reduce the risk of** a severe accident and **limit its consequences.**

REDUCING PRESSURE IN THE EVENT OF AN ACCIDENT
In operation, the water is pressurised to 155 bar.
If there is a leak, the pressure rises in the reactor building and could lead to loss of leaktightness.
In this case, a cold water circuit is triggered, lowering the pressure by spraying fine droplets in the reactor building.

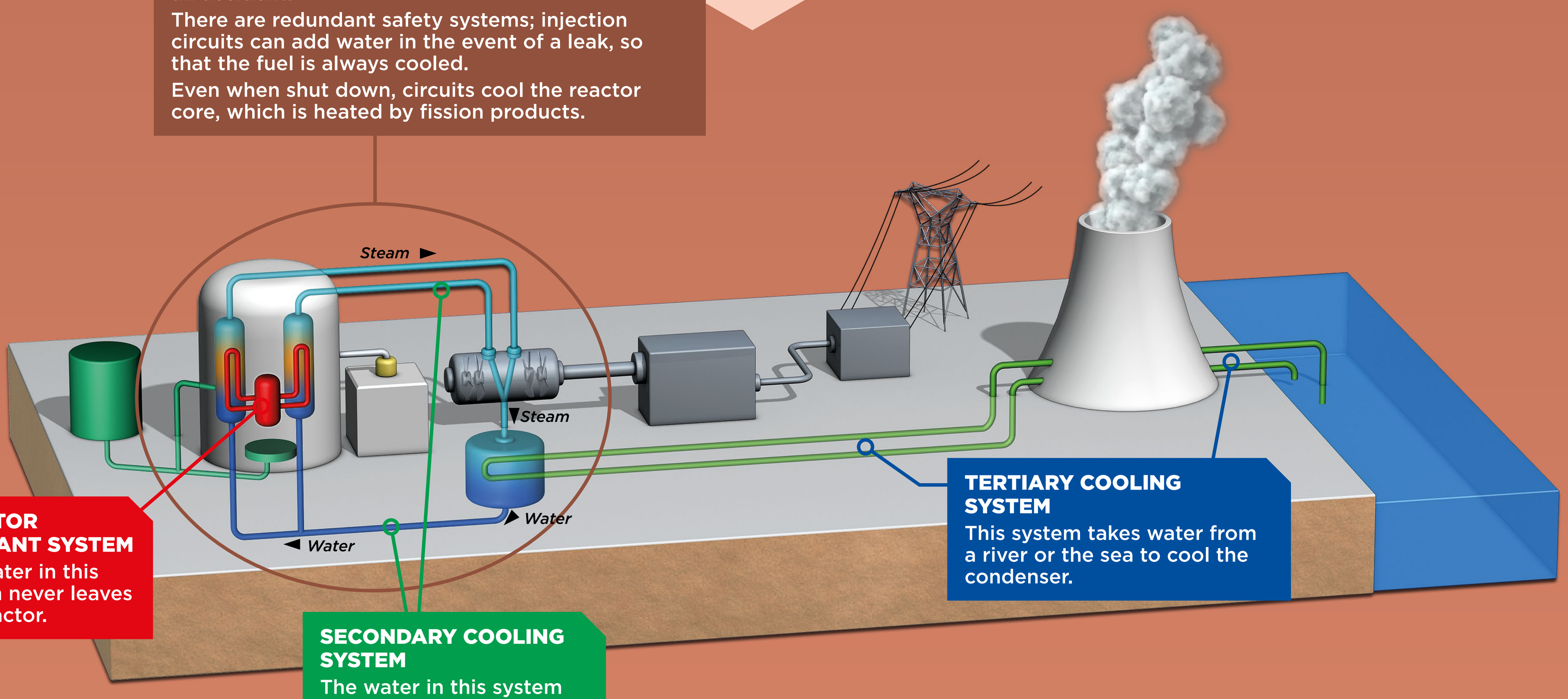
CONTAINING RADIOACTIVE FISSION PRODUCTS
The metal cladding surrounding the fuel and the reactor coolant system (including the reactor pressure vessel) form two containment barriers.
In addition, the reactor building itself acts as a third barrier.
On 900 MWe reactors, this barrier consists of a prestressed concrete enclosure with a steel shell.
On more powerful reactors, a double wall of prestressed concrete provides a containment barrier.

CONTROLLING THE CHAIN REACTION
Control rods and borated water are used to control the chain reaction.
The rods immediately shut down the reactor in the event of a malfunction or earthquake, for example.



DEPRESSURISING IN THE EVENT OF AN ACCIDENT
If too much pressure threatens the leaktightness of the building, it is depressurised by opening this circuit.
This is the last resort, as it releases fission products into the environment through a stack after filtering them.

COOLING TO PREVENT CORE MELTDOWN
The plant is equipped to ensure continuous cooling of the fuel during operation, shutdown, and during an accident.
There are redundant safety systems; injection circuits can add water in the event of a leak, so that the fuel is always cooled.
Even when shut down, circuits cool the reactor core, which is heated by fission products.



REACTOR COOLANT SYSTEM
The water in this system never leaves the reactor.

SECONDARY COOLING SYSTEM
The water in this system changes state, passing successively between liquid and gaseous forms.

TERTIARY COOLING SYSTEM
This system takes water from a river or the sea to cool the condenser.

POWERING ALL SAFETY SYSTEMS
Emergency generators keep pumps, measuring instruments and valves running in the event of a power failure.

SINCE THE FUKUSHIMA ACCIDENT

In France, IRSN experts have recommended the addition of new safety systems: the "hard core".

On the basis of these recommendations, ASN has imposed the installation of new equipment in the power plants: "bunkerised" emergency management centres, additional emergency generators, etc.

In addition, EDF has set up a Nuclear Rapid Action Force (FARN) to intervene at a site in the event of an accident to restore water, air and electricity supplies in less than 24 hours.

