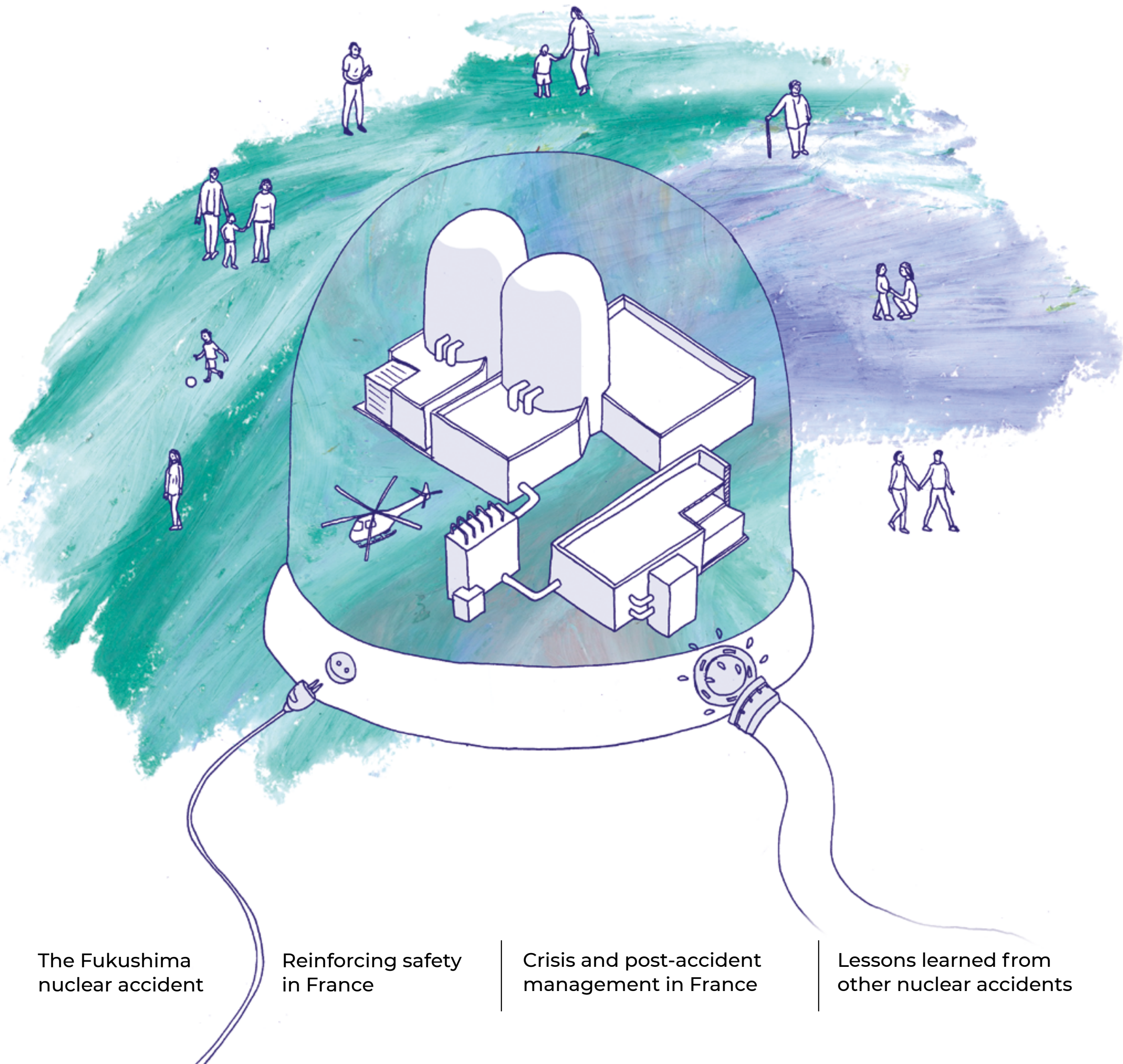
AUTORITÉ DE SÛRETÉ NUCLÉAIRE #03 • MARCH 2021

LES CAHIERS DE L'ASN #03

10 YEARS AFTER FUKUSHIMA

What safety improvements for nuclear facilities in France?



The Fukushima nuclear accident

Reinforcing safety in France

Crisis and post-accident management in France

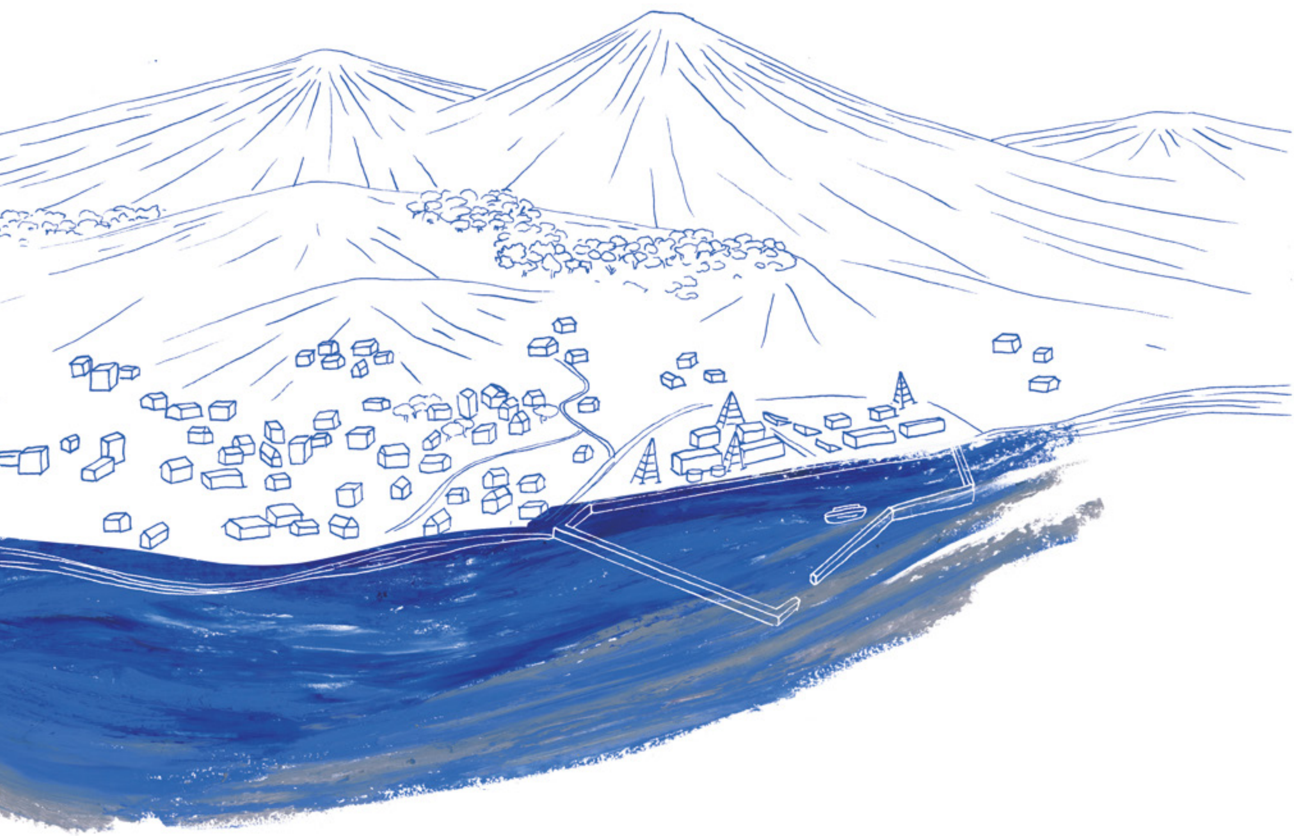
Lessons learned from other nuclear accidents

Contents

Rated level 7, the highest on the international nuclear events scale (INES), **the accident which struck the Fukushima Daiichi nuclear power plant** had considerable human and environmental consequences.

"*There can be no grounds for complacency about nuclear safety in any country. Some of the factors that contributed to the Fukushima Daiichi accident were not unique to Japan.* ***Continuous questioning and openness to learning from experience are key to safety culture*** *and are essential for everyone involved in nuclear power. Safety must always come first.*"

These words from Yukiya Amano, Director General of the International Atomic Energy Agency (IAEA) from 2009 to 2019, illustrate what underpinned **ASN's deliberations and decisions** with a view to improving the safety of nuclear facilities in France.

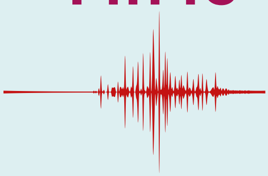


Disaster scenario
for a major nuclear accident

**A sequence of natural phenomena of an exceptional scale creating a domino effect: all the ingredients were there for a major accident at the Fukushima Daiichi NPP.
In four days, one of the world's largest nuclear power plants was destroyed.**

11 march 2011

14h46

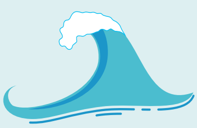


EARTHQUAKE

Japan recorded the strongest earthquake in its history. Its magnitude was 9.1 on the Richter scale, with an epicentre at sea, 130 km off the North-East coast.

The electrical power supply was damaged by the earthquake but the emergency supply took over. The three reactors in operation were immediately shut down by the automatic safety systems, and the cooling procedure began normally.

15h41



TSUNAMI

The wave caused by the earthquake, which was up to 30 m high, devastated 600 km of shoreline and penetrated up to 10 km inland.

**The emergency electricity source was flooded by the tsunami and the water supply pumps were thus disabled. At the same time, the seawater intakes were clogged with detritus created by the tsunami.
The reactor cores were then only cooled by a single system, the failure of which would inevitably lead to core melt.**

12 march 2011

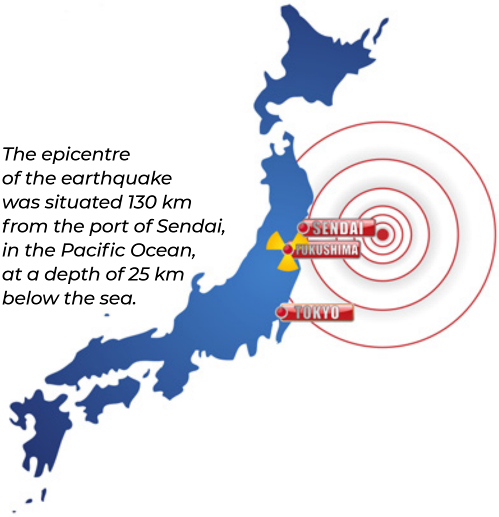
EXPLOSION IN REACTOR 1 BUILDING

The building which housed this reactor collapsed following a hydrogen explosion.

A major earthquake, followed by an exceptional tsunami, led to the failure or loss of all the emergency systems.

* See glossary page 24

The epicentre of the earthquake was situated 130 km from the port of Sendai, in the Pacific Ocean, at a depth of 25 km below the sea.



The Fukushima Daiichi NPP comprised 6 boiling water reactors (BWR). The fluid which passes through the core is demineralised water which, when brought to boiling point on contact with the fuel rods, turns into steam and drives the generators to produce electricity. At the time of the accident, only reactors 1, 2 and 3 were in operation (the others were shut down for maintenance).

14 march 2011

EXPLOSION IN REACTOR 3 BUILDING

The roof of the reactor 3 building was blown off by a hydrogen explosion.

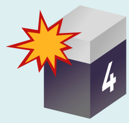
15 march 2011

EXPLOSION IN REACTOR 2 BUILDING

The explosion was once again caused by the hydrogen which had built up in the reactor building.

EXPLOSION IN REACTOR 4 BUILDING

The roof of the spent fuel pool was blown off, probably owing to an explosion of hydrogen from reactor 3.



The successive explosions in these buildings are due to the consequences of core melt. Owing to the lack of cooling, the water in the vessel turned into steam and the temperature rose to more than 1200°C. The zirconium* making up the fuel cladding then oxidised and this reaction produced hydrogen. On contact with air, this pressurised hydrogen created violent explosions.

As a result of the accident, the Fukushima Daiichi NPP is to be decommissioned; The duration of this decommissioning process was initially evaluated at 40 years but, owing to the difficulties encountered, this time-frame has been extended.

Discussing, analysing and continuously informing

As soon as the Fukushima disaster was announced, ASN activated its emergency centre, which was then to operate 24/7 for a month. The goal was two-fold: to understand the causes of the accident and to continuously inform the French population.

With a time difference of 8 hours, a geographical distance of 10,000 km and the language barrier, information and understanding were rendered particularly complex.
ASN's Paris office took on the role of an information centre, responsible for producing reliable information about the accident itself and any atmospheric fall-out from Japan, which had no health consequences within France, so that it could then be sent out to the various audiences.

> "The Fukushima nuclear emergency reminds us that we can never become complacent."
>
> **André-Claude Lacoste,** ASN Chairman, from 2006 to 2012

An international information network

ASN produced its analyses of the situation with the assistance of IRSN* – which has its own crisis unit – and via daily contacts with the French Embassy In Japan. At the same time, it collected press releases from the Japanese authorities and analysed the information put out by the local media. Finally, it enhanced its understanding of the situation through daily telephone conferences with the International Atomic Energy Agency (IAEA*) and with other western safety regulators, such as those of the United States, Canada and Great Britain.

* See glossary page 24

1,500
Media queries

36
Press releases

17
press briefings *(between 12 March and 14 April 2011)*

700,000
connections to the ASN website

Informing and advising the authorities

The crucial information collected by ASN is of primary interest to the State, which may be required to take rapid decisions concerning the national nuclear fleet. With regard to the contamination of goods imported from Japan, ASN also issued recommendations concerning products other than foodstuffs. Foodstuffs were subject to European regulations that were automatically applicable in France. ASN advised the Government and kept Parliament and the HCTISN* informed.

With regard to communications, there is also a before and after Fukushima

Since 2011, ASN has become the go-to source for nuclear information in France. On the occasion of this crisis, there was a considerable rise in ASN's profile, and in the awareness of its interventions and the credibility given to them.

40%

of the French population stated that they were familiar with ASN after the Fukushima crisis (as compared with 24% in 2010)*

* According to the TNS SOFRES barometer (today Kantar Public)

Diversified means of communication

At the same time, in order to carry out its role of informing the French population, ASN published daily press releases and held 17 press conferences to answer questions from journalists. It also set up a website devoted to the incident and made extensive use of video in order to reach out to the general public. A telephone hotline for the public constituted another information source, in order to answer the numerous queries arising from the accident.

WHAT THE LAW SAYS

When a radiological emergency situation arises, ASN assists the Government with all questions within its field of competence. It sends the competent authorities its recommendations regarding the medical and health measures or the civil security measures to be taken. It informs the public of the condition of the facility which caused the emergency situation, when under its authority, and of any releases into the environment and the risks for human health and the environment.

Global mobilisation for a momentous event

The Fukushima accident sent a shockwave around the world, raising questions about the robustness of nuclear installations. A few days after the accident, mobilisation was under way nationally, Europe-wide and internationally, in order to learn lessons from what had happened. Ten years later, here is an overview of the progress made in the safety of nuclear installations in France and around the world.

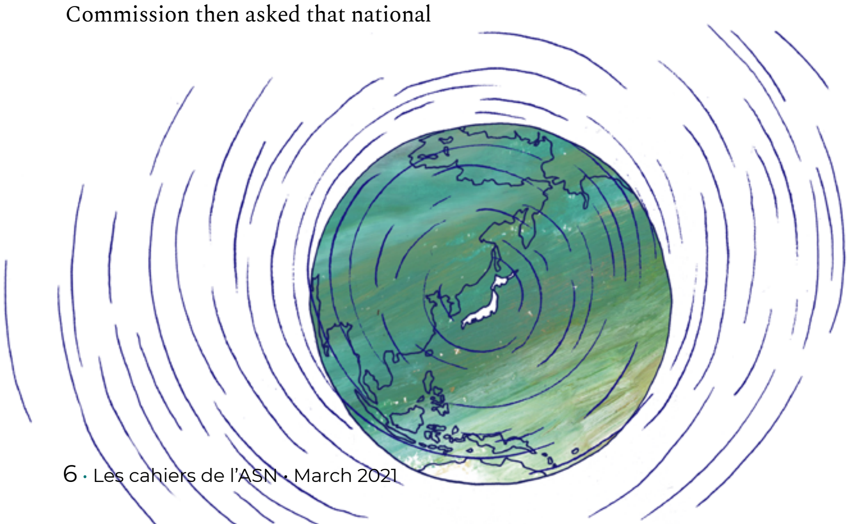
In Europe, stress tests were initiated on the nuclear power plants

Less than two weeks after the disaster, the **European Council** asked that stress tests be performed to evaluate the robustness of the European NPPs to the extreme conditions to which they could be subjected: earthquake, flooding, loss of electrical power, loss of heat sinks, combination of these events, reactor core melt. In the following weeks, **WENRA*** drafted specifications to address this request and enable each Member State to conduct a national review of the robustness of its installations against an identical requirements baseline.
In April 2012, on the basis of these data, **ENSRE**G* and the European Commission then asked that national action plans be put into place so that these tests would result in tangible safety improvements.
In December 2012, **ASN** drew up the national action plan identifying the necessary improvements.
These concerned:
• protection against internal and external hazards;
• electricity supply and water make-up means;
• the means for the prevention of accidents with core melt;
• the means for preventing uncovering of fuel assemblies in the pool;
• the management of accidents with core melt;
• crisis management;
• the means for providing an on-site response by deploying a nuclear rapid intervention force (FARN*).