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ARE NUCLEAR POWER PLANTS SAFE?

POWER PLANTS
AND PEOPLE

Nearly 30,000 people work in nuclear power plants in France. In addition, **300,000 jobs** are directly or indirectly linked to power plants.

PEOPLE
AT THE HEART OF SAFETY

All kinds of professions are involved: valve makers, engineers, electricians, control operators, etc. Taking into consideration the organisational, social and human factors is therefore of crucial importance.

Management, training, documents and working methods are at the heart of industry concerns. For example, each operator is trained for two years to operate the reactors, and each year they return to a training course where they revise the conduct to be adopted in the event of an accident.

ASN is responsible for labour inspections at nuclear power plants.

PROTECTING
NUCLEAR WORKERS

Nuclear workers are more exposed to radiation than other citizens. The legal limit on the dose of radioactivity they can receive each year is set at 20 millisieverts instead of 1 millisievert for the general public.

They wear dosimeters to warn them of ambient doses and calculate the dose they receive. They have regular medical check-ups.

Epidemiological studies carried out on the health of CEA, EDF and Orano staff show that their health is equivalent to that of staff in large French companies.

SUBCONTRACTING

80% of the work carried out on nuclear sites is carried out by contractors. For example, during maintenance work on a power plant, known as "unit shutdowns", when the reactors are temporarily shut down, around a thousand people carry out more than 10,000 operations, organised and planned by EDF.

Subcontractors are trained in radiation protection. Checks and verifications are part of the quality rules.

THE RISKS ASSOCIATED WITH
MALICIOUS INTENT

Nuclear facilities and the transport of radioactive substances could be the target of malicious acts. Facilities are protected by:

- anti-terrorism measures, air traffic control, bans on flying over nuclear sites;
- strengthening infrastructure and buildings;
- implementation of procedures and resources to limit the possible consequences of an attack.

These topics are examined by the Ministry of Energy's Senior Defence and Security Official, with the support of IRSN.

DEBATE
SUBCONTRACTING
AND OPERATION

Subcontractors say that they are exposed to 80% of the doses received during maintenance, even though they do not receive the same medical monitoring because they travel so much, nor the same benefits as the employees of the nuclear operators for whom they work.

The number of levels of subcontracting worried the French authorities: up to 7 tiers of subcontractors were used in some cases.

Operators consider that when it comes to work on pumps, valves, automated systems, etc., the expertise of subcontractors is essential.

Since then, regulations have been imposed. In particular, subcontracting has been limited to 3 levels, maximum. In addition, the operator must retain control of the operations it subcontracts.

ANNUAL REVIEW

of occupational exposure to ionising radiation in France.

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ARE NUCLEAR POWER PLANTS SAFE?

CHECKS AT EVERY STAGE **IN THE LIFE OF A POWER PLANT**

From design to decommissioning, the life of a power plant is governed by a set of **strict procedures**.

STEP 1: CONSTRUCTION

As soon as the facility is designed, ASN and IRSN check that all possible accident scenarios are taken into account (pipe rupture, valve or pump failure, loss of electricity, etc.), including those linked to external hazards (earthquake, flood, etc.).

They check that the emergency systems and equipment provided for in the safety demonstration are capable of avoiding the consequences of accidents.

When the facility is built, ASN and IRSN check that the work carried out complies with the safety demonstration and that the tests before commissioning are conclusive.

STEP 2: OPERATION

When the facility is commissioned, ASN and IRSN check that the operation and maintenance comply with procedures. They analyse the operator's activities and reported incidents.

The facilities are subject to regular inspections by ASN. Every 10 years, during periodic reviews, ASN and IRSN also ensure that the facility complies with safety requirements by imposing numerous checks, such as pressurising the reactor building to check that it is leaktight. At the same time, safety requirements are revised to integrate the latest knowledge and practices.

Construction of the EPR reactor in Flamanville.

Inspection of the Tricastin power plant.

REGULAR CHECKS

At any time, new work may be required by ASN to improve the level of safety, taking into account national and international lessons learned. For example, new devices have been installed to limit the risk of hydrogen explosion or to trap the caesium atoms released in the event of an accident.

Under normal operating conditions, releases from the facilities into the environment are strictly controlled by ASN.

IRSN carries out measurements in the environment near the facility in the air, water and agricultural products to check the level of radioactivity.

STEP 3: DECOMMISSIONING

Once the operating period is over, a closely monitored deconstruction process follows, lasting around thirty years:

1. the fuel elements are removed and the water circuits drained;
2. the installations are partially dismantled: the main components of the reactor coolant system are isolated, cut and enclosed in concrete structures;
3. around 10 years later, once its radioactivity has been reduced, the facility is completely dismantled. Radioactive materials and equipment are removed. The site is returned to its original state or used for another installation.

EVERYONE HAS A ROLE

THE OPERATOR (Orano, CEA, EDF, etc.)

The operator remains primarily responsible for the safety of its facility.

ASN (French Nuclear Safety Authority)

ASN is responsible for controlling, authorising and regulating the safety of installations.

IRSN (Institute for Radiation Protection and Nuclear Safety)

IRSN is responsible for the scientific and technical assessment of safety implemented by operators. In particular, it provides technical support to ASN.