In France, the stress tests are expanded to cover all nuclear facilities

In parallel, on 23 March 2011, the **Prime Minister** asked ASN to conduct an audit on the safety of the nuclear facilities in the light of the Fukushima accident. The French approach to the stress tests (called complementary safety assessments (ECS* in French), was integrated into the European stress tests approach, but with a broader scope, encompassing all nuclear facilities (research, fuel cycle, waste management facilities and decommissioning sites).
Questions regarding social, organisational and human factors were also raised and examined in greater depth.

An innovative approach in France: the concept of the "**hardened safety core***", an ultimate safety measure to deal with extreme situations, was prepared and made mandatory (*see page 8*).



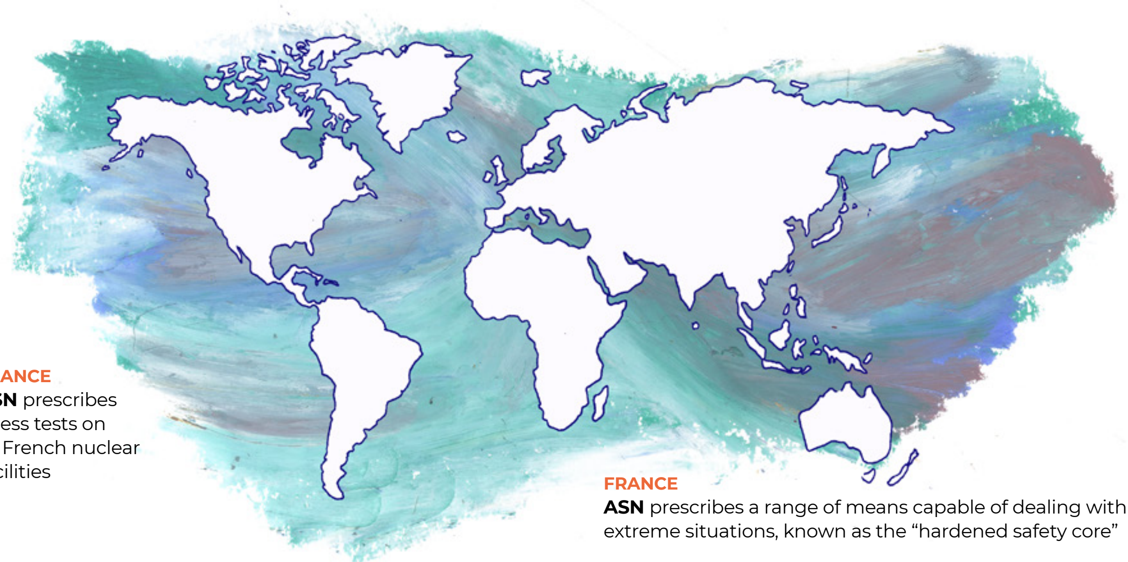
** See glossary page 24*

The French, European and international approaches to nuclear safety following the Fukushima accident

INTERNATIONAL
The IAEA draws up a 12-point action plan

EUROPE
The **European Council** requires stress testing of the NPPs.
WENRA draws up the specifications

EUROPE
HERCA and **WENRA** recommend improved transboundary coordination of population protection measures



Internationally and in Europe, safety doctrines are modified

One of the roles of the **IAEA*** is to draw up and promote high-level international safety standards and it reacted to the Fukushima accident by implementing a 12-point action plan as of the end of 2011, aiming to reinforce nuclear safety. The work done to implement this action plan is included in the report from the IAEA Director General on the Fukushima accident and in the five technical volumes that accompany it. These publications, which were issued at the IAEA General Conference in 2015, examine the causes and consequences of the accident.

In February 2015, the **Vienna Declaration** of the Contracting Parties to the Convention on Nuclear Safety was to go a step further, by setting out the principles aiming to prevent accidents with radiological consequences and to mitigate their consequences should such accidents occur.

With regard to the **European Union**, the Euratom Directive* of 8 July 2014 aims to create a framework for ensuring nuclear safety in Europe, by learning the lessons of the Fukushima accident. It was transposed into French law in 2016 and strengthens ASN's powers of oversight and sanction.
It requires that at least every 10 years, the State organise an evaluation of its regulations and its regulatory authority, and sets up a process for a thematic peer review every 6 years.

For its part, **WENRA** initiated an update of its reference safety levels in 2014, to take account of the lessons learned from the accident. Each member then undertook to incorporate these levels into its regulations, thus reinforcing safety requirements and their harmonisation among the member countries of the association.

On the topic of protection of the population, recommendations were published in 2014, called the ***HERCA*-WENRA approach***, to make advance planning for the consequences in Europe of an accident on a scale similar to that of Fukushima, with improved transboundary coordination of protection measures during the first phase of a nuclear accident. They notably recommend preparations for evacuation up to 5 km around the NPPs and preparations for sheltering and the ingestion of iodine tablets up to a radius of 20 km, as well as the possibility of extending t hese measures to 20 and 100 km respectively.

Fukushima: a nuclear safety catalyst

The Fukushima accident highlighted the need to reinforce the resilience of nuclear facilities and organisations in the face of extreme situations. This accident led to significant progress being made in nuclear safety.

The safety improvements to nuclear facilities in France owe much to the Fukushima accident. The number one lesson is that, despite all the precautions taken in the design, construction and operation of nuclear facilities, an accident is always possible.
After a period of audit and reflection, ASN issued 32 resolutions as of June 2012, each setting out thirty or so requirements stipulating that the nuclear licensees of 80 nuclear facilities with the highest potential consequences (CEA*, EDF*, Framatome*, Institut Laue-Langevin* and Orano*) had to define arrangements to deal with extreme situations:

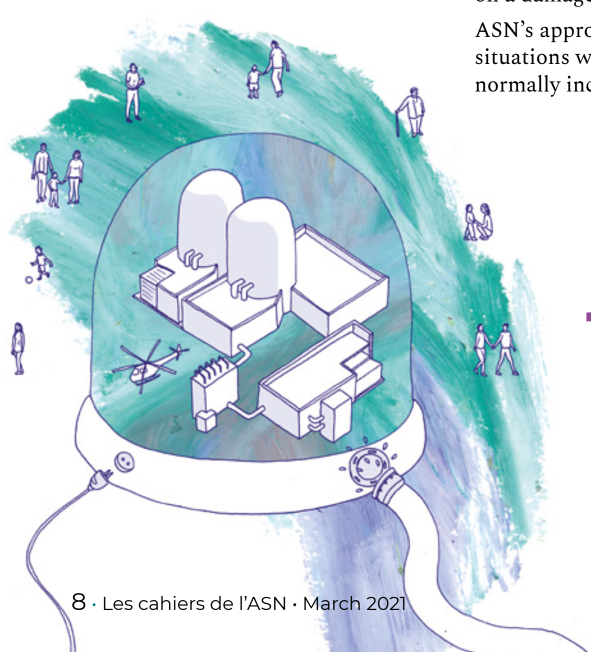
- **implementation of systems (water make-up, electricity supply, instrumentation)** to improve the management of loss of electrical power or loss of cooling situations affecting the entire site;
- **the definition of a "hardened safety core"*** of material and organisational measures which, in extreme conditions, would be designed to prevent an accident with fuel melt or mitigate its spread, as well as to mitigate large-scale releases;
- **reinforcement of emergency management resources on each site**;
- implementation of **a nuclear rapid intervention force** (FARN* for CEA and EDF, FINA* for Orano), to ensure an emergency response on a damaged nuclear site.

ASN's approach aimed to anticipate situations well beyond the situations normally included in the safety case.

The stringency of its requests stand out on the international stage and are part of the "defence in depth" approach. The philosophy of this approach is based on a safety system with superposed, multiple layers (equipment, organisation and teams) so that if one layer fails, the next one can take over.

Ten years after Fukushima, the results of the safety improvements to nuclear facilities in France are positive.

Tomorrow, with the completion of the "hardened safety core", the installations will be more robust to extreme situations.