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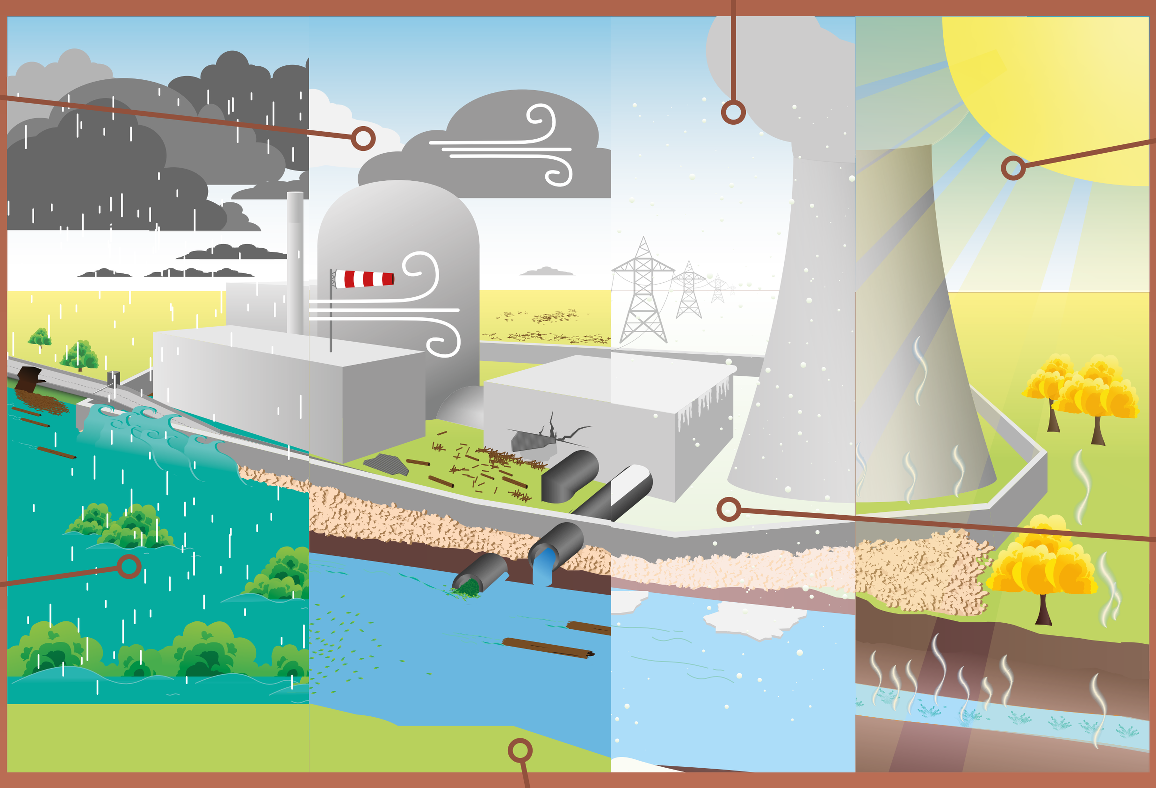
PROTECTION AGAINST NATURAL HAZARDS

A nuclear power plant has safety systems to deal with natural hazards.

NATURAL **HAZARDS**

Nuclear power plants have to withstand a wide range of natural hazards. For each of them, we need to assess the levels of exceptional stress and check that the facility will be able to withstand them without causing a nuclear accident or releasing radioactivity into the environment.



APPROPRIATE **PROTECTION**

Natural phenomena can damage equipment important for plant safety or the buildings that protect this equipment. For example, flooding can cause water to enter the plant buildings, leading to the failure of equipment located there. It can also make access to the site difficult and damage the plant's external power supplies. Or, during extreme winds, projectiles can damage structures, buildings or equipment located outdoors.

Power plants are protected against these risks by physical measures (dykes, reinforced structures, anti-projectile screens or nets, etc.) or organisational measures (weather warning systems, surveillance rounds, etc.).

Plant protection measures against natural hazards are reassessed every 10 years during periodic reviews.

OTHER NATURAL HAZARDS

Other natural hazards (snow, hail, lightning, etc.) are also taken into account, by checking the strength of structures and buildings and the availability of the equipment needed to ensure the safety of the facility and, if necessary, by implementing dedicated protection measures.

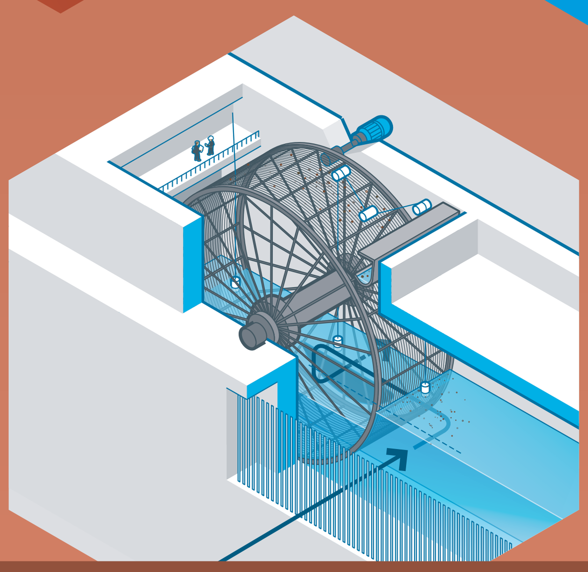
The pumping station, which extracts the water needed to cool the reactor, is also protected against phenomena that could obstruct transit or degrade water quality, such as freezing, silting or clogging by plants, fish, jellyfish, etc.

HOW ARE LESSONS LEARNED INTEGRATED?

National and international events are systematically taken into account. The Fukushima Daiichi accident in Japan, for example, led to the definition of additional seismic and flooding threshold levels, which are now higher than those existing in 2011.

More recently in France, the Le Teil earthquake in the Ardèche in 2019 led to the shutdown of reactors at the Cruas power plant as a precautionary measure. After checks, ASN authorised their restart. Analysis of the data and research into this event will enable scientific lessons to be learned to improve plant safety in the years to come.

More information



Filter drums are installed upstream of power station cooling systems, to filter out any elements that might clog the water intakes.

Concrete blocks fitted with earthquake-resistant pads. The pads are made of rubber and metal. They can limit the accelerations and shear forces associated with ground movements during an earthquake.