124 basic nuclear installations are subject to ASN regulation and oversight *(as at 31 December 2020)*

* See glossary page 24

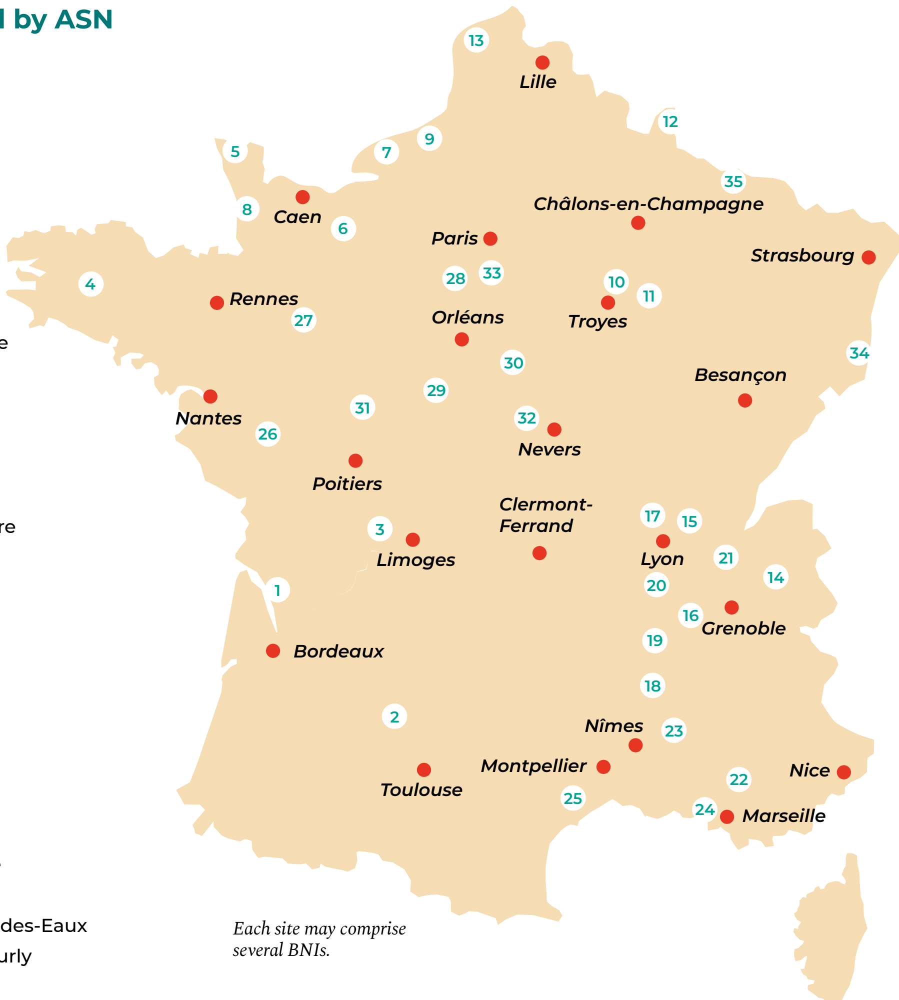
So what is a BNI?

A basic nuclear installation (BNI*), is an installation which, by its very nature, or because of the quantity or activity of the radioactive substances it contains, is subject to a specific regulation and oversight system defined by the Environment Code. Its design, construction, operation and decommissioning are regulated.

The following are concerned: nuclear reactors • facilities for the preparation, enrichment, fabrication, reprocessing or storage of nuclear fuels, or for the processing, storage or disposal of radioactive waste • facilities containing radioactive or fissile substances • large particle accelerators • repositories for the most highly radioactive waste.

Sites regulated by ASN

1 ▲ Blayais
2 ▲ Golfech
3 ▲ Civaux
4 ▲ Brennilis
5 ▦ ■ La Hague
6 ● Caen
7 ▲ Paluel
8 ▲ Flamanville
9 ▲ Penly
10 ▲ Nogent-sur-Seine
11 ■ Soulaines-Dhuys
12 ▲ Chooz
13 ▲ Gravelines
14 ○ ● Grenoble
15 ▲ ○ Bugey
16 ▦ Romans-sur-Isère
17 ○ Dagneux
18 ▲ ▦ ○ Tricastin
19 ▲ Cruas-Meysse
20 ▲ Saint-Alban
21 ○ ▲ Creys-Malville
22 ○ ● Cadarache
23 ▲ ▦ ○ ● Marcoule
24 ○ Marseille
25 ○ Malvési
26 ○ Pouzauges
27 ○ Sablé-sur-Sarthe
28 ● Saclay
29 ○ ▲ Saint-Laurent-des-Eaux
30 ▲ Dampierre-en-Burly
31 ▲ ○ Chinon
32 ▲ Belleville-sur-Loire
33 ● Fontenay-aux-Roses
34 ▲ Fessenheim
35 ▲ Cattenom



TYPES OF FACILITIES
▲ Nuclear Power Plants
▦ Plants
● Research facilities
■ Waste disposal repositories
○ Others

Guided tour of the safety improvements today in place in the nuclear power plants

1 Improving the safety of the spent fuel pool

Several improvements have reinforced the safety of this pool: reinforced instrumentation so that it can withstand an earthquake, automatic leak isolation on the piping connected to the pool, etc.

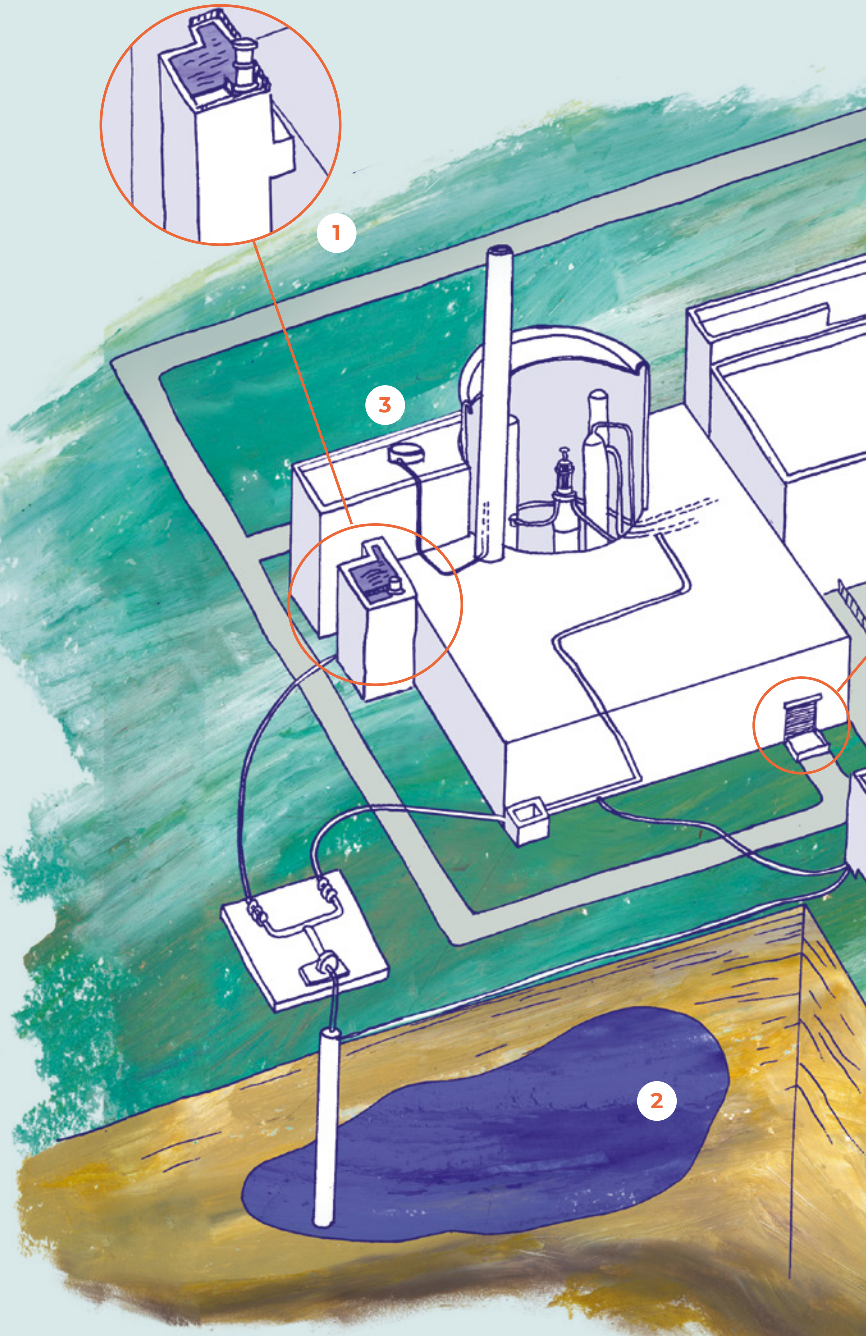
2 Ultimate water source

This consists of new wells, ponds or tanks, depending on the sites, providing water to supply the steam generators and the spent fuel pool, in addition to the existing means. All the reactors should be equipped in this way by 2023. In the meantime, temporary sources will be installed in 2021.

3 Depressurisation of the containment

In the event of an accident situation leading to a pressure rise in the containment, this device enables the air inside it to be depressurised and filtered before release, in order to prevent damage to the containment.

The aim is to make the filter more robust so that it remains operational in the event of an earthquake. At the end of 2020, the modification had been made on 10 reactors and should be applied to all EDF* reactors in service by the end of 2022.