CLIMATE **CHANGE**

The effects of climate change are already being felt and will continue to be in the years to come, potentially altering the frequency and intensity of natural phenomena.

Where scientific knowledge permits, the effects of climate change on meteorological and hydrological phenomena are taken into account. This is particularly true of rising sea levels and heat waves.

Climate change can also have an effect on the flow of rivers that supply water to power stations. The risk of low flow is assessed at the design stage to ensure that, even in the event of prolonged heatwaves, there will still be enough water to cool the reactors. In addition to the safety risk, which is assessed by IRSN, this issue also touches on other questions, such as the protection of the flora and fauna of the waterways, which can lead to reactors being shut down when they cause water temperature to rise too high, and the sharing of water for various uses.

FIND OUT MORE

- EARTHQUAKE
  Accounting for seismic risk at nuclear facility sites (irsn.fr)
- FLOODING AND CLIMATIC VARIATIONS
  Climate-related hazards (irsn.fr)

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THE AGEING OF INSTALLATIONS

Like any other industrial installation, nuclear power plants are subject to ageing. We need to control the risks.

DEBATE

THE GENERAL STATE OF FRENCH NUCLEAR POWER PLANTS

After each periodic review, ASN sets the conditions required for continued operation for an additional 10 years. A plant can be shut down for safety reasons, for example if the operator detects a serious problem or considers that the work required is too costly.

Most French reactors were built between 1977 and 1984. The appearance of serious generic anomalies in equipment could cause a series of shutdowns of many power plants in a relatively short period of time.

WHAT IS THE LIFESPAN OF A POWER PLANT?

In some countries, operating licences for nuclear power plants are granted for a limited period of time. In the United States, for example, this period used to be 40 years, then it was extended to 60 years for the majority of reactors and to 80 years for some.

In other countries, such as France, the authorisation to operate a nuclear facility does not specify a time limit. In exchange, the plants are subject to an in-depth periodic review every 10 years. The purpose of this review is to verify the level of safety and make technical improvements.

However, ASN considers that the continued operation of EDF's reactors beyond the age of 40 is only conceivable if it is associated with an ambitious improvement programme. It insists that safety targets should be aligned with those for new reactors, such as the EPR.

CAN WE CONTROL WEAR AND TEAR OF MATERIALS?

In a nuclear reactor, the reactor vessel, the containment vessel and certain electrical cables are components that cannot be replaced. The effects of their ageing are therefore closely examined.

IRSN is studying the main degradation mechanisms: deterioration of the concrete of the containment, development of defects in the steel of the reactor vessel, oxidation of the cable sheaths. These mechanisms are taken into account at the design and manufacturing stages and then in a preventive maintenance programme. The aim is to keep an accurate picture of the state of the materials and to remain in control of the risks associated with ageing.

CAN EQUIPMENT EXPIRE?

Safety-critical equipment is subject to qualification: its performance and operation are checked under accident conditions. They are subject to regular maintenance to ensure that parts are replaced and their reliability maintained.

The cessation of production of certain components or the disappearance of their manufacturer can lead to difficulties, which is why the operator must be able to replace them.

However, replacement with a new model or a new supplier must be subject to prior qualification.

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ARE NUCLEAR POWER PLANTS SAFE?

DECOMMISSIONING

Even when shut down **definitively**, a nuclear power plant continues to present **risks.** It has to be decommissioned according to a very **precise** scenario.

THE SPECIFIC CHALLENGES OF DECOMMISSIONING A NUCLEAR POWER PLANT

During the decommissioning of a nuclear power plant, ASN pays particular attention to:

PROTECTION OF WORKERS

Scenarios are designed to protect workers. If the risk of exposure is too great, the work is carried out remotely using robots.

RADIOACTIVE WASTE MANAGEMENT

Waste is produced in greater quantities than during the operating phase and is of a different nature because the equipment and structures are activated or contaminated. When the time comes, the appropriate disposal facilities must be available.

AVAILABILITY OF FINANCIAL RESOURCES

It must be ensured that the budget required for decommissioning is available.

Why not wait until the radioactivity disappears?

ASN recommends that the nuclear operator dismantle its facility as soon as possible after shutdown.

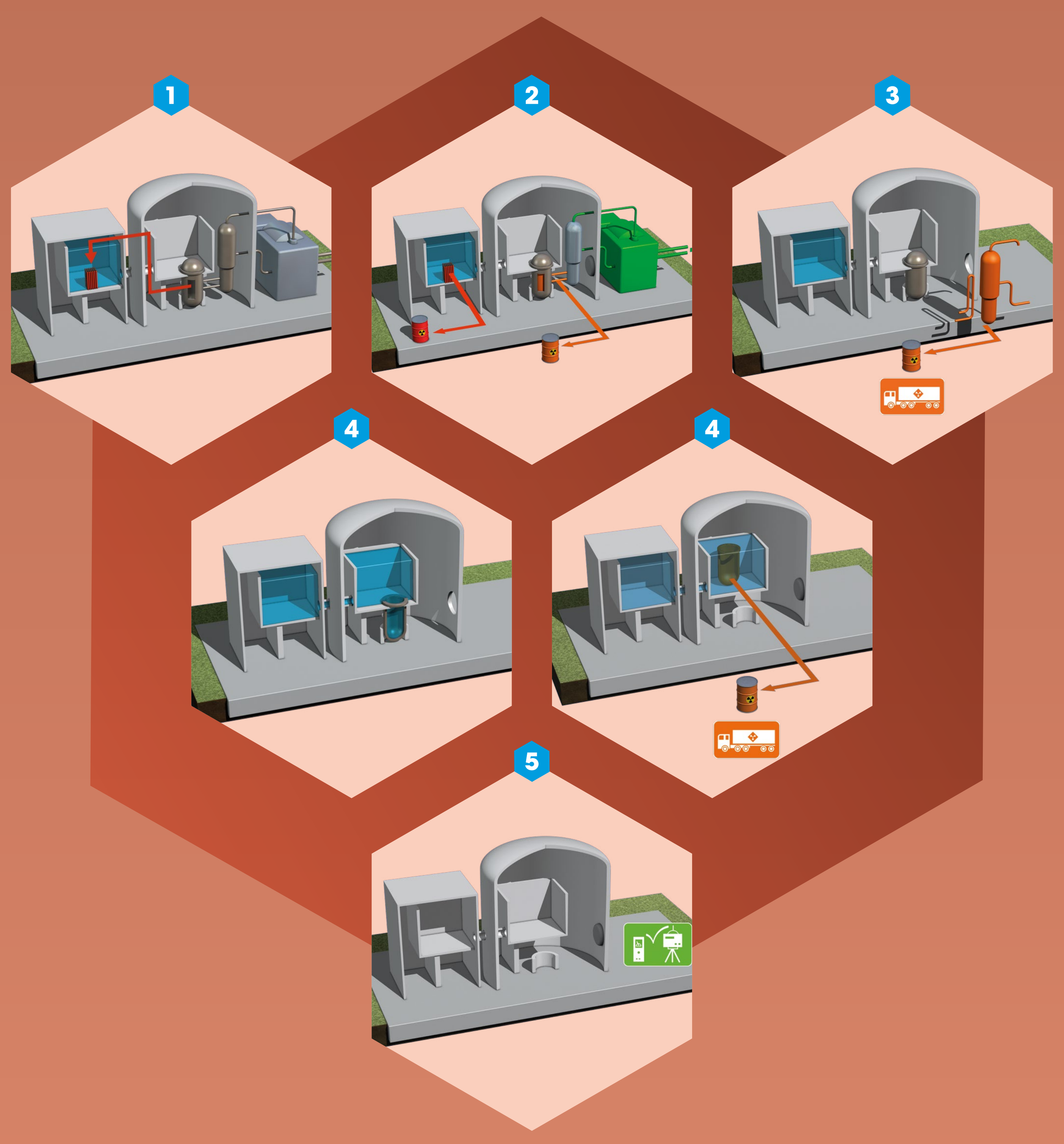
A waiting period certainly contributes to a reduction in radioactivity through decay, but it has its drawbacks: ageing structures, possible loss of containment, loss of technical knowledge, burden of decommissioning on future generations.

The duration and cost of decommissioning

The total decommissioning time for a power plant is estimated at around twenty years.

Due to a lack of experience, costs are still poorly estimated. What's more, the calculation methods can be very different.

SCENARIO AND TIMESCALES FOR THE UNDERWATER DISMANTLING OF A REACTOR (strategy chosen for the Chooz A reactor)



1. PERMANENT SHUTDOWN

The fuel is unloaded from the reactor core. It will cool for a few years in the storage pool.

2. ABOUT 2 YEARS LATER

The fuel is sent to the La Hague plant for processing. The water in the reactor coolant system is drained. The steam system and turbine are dismantled.

3. ABOUT 5 YEARS LATER

Dismantling operations begin in the reactor building, except for the reactor vessel.

4. ABOUT 10 YEARS LATER

The reactor vessel is flooded to limit radiation during its dismantling. The reactor vessel and internal structures are then dismantled.

5. 20 TO 30 YEARS LATER

The site is cleaned up: either the buildings are kept for a possible identified future use, or they are demolished.

DECOMMISSIONING UNDER WAY

Decommissioning operations differ depending on the type of reactor.

Map of current decommissioning operations.

THE COST OF DECOMMISSIONING

A recent report by the French Court of Auditors shows that the actual cost of decommissioning exceeds the initial forecasts.

Some organisations are concerned about the final cost of decommissioning and how it will be financed.

Despite the experience gained during the decommissioning of the Chooz A pressurised water reactor (PWR), France does not yet have the experience of complete decommissioning of pressurised water reactors (PWRs).

However, EDF includes the estimated cost of decommissioning in the price per kilowatt-hour.

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ARE NUCLEAR POWER PLANTS SAFE?

TOMORROW'S
POWER PLANTS

In order to achieve more ambitious objectives in terms of safety, security and resource savings, the range of nuclear power plants on offer is set to **diversify** worldwide. While some **technologies** are already available, others are still being studied and could make an appearance in **the coming years**.

DIFFERENT TECHNOLOGIES ON DIFFERENT TIMESCALES...

Around the world, there have been several generations (technologies and versions) of nuclear reactors over the years. In France, for example, the first generation of UNGG (graphite-moderated, gas-cooled natural uranium) nuclear reactors were designed in the 1950s and 1960s. They are all currently being decommissioned.

The second generation corresponds to the fleet of pressurised water reactors currently in operation in France.