* See glossary page 24

4 Improving site protection against flooding

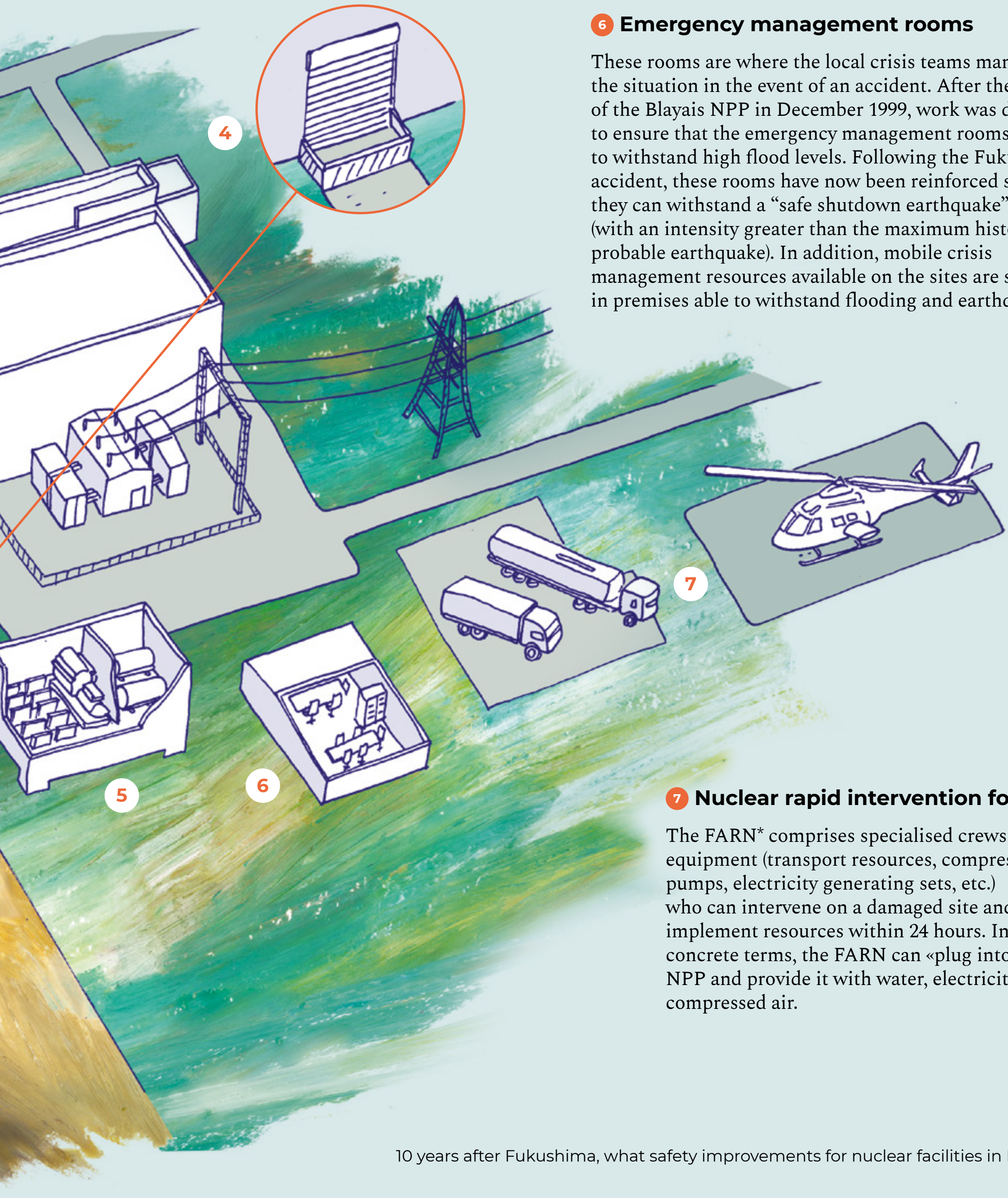
The aim is to prevent water entering the buildings of the nuclear platform in the event of extreme flooding. This for example consists in installing protections in front of the exterior access doors, reinforced concrete walls, and in filling in the openings situated in the lower part of the buildings. Since 2017, this work has been carried out on all the sites that so require.

5 Ultimate backup generating set

If all the existing back-up electricity resources are lost, the diesel ultimate backup generating set can restore electrical supply to the equipment needed to ensure the safety of the reactor and the spent fuel pool. It also supplies the ultimate water source pumps. The building housing this equipment is designed to protect it from extreme hazards (earthquake, flooding and tornado). An ultimate backup generating set is today installed on each EDF reactor in service.

6 Emergency management rooms

These rooms are where the local crisis teams manage the situation in the event of an accident. After the flooding of the Blayais NPP in December 1999, work was done to ensure that the emergency management rooms were able to withstand high flood levels. Following the Fukushima accident, these rooms have now been reinforced so that they can withstand a "safe shutdown earthquake" (with an intensity greater than the maximum historically probable earthquake). In addition, mobile crisis management resources available on the sites are stored in premises able to withstand flooding and earthquakes.



7 Nuclear rapid intervention force

The FARN* comprises specialised crews and equipment (transport resources, compressors, pumps, electricity generating sets, etc.) who can intervene on a damaged site and implement resources within 24 hours. In concrete terms, the FARN can «plug into» an NPP and provide it with water, electricity or compressed air.

Safer NPPs, **today…**

As early as 2012, ASN instructed EDF* to strengthen the safety margins on its NPPs. Starting from the simple observation that during the accident at the Fukushima NPP, the water and electricity resources needed to cool the fuel were lacking, new equipment was installed so that the nuclear installations could deal with degraded situations and function independently for a period of several days.

Gaining time

The improvements made *(see the guided tour on pages 10 and 11)* reinforce the robustness of the installations to situations involving a total loss of electrical power or a total loss of cooling by river or sea water. **They help enable the installation to function independently for several days in the event of an accident**, thus gaining time so that the resources initially lost can be **repaired** or the response by the emergency crews organised. The improvements made also **facilitate crisis management**, thanks to additional human and material resources and reinforcement of the existing resources.

ASN wants to go even further…

Some of this new equipment installed is designed to withstand natural hazards of extreme intensity. However, it is today connected to parts of the installation for which operation cannot be guaranteed in the face of such hazards.

ASN therefore asked EDF* to **further reinforce the safety of the NPPs, so that there is a complete "hardened safety core*"** of resources capable of withstanding extreme situations.

18 NPPs in service are subject to ASN regulation and oversight

** See glossary page 24*

... and tomorrow

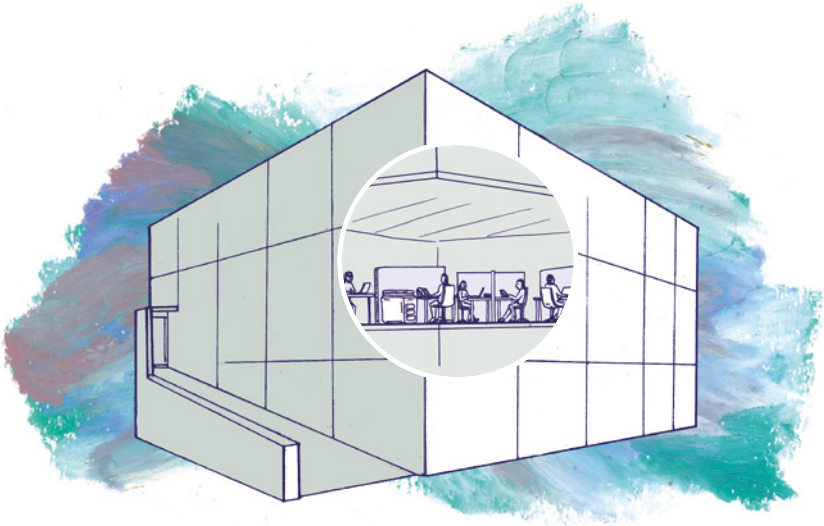
An operational hardened safety core

The "hardened safety core" is a significant and specifically French step forward, which should enable the essential safety functions of the reactors and spent fuel pools to be guaranteed in the event of an extreme hazard greater than that considered in the design of the NPP: earthquake, flooding (including very heavy rain), wind, lightning, hail and tornadoes.

This "hardened safety core", the aim of which is to **prevent an accident with fuel melt and to mitigate large-scale releases and long-term effects** in the environment, will be implemented as part of the safety improvements linked to continued operation of the 900 MWe and 1300 MWe reactors beyond 40 years and of the 1450 MWe reactors beyond 30 years. Some of this equipment is already in place, such as the ultimate backup generating set.

MORE WATER FOR THE POOL

Additional means for cooling and topping up the spent fuel pool water will be installed. This will consist of fixed equipment (pipes and connection systems outside the fuel building) and mobile equipment brought in and deployed on the site by the FARN* (pump and heat exchanger, electricity generating set, system for pumping water from the river or sea).



A BUNKER FOR THE CRISIS UNIT

A new crisis management centre, capable of withstanding extreme hazards, will be created on each NPP. It will enable the local crews to provide long-term management of a major nuclear crisis. The first one was commissioned in 2020 in Flamanville. EDF aims to complete the construction of these centres in 2026 for all its NPPs in service.