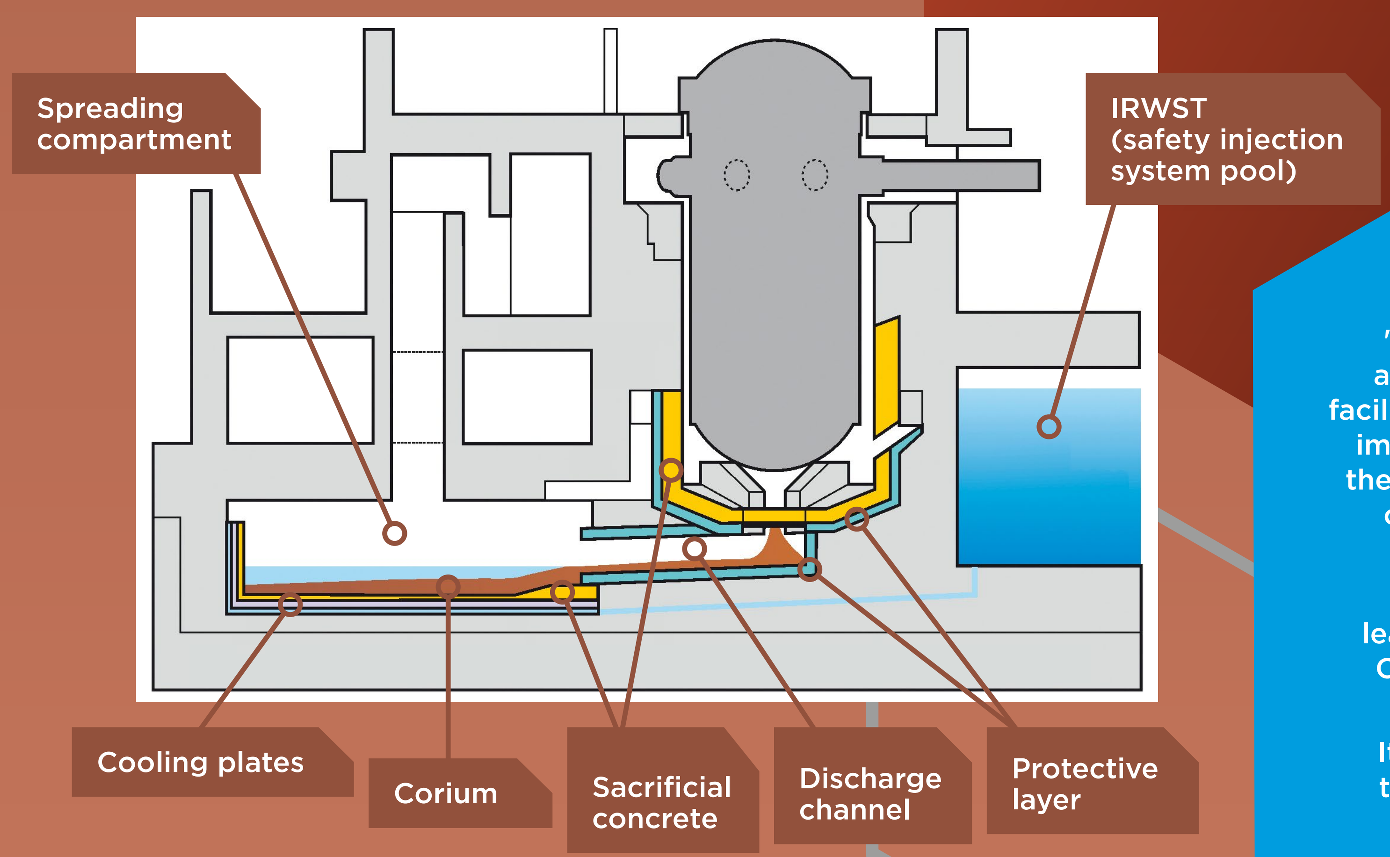
The EPR reactor under construction in Flamanville is known as a "third-generation" reactor.

Prototypes are already being built, foreshadowing the power plants of tomorrow. Other technologies are still in the research phase: they are sometimes referred to as the fourth generation.

4TH GENERATION REACTORS

Fast neutron reactors, high temperature reactors (HTR-PM), even very high temperature reactors (VHTR), molten salt fast reactors... there are many different concepts for 4th generation reactors!

Side view of the core catcher of an EPR reactor



EPR

The EPR *(European Pressurized Reactor)* is a powerful "evolutionary" reactor (1650 MWe) that does not represent a major technological breakthrough compared with existing facilities. Nevertheless, this 3rd generation reactor offers significant improvements to safety systems, in particular four channels for the safety-critical water systems (compared with two in reactors currently in operation) capable of operating independently and spread across four different buildings.

It is the first French reactor to benefit from the lessons learned from the nuclear accidents at Three Mile Island (USA), Chernobyl (Ukraine) and Fukushima (Japan), as well as from lessons learned from the reactors in operation.

It is equipped with a core catcher to cool the molten core in the event of a severe accident, and its design has taken into account increased requirements in terms of radiation protection for humans.

Finally, the buildings housing the reactor, control room and fuel storage are covered by a concrete structure that can withstand aircraft crashes.

...AND OF DIFFERENT SIZES

Nuclear reactors for electricity production come in a wide range of sizes and power ratings, from the EPR (1650 MWe) to the SMR (10 to 300 MWe), and even the micro-reactor (10 MWe)!