A COLD SHOWER FOR A MOLTEN CORE

New ultimate cooling systems for the containment and for stabilisation of the corium* in the event of core melt will be added.

The challenge is to be able to evacuate the heat from a damaged reactor outside the containment, notably by means of a new heat exchanger. In addition, corium (magma of molten fuels and reactor components) could melt through the reactor vessel. Changes will be made so that the corium can spread and then be covered with water and cooled.

These provisions will significantly mitigate releases of radioactivity into the air and into the groundwater in the event of an accident with core melt.

Specific challenges
for the other nuclear facilities

Nuclear Power Plants are not the only nuclear facilities to be improved following the Fukushima accident. The other nuclear facilities are concerned, notably those which produce or store fuel, and those which process or store radioactive waste, and ASN issued binding requirements applicable to them.

The fuel cycle facilities in service*

These are facilities performing the conversion, enrichment and fabrication of fuel, as well as spent fuel reprocessing facilities. They all utilise hazardous substances in industrial quantities. The licensees of these facilities are Orano* and Framatome*. Following the Fukushima accident, ASN asked them to conduct stress tests (ECS* in French), which led to safety improvement requirements being stipulated.

This notably included the **definition of a "hardened safety core*", the implementation of robust crisis management centres** and, if the context so demands, the creation of significant reserves of water usable in extreme situations. In addition, the Comurhex 1 plant at Tricastin, which could not be reinforced in compliance with the post- Fukushima requirements, was closed. ASN considers that the progress of post-Fukushima works and the organisational provisions made are satisfactory.

Major advances

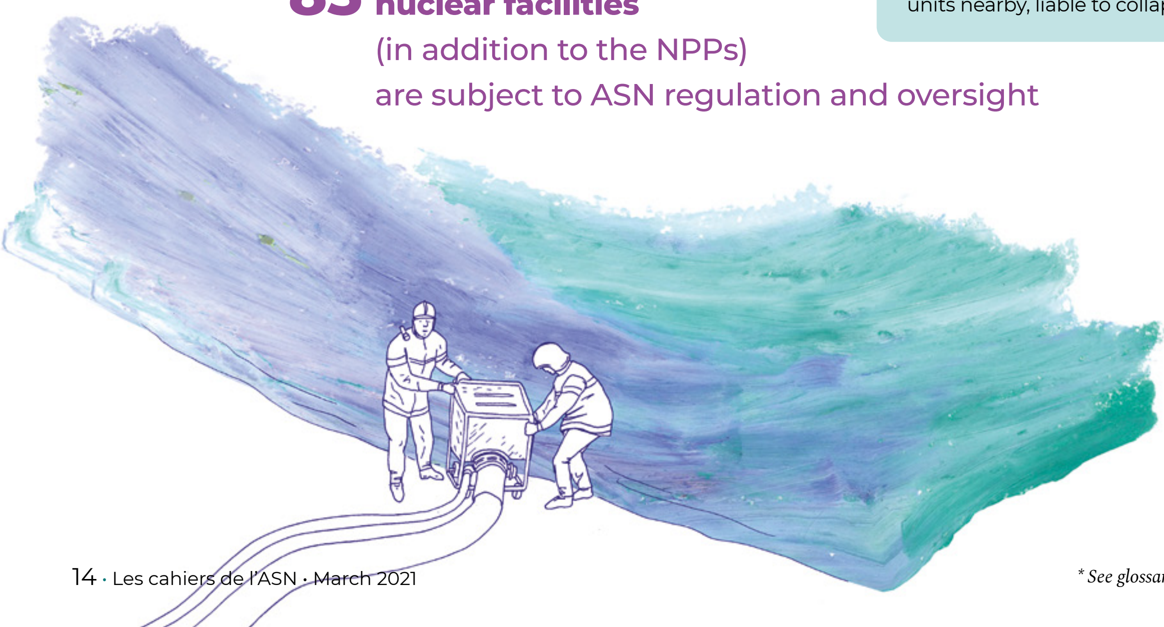
Reinforcement of electrical resources with connection of electricity generating sets in 2016

Water make-up using mobile resources in 2016 and replacement of the valves at La Hague in 2018

Crisis management with the construction of a bunker for the crisis units and the deployment of material and human assistance to a damaged site

Reinforcement of the safety of pools, with the installation of pumps under the pools to prevent them emptying in the event of an extreme earthquake at La Hague (along with dismantling of the older units nearby, liable to collapse)

85 nuclear facilities
(in addition to the NPPs)
are subject to ASN regulation and oversight

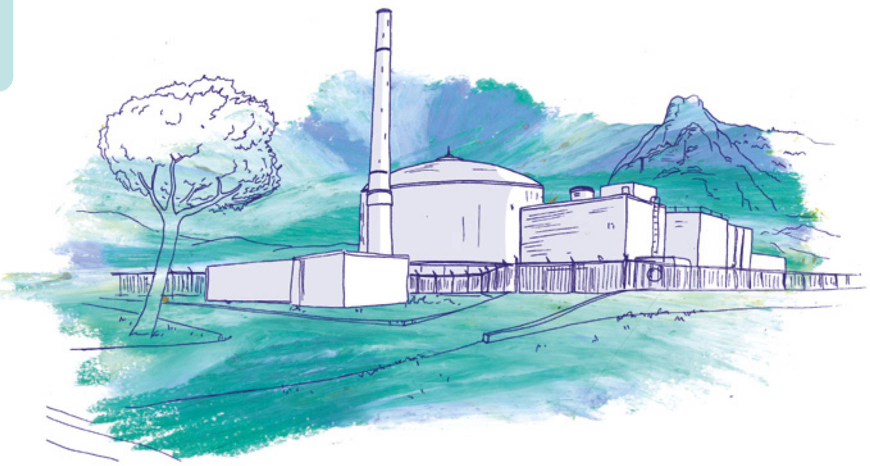


** See glossary page 24*

In brief

Unlike the NPPs, which represent a homogeneous fleet of installations managed by a single licensee, the other nuclear facilities vary and are managed by different licensees, such as CEA, Framatome, the Institut Laue-Langevin, ITER Organization* and Orano.

Adapting the French stress tests (ECS) specifications to all the facilities, in the light of situations leading to large-scale releases, and prioritising the facilities according to their potential safety implications represented a very real challenge that was specifically French!



Research facilities

Some nuclear facilities are devoted to scientific and technological research. **In France, these facilities are mainly operated by CEA***. It also operates facilities that support its research work (materials and waste storage, effluent treatment facilities, etc.).

For CEA, the stress tests confirmed a certain number of weak points in the older facilities, such as the Masurca and Osiris reactors or the MCMF storage facility, which were in service in 2011. **The stress tests led to their final shutdown and the removal of several tons of fissile materials** to more robust storage facilities, in order to significantly reduce the risks. Between 2013 and 2014, several tons of fissile materials were removed from the Masurca research reactor, representing some 38,000 objects!

The stress tests allowed the storage facilities to be reorganised in order to improve safety and the permanent facilities completed the necessary work (more specifically, improvements to maintaining ventilation, earthquake resistance and the installation of an earthquake detection sensor). The crisis management rooms still need to be built and legacy waste retrieved and conditioned.

For its part, the **Institut Laue-Langevin* met an ambitious schedule**, between 2013 and 2018, and completed an exemplary range of post-Fukushima reinforcement measures on the high-flux research reactor (RHF*). The wide-ranging works were completed in 2018, notably with the construction of new, robust crisis management rooms, reinforced leak tightness of the reactor building to cope with extreme flooding and the commissioning of back-up systems to resupply the reactor and spent fuels with water in the event of an accident.

Installations with lesser safety implications

For these facilities, ASN specified a calendar for the submission of the stress tests, which ran until 2020. The study of the consequences of a major accident on a site with several facilities with lesser safety implications was taken into account in the reinforced crisis management provisions. However, these stress tests showed that there was no need to adopt “hardened safety core” type measures.

Storage facilities for legacy waste and reactors undergoing decommissioning

The stress tests confirmed that a certain number of legacy waste storage facilities were insufficiently safe and that **the retrieval and conditioning operations needed to be speeded up**.

The licensees (CEA, EDF and Orano) are encountering a certain number of technical difficulties in carrying out these operations. ASN considers that the management of these projects needs to be made more robust.

Dealing with a nuclear accident

The Fukushima accident showed that, in addition to reinforcing the installations, better preparation for management of multi-factor crises was also needed. The goal is to have an organisation that is robust and agile enough to adapt to all types of new situations. Close-up on a number of remarkable achievements.