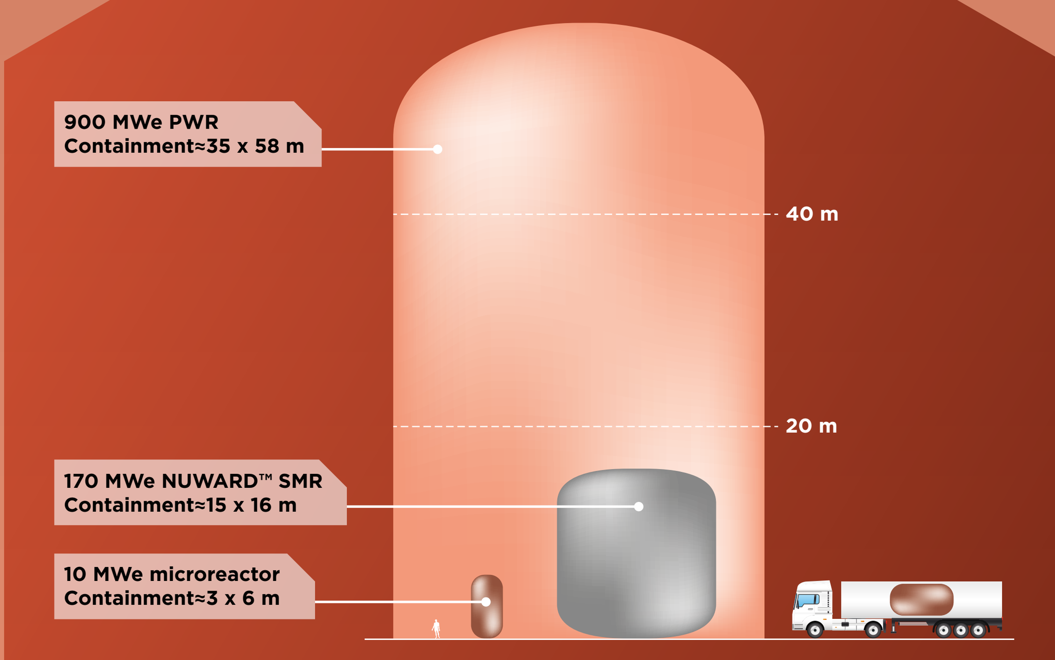
SMALL MODULAR REACTORS

Compact nuclear reactors have been used for naval propulsion for decades. However, a new generation of small reactors has been gaining popularity around the world in recent years: *Small Modular Reactors* (SMR). These reactors have an output of less than 300 MWe (1650 MWe for an EPR).

Built from elementary modules manufactured in dedicated factories and transported by road or river, the SMRs are assembled on the operating site. There are many different concepts (over 70) based on different technologies and generations of reactors.

Their small size and low power give them greater safety. In the event of an incident or accident, they should enable the reactor to be brought to a safe shutdown state and kept there for a long period without human intervention.

NUWARD™ reactor vessel and containment in the overall view of the main nuclear building.



Even smaller than SMRs, microreactors have an output of less than 10 MWe (the equivalent of 1 tonne of petroleum per hour). Extremely compact, they can be easily moved and integrated into very limited spaces and used in very specific situations (supplying power to isolated areas, space modules or military bases in operation, crisis intervention, etc.).

And beyond domestic electricity...

The heat produced by nuclear reactors can be used for purposes other than electricity generation: desalination of seawater, district heating, energy-intensive industrial processes (chemicals, paper, steelworks).

They can also be used to provide solutions to growing local electricity needs, such as powering the ever-increasing number of data centres!

Design: ASN and IRSN Communications Departments - May 2022
Graphic design and production: www.kazoar.fr - Pictograms: Freepik, Kazoar - Illustrations: Georges Goué/Médiathèque IRSN, Nuward/EDF, Kazoar

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ARE NUCLEAR POWER PLANTS SAFE?

NUCLEAR FUSION

Fusion is the phenomenon at work in stars like our sun.

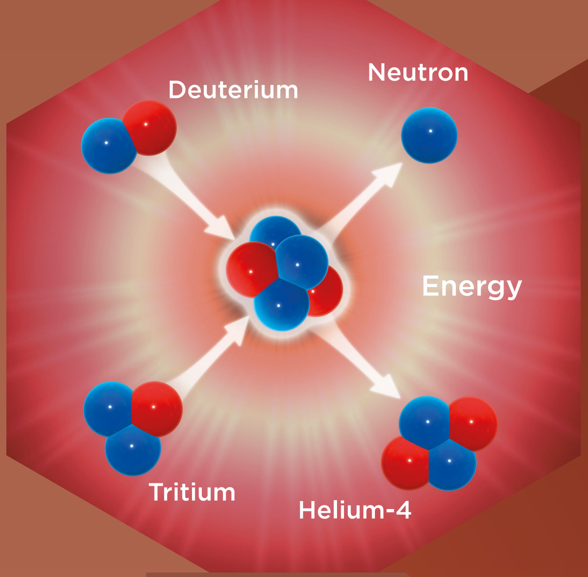
HOW DOES, FUSION WORK?

In the fission process, heavy atoms are broken into several pieces by bombarding them with neutrons.

In the fusion process, the opposite occurs: matter is compressed with such force that two light atoms come together to form a single heavier atom.

Both physical processes release energy, but the fusion reaction has a dual theoretical advantage:

- It does not generate high-level, long-lived radioactive by-products;
- It uses a fuel that can be extracted from water, a very abundant resource. However, as the tritium extraction process is very costly, systems that produce tritium under neutron bombardment (such as "tritium breeding blankets") are being studied.



Fusion process

PRODUCING THE FUSION REACTION

Nuclear fusion reactions naturally take place at the core of stars, as in the sun, at extreme pressures and temperatures (around 200 billion times the Earth's atmospheric pressure and 150 million degrees Celsius). Under these conditions, matter takes the form of plasma: the nuclei and electrons surrounding them are no longer bound together.

To reproduce and control this fusion process on Earth, it is therefore necessary to be able to reach high pressures and temperatures. There are two possible technologies:

- **magnetic confinement:** inside a tokamak, the plasma, created by a very powerful current and additional heating systems, is "trapped" in a magnetic field created by electromagnetic coils. The fuel used is a mixture of hydrogen isotopes;
- **inertial confinement:** very high temperature and pressure conditions are provided by lasers placed around the fuel, confined in a very small volume.
The pressure exerted by the lasers and the heat produced enable the fuel to become plasma.