Broadening the scope of the emergency plans

The Fukushima accident led France to revise its population protection provisions, consistently with the recommendations of the European authorities *(see HERCA*-WENRA* approach p. 7).* The extension of the off-site emergency plans (PPI*) from 10 to 20 km around the NPPs, decided on in 2016, is not linked to an increase in the nuclear risk within the country, but is a means of improving the information and protection of the population and the reactivity of the crisis management players.

** See glossary page 24*

The creation of rapid intervention forces

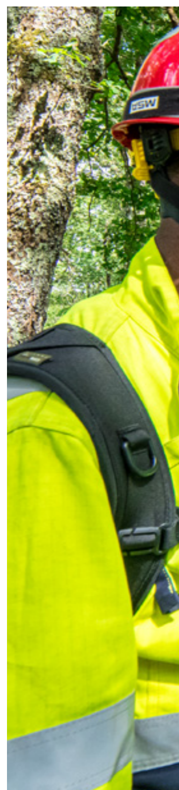
Each of the major licensees deployed units capable of providing emergency material and human assistance to a damaged nuclear site: the national intervention force (FINA*) set up by Orano*, and the nuclear rapid intervention forces (FARN*) set up by EDF* and CEA*.

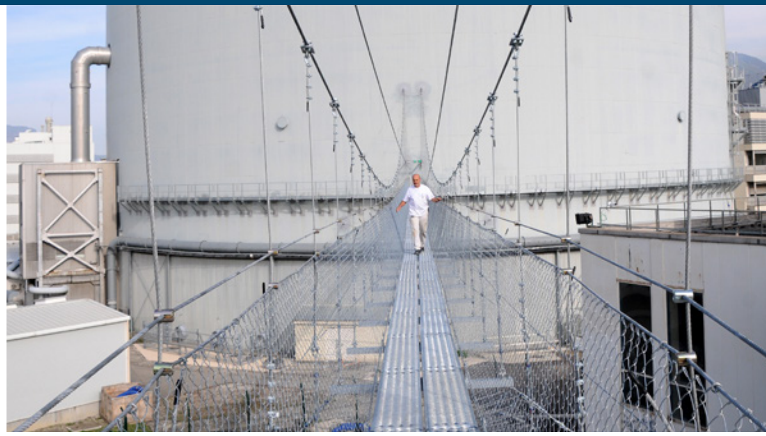
A more resilient crisis organisation

In 2017, ASN set out specific requirements for the management of emergency situations, in terms of personnel instruction and training. The licensees' crisis teams therefore have to practice their role at least once a year, during an exercise or simulation.

The Fukushima accident showed that the crisis crews who are normally required to reach their posts in less than one hour may be unable to do so owing to external constraints (blocked roads for example). EDF* therefore made provision for an organisation able to perform the essential crisis management duties with a small team. Sixteen of the 18 NPPs in service have so far adopted this arrangement.

ASN also has a round-the-clock on-call system comprising about twenty personnel members in the head office and the regions. The ASN crisis organisation is tested about ten times a year during national exercises held with the offices of the Prefects, the IRSN* and the licensees.





Reinforced crisis management buildings

The crisis management rooms must be accessible, available and habitable in extreme situations, including in the event of long-duration releases of radioactive or chemical substances. They must be self-sufficient in terms of electrical power, thermal conditioning, air filtration and food and water supplies.

The Orano* sites of La Hague and Tricastin today have a reinforced crisis management building. That of Orano Melox is scheduled to be commissioned in 2023.

The CEA* crisis building in Cadarache is for its part still at the design stage.

Since the end of 2016, the high-flux research reactor in Grenoble, operated by the Institut Laue-Langevin*, has been equipped with an emergency control station capable of withstanding extreme hazards.

EDF built a new crisis management building at Flamanville capable of withstanding extreme hazards and intends to equip all of its nuclear power generating sites in this way by 2026. In the meantime, its existing crisis rooms are capable of withstanding flooding and "safe shutdown earthquakes" (with an intensity greater than the maximum historically probable earthquake).

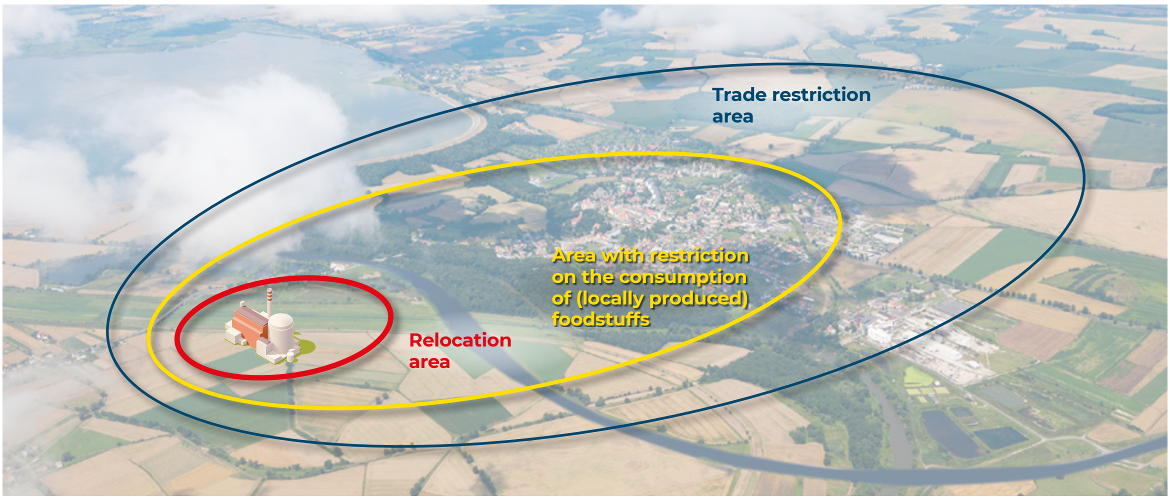
Revised emergency exercises

The various works carried out for the stress tests took into account scenarios that had not been tested in the past. This had consequences for the exercise scenarios, which now include earthquakes and accidents affecting the spent fuel pools.

** See glossary page 24*

Anticipating the consequences of a nuclear accident

On the assumption that an accident leading to radioactive releases is possible in France or elsewhere in Europe, ASN set up in 2005 the nuclear steering committee for managing the nuclear post-accident phase (Codirpa*) which in 2012 published the first aspects of its doctrine. In the wake of the Fukushima accident, French doctrine was modified in 2019. Review of the situation.



The Fukushima accident led to environmental releases lasting three weeks. Until then, the Codirpa* had worked on the assumption of a short-duration, low-intensity release. It thus chose to work on the hypothesis of a large-scale, long-duration release, more similar to what happened in Fukushima.

This had consequences for numerous aspects of post-accident management, such as the sizing of population protection zones for example. As a result of this work, the Codirpa proposed changes to post-accident doctrine in 2019, and these have now been accepted by the Government.

Determining decontamination and waste management strategies following an accident

The Japanese authorities decided to carry out very large-scale environmental decontamination work. The consequence of these operations was to generate a large volume of radioactive waste, with widely varying levels of contamination, and a strategy for managing this waste had to be gradually implemented. **Decontamination and waste management are closely interlinked.** The Codirpa thus set up a new working group tasked with defining an overall strategy for this challenge.

Managing the consequences for aquatic environments

The Fukushima accident triggered considerable radioactive releases into the marine environment, with consequences for fishing and nautical leisure activities. Managing the consequences of a nuclear accident on aquatic environments

* See glossary page 24

3 FUNDAMENTAL GOALS OF POST-ACCIDENT MANAGEMENT:

- **Protecting people** against the harmful effects of ionizing radiations
- **Bringing support to the population** affected by the consequences of the accident
- **Ensuring economic and social recovery** of affected territories

is now included among the subjects dealt with by the Codirpa. A working group will be tasked with **examining the specific aspects of aquatic environments** and proposing specific management modes for the corresponding risks.

Informing and involving the population and stakeholders

Difficulties with communication and the lack of coordination of the protection measures led to the population initially losing confidence in the authorities. Restoring the trust of the population is one of the factors that can help improve the resilience of those affected.

The dialogue created at the initiative of the International Commission for Radiological Protection (ICRP*) is a good example of this: it enabled **informed or expert citizens to be identified, and they were able to create a bridge between the authorities and the population**.

Since it was created, the goal of Codirpa has been one of openness, with the participation of members of civil society in the various working groups, alongside institutional experts and representatives of the various Government departments.

This joint assessment process helps raise the awareness of the population around the nuclear sites. The website *post-accident-nucleaire.fr*, devoted to public information, as well as a guide for the population living in an area affected by a nuclear accident, were created together with the stakeholders. A health professionals guide will be published at the end of 2021.

To go a step further, the Codirpa has set up a new working method for its working groups. This involves **submitting proposals for protection measures defined by experts to panels of citizens**, in order to obtain their opinion and adapt these measures. These panels, organised as of 2021, will examine the means of providing protection against contamination through foodstuffs.