THE LONG ROAD TO INDUSTRIALISATION

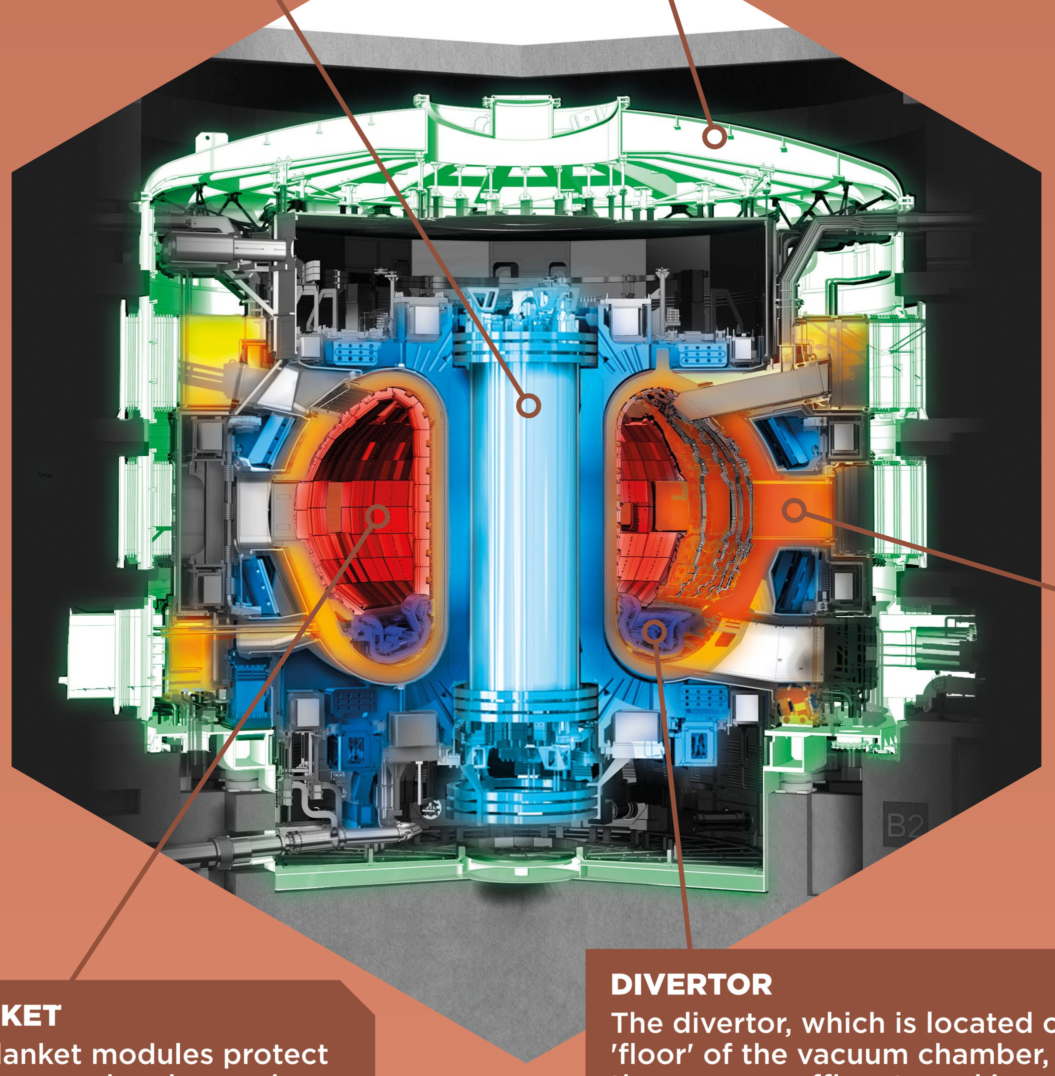
Large-scale electricity generation using nuclear fusion still presents major technological hurdles:

- the balance between energy released and energy supplied must be positive. Unlike fission, which is sustained by a chain reaction, fusion requires an enormous amount of energy to bring the atoms together;
- fusion must continue. Plasma has many intrinsic instabilities: so far, the positive balance has been maintained for just a few minutes.

TOKAMAK FOR THE ITER PROJECT

MAGNETS
The magnetic field generated by 10,000 tonnes of superconducting magnets will be needed to confine and shape the plasma inside the vacuum chamber.

CRYOSTAT
The cryostat is a large stainless steel structure (29 m x 29 m) enclosing the vacuum chamber and superconducting magnets, creating an extremely cold vacuum environment.



TOROIDAL VACUUM CHAMBER
The vacuum chamber is a sealed stainless steel enclosure in which the fusion reactions take place.

BLANKET
The blanket modules protect the vacuum chamber and superconducting magnets from the very high-energy neutrons produced by the fusion reaction.

DIVERTOR
The divertor, which is located on the 'floor' of the vacuum chamber, extracts the gaseous effluents and impurities from the machine, and must be capable of withstanding very high surface thermal loads.

ITER, THE INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR

ITER is an international project for a civil nuclear fusion research reactor of the tokamak type, located in the immediate vicinity of the Cadarache nuclear research centre in Saint-Paul-lez-Durance (Bouches-du-Rhône, France). It operates on the principle of thermonuclear fusion, whereas current reactors use fission.

The ITER project aims to verify the scientific and technical feasibility of nuclear fusion as a new source of energy, with a view to building commercial fusion reactors that produce electricity in the future. Researchers are currently working on various fusion reactor projects (such as the European DEMO project).

The project involves a number of countries: those of the European Union, as well as India, Japan, China, Russia, South Korea, the United States, Switzerland and the United Kingdom.

DEBATE IS FUSION CLEAN?

A fusion reactor would not produce the same nuclear waste as current power plants (fission products, actinides, etc.) but rather tritiated waste with a lower level of activity and a shorter lifespan.

The fusion reaction requires tritium, a radioactive substance. Although the fusion reaction requires little fuel (a few grams of tritium), around 4 kg of tritium will be present in the ITER installation. Also neutrons activate the tokamak's metal structures. These activated structures are a source of waste in addition to tritiated waste. The total volume of waste will be greater than that of a current reactor, but will not be high activity waste. In addition, these activated metal structures produce dose rates that make human intervention impossible, which means that maintenance operations must be automated.

Design: ASN and IRSN Communications Departments - May 2022
Graphic design and production: www.kazoar.fr - Pictograms: Freepik, Kazoar - Illustration: La-fabrique-créative/Bruno Bourgeois, @iter.org

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