The Codirpa also set up two other working groups, one in charge of examining means of **promoting “safety and radiation protection culture”** among the population living near nuclear facilities, and the other tasked with **examining means of involving the population** affected by a nuclear accident in the management of the contaminated areas.

These participative approaches draw on good practices identified in Japan.

A look back **at two significant accidents**

When they occurred, the major nuclear accidents of Three Mile Island in the United States and Chernobyl in Ukraine were analysed by ASN and its technical support body, IRSN*, and were debated within international organisations, such as the IAEA*. The lessons learned led to significant progress being made in the safety of nuclear facilities.

28 march 1979
THREE MILE ISLAND

REACTOR STATUS AT THE BEGINNING OF THE ACCIDENT

Automatic shutdown of pressurised water reactor (PWR) N° 2 owing to a failure of the normal water supply to the steam generators.

MAIN CAUSES OF THE ACCIDENT

Combination of failures (steam generators normal feedwater system and system which was supposed to back it up, as a result of incorrect reconfiguration following a test).

Information on the status of the safety equipment not available (position of the pressuriser letdown valve).

Loss of reactor core cooling (water injection stopped) owing to an incorrect diagnostic, which led to core heating, uncovering and then partial melting.

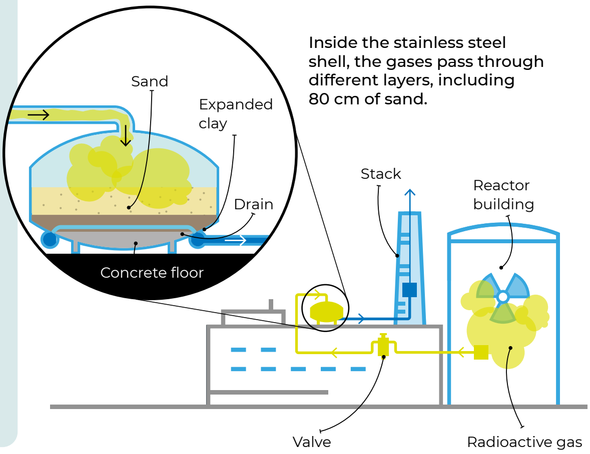
LESSONS LEARNED

This accident showed that combinations of failures could lead to core melt and how important it is for control crews to have information about the status of the facility. Insufficient account was taken of human and organisational factors. **Humans are however an essential link in the safety chain.** Following this accident, changes were made to the installations, in particular additional measures to manage combinations of failures, means to mitigate releases of radioactive products outside the containment *(see diagram)* and the creation of emergency plans and emergency exercises to test them.

A SIGNIFICANT STEP FORWARD IN SAFETY

Containment air filtration

In the event of an accident, if a pressure increase were to threaten damaging the containment, the depressurisation system would, as a last resort, enable the gases in the containment to be released after filtration. This filter is capable of retaining some of the radioactivity and thus mitigate the environmental consequences of the accident.



* *See glossary page 24*

26 april 1986
CHERNOBYL

REACTOR STATUS AT THE BEGINNING OF THE ACCIDENT

RBMK* type reactor (high power reactor with pressure tubes), operating at low power.

MAIN CAUSES OF THE ACCIDENT

Low-power operating test run in unstable reactor conditions: a number of safety devices had been intentionally disabled, which led to a reactivity accident, with explosion and fire in the reactor core.

LESSONS LEARNED

The need to reinforce the fundamentals of safety: prime responsibility of the licensee, independence of the regulatory authority, establishment of regulations, development of a safety culture.

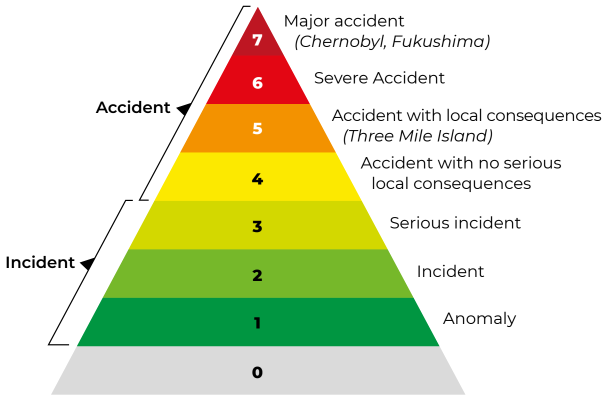
The need to improve public information, the consequence of which was the creation of the INES* scale *(see diagram)* and the need to inform neighbouring countries, with rapid notification of the nuclear accident.

A SIGNIFICANT STEP FORWARD IN SAFETY

Management of the emergency and post-accident phases

Following the Chernobyl accident, the response organisation was reinforced, both on the installation itself and in its environment. International crisis exercises are held regularly. Under the supervision of the IAEA*, international conventions were signed to provide countries with rapid notification of any nuclear accident and improve the assistance process. Finally, the management of the long-term consequences of a nuclear accident (decontamination of the environment, mitigation of exposure of persons) has progressed.

The INES scale, created after the accident at the Chernobyl NPP, provides information on the severity of a nuclear incident or accident.



GLOSSARY

IAEA – International Atomic Energy Agency, an inter-governmental organisation created in 1957, which is part of the United Nations Organisation. Its role is to foster and promote the safe, secure and peaceful use of nuclear technologies worldwide.

CEA – French Alternative Energies and Atomic Energy Commission. Active in research, development and innovation in the fields of energy, defence, information technologies and health.

ICRP – The International Commission for Radiological Protection is a non-governmental organisation issuing recommendations for the measurement of exposure to ionising radiation and for radiation protection provisions.

Codirpa – Steering committee for managing the post-accident phase of a nuclear accident or radiological emergency situation.

Corium – Mass of molten fuels and nuclear reactor core structural elements mixed together, which could form in the event of a severe accident.

Fuel cycle – Begins with the extraction of uranium ore and ends with packaging of the various radioactive wastes from the spent fuels so that they can be sent for disposal.

ECS – Acronym for the French stress tests decided on after the Fukushima accident (Japan) in 2011 for French nuclear facilities.

EDF – Électricité de France – licensee of the French NPP fleet.

Framatome – Nuclear steam system supply designer and manufacturer supplying equipment, services and fuel.

ENSREG – European Nuclear Safety REgulators Group (high-level European Union group on nuclear safety and waste management – formerly GHN).

Euratom – European Atomic Energy Community, created in 1957.

FARN – Nuclear rapid intervention force (CEA; EDF).

FINA – National intervention force of the licensee Orano

HCTISN – The High Committee for Transparency and Information on Nuclear Safety (created by the 13 June 2006 Act).

HERCA – Heads of European Radiation Control Authorities: Created in 2007 at the initiative of ASN, brings together all the European radiation protection oversight authorities

BNI – Basic Nuclear Installation: Installation which, due to its nature or the quantity or activity of the radioactive substances it contains, is governed by a particular regulatory system, defined by the Environment Code and the Order of 7 February 2012.

INES – International Nuclear Event Scale: international scale of nuclear and radiological events, graded from 0 to 7 in increasing order of severity.

Institut Laue-Langevin – International research organisation specialising in neutron sciences and technologies, located in Grenoble.

IRSN – French Institute for Radiation Protection and Nuclear Safety. The IRSN is an industrial and commercial public establishment. The IRSN notably acts as ASN's technical advisory body.

ITER Organization – International organisation for nuclear fusion energy operating the ITER reactor currently under construction in the Bouches-du-Rhône *département**.

Hardened safety core – Material and organisational provisions designed to prevent an accident with core melt, or limit its spread, despite heavily degraded conditions.

Orano (ex-Areva NP) – Player active throughout the fuel cycle, from raw materials up to waste reprocessing.

PPI – Off-site emergency plan: local system defined in France to protect the population, property and the environment, to deal with particular risks related to the existence of an industrial facility.

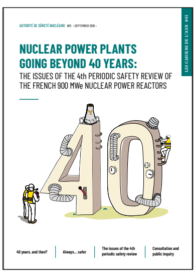
RBMK – Soviet designed high-power, pressure tube nuclear reactor used in the Chernobyl NPP.

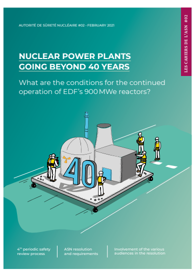
RHF – High-flux reactor in Grenoble, operated by the Laue-Langevin Institute (ILL). It is a 58-MW heavy-water high-flux neutron reactor which produces high-intensity thermal neutron beams for fundamental research, particularly in the areas of solid-state physics, neutron physics and molecular biology.

WENRA – Created in 1999, WENRA (Western European Nuclear Regulators' Association) brings together the heads of the nuclear safety authorities of the 18 European countries equipped with nuclear power reactors.

Zirconium – Zirconium is a metal that is particularly resistant to corrosion at high temperatures. It is thus used in the form of an alloy to fabricate nuclear fuel assemblies (grids, tubes, guides, etc.).

** Administrative region headed by a Prefect*





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