AUTORITÉ DE SÛRETÉ NUCLÉAIRE • NOVEMBER 2023

LES CAHIERS HISTOIRE DE L'ASN • #01

NUCLEAR ACCIDENTS AND DEVELOPMENTS IN NUCLEAR SAFETY AND RADIATION PROTECTION

How nuclear safety and radiation protection have evolved further to accidents in France and across the world.

1969 / 1980
Saint-Laurent-des-Eaux

1979
Three Mile Island

1986
Chernobyl

2004 / 2005
Épinal

2011
Fukushima

The aim of "Les Cahiers Histoire de l'ASN" magazine is to shed light on nuclear safety and radiation protection through interviews with those involved yesterday and today. It intends to supplement the historical account of the facts with the testimonials of the actors of the time.

Contents

FOREWORD

This first issue of “Les Cahiers Histoire de l'ASN” is devoted to the subject of “nuclear accidents”. Although some nuclear accidents are well known, to the extent moreover that the name of the site is now part of everyday language, others represent distant memories or have been completely forgotten. This is the case with two accidents at Saint-Laurent-des-Eaux described in this issue. We have a duty to build up a collective memory that can be used by future generations.

In our opinion, three key ideas must be considered at this stage.

First, in a society that aspires to be risk-free, one must remember that there is no such thing as zero risk and the nuclear sector is no exception to this universal rule. As André-Claude Lacoste, ASN Chairman from 2006 to 2012 pointed out, *“nobody can guarantee that there will never be a serious accident in France. It is therefore necessary to do two things: try to reduce the probability of this happening, and mitigate the consequences if it does. That, in a nutshell, is the philosophy underpinning nuclear safety”.*

Next, with regard to past accidents, one must go beyond their uniqueness to investigate the root causes and draw the lessons that will enable potential accidents to be foreseen and allow optimal management of the accident and the post-accident phase. Many developments in the organisation or the doctrine of nuclear safety and radiation protection stem from the analysis of past experience. We have decided to describe this work through five milestone events, each of which led to major advances in nuclear safety and radiation protection.

Lastly, one of the consequences of major accidents is effectively the emergence of international awareness of nuclear-related risks. The message stating that nuclear safety is a common asset and must not form the subject of competition or geostrategic manipulations remains, in view of recent events, more relevant than ever.

The ASN History Committee

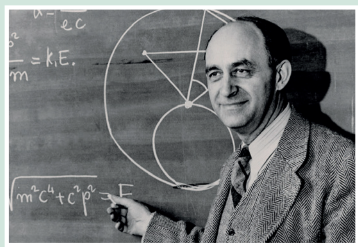
Nuclear safety and radiation protection, a continuous learning process

Accidents – random, unexpected and undesired events – are part of the existence of all natural and artificial things. The nuclear sector is no exception to the rule.

The discovery of nuclear energy was marred by ill-fated events from the outset. The world's first uranium-based nuclear reactor, or "atomic pile" as it was referred to at the time, created by Enrico Fermi in 1942 in Chicago, was followed very quickly by the design and then the production of the atomic bomb. Furthermore, it was during the preparatory work on the bomb that the first criticality incident in history took place in Los Alamos in the United States on 11 February 1945. It caused one operator to lose a significant amount of hair but had no lethal effect.

In the 1950's, the civil nuclear activities lent moral support to the nuclear sector: it can be used for other things than killing, such as producing heat. Among the many projects to emerge at that time, the production of electricity by using reactors to heat water to produce steam to rotate a turbine is a concept that is still relevant today. On 20 December 1951, in Idaho Falls in the United States, EBR-1, a fast neutron reactor cooled by liquid sodium produced enough electricity to illuminate the building housing the reactor!

The gateway to industrial production was open.



Enrico Fermi (1901-1954)
Designer of the first ever operational nuclear reactor, Fermi is considered by his peers to be a giant of modern physics. The Italian physicist, who won the Nobel Prize in Physics in 1938, became an American citizen in 1945 and worked intensively on the Manhattan project to produce the atomic bomb.

See glossary pages 33 to 36

“Nobody can guarantee that there will never be a serious accident in France. It is therefore necessary to do two things: try to reduce the probability of this happening, and to mitigate the consequences if it does. That, in a nutshell, is the philosophy underpinning nuclear safety.”

André-Claude Lacoste
ASN Chairman from 2006 to 2012

People were aware of the risk from the very beginning

From the construction of the first Fermi pile in 1942, precautions were taken to ensure reactor safety, with several – albeit rudimentary – means of shutdown, but which inspired the systems in use today. An operator was thus stationed above the pile, armed with an axe, ready to cut the rope which retained an emergency stop bar coated with cadmium, a powerful neutron absorber, which would then drop by gravity into the reactor core. A second operator, also stationed above the pile, held a bucket filled with a cadmium sulphate solution ready to be poured onto the reactor if necessary. The pile was controlled by a hand-operated horizontal cadmium control rod and the neutron flux was monitored by measuring instruments.

October 1956, the first incident in France

In October 1956 in reactor G1 on the Marcoule site, a fuel cartridge that was incorrectly positioned in its channel heated up and caught fire. Seven kilograms of nuclear fuel melted. Thanks to the cladding failure detection system, the reactor pile stopped, but lacking appropriate handling systems, extraction of the cartridge – which was done virtually by hand – was complicated. This first incident in France remains unknown to the general public.

The beginning of regulation of nuclear safety

Between 1945 and 1955, the first years of development of nuclear energy in France, there were no specific safety rules other than those that the researchers, engineers and technicians imposed upon themselves. At the end of 1957, Francis Perrin, the High-Commissioner for Atomic Energy in France, initiated a reflection of the organisation of nuclear safety.

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Criticality

In the field of nuclear engineering, criticality is a discipline which aims to assess and prevent the risks of an unwanted chain reaction in nuclear facilities. It is a sub-discipline of neutronics. The criticality risk is the risk of triggering an uncontrolled fission chain reaction.

There can be no grounds for complacency about nuclear safety in any country. [...] Safety must always come first.

Yukiya Amano
Director General of the International Atomic Energy Agency (IAEA) from 2009 to 2019

"Any accident is by definition unique. You have to go further and seek out the root causes. That is why we did what was done in France, and more broadly in Europe, following the Fukushima disaster, because there was a real need to take things beyond the particular circumstances encountered at Fukushima or Chernobyl."

Pierre-Franck Chevet
ASN Chairman from 2012 to 2018

...

Drawing from the American, British and Canadian examples, it resulted in the creation in January 1960 of the Atomic Installations Safety Commission (CSIA), tasked with examining the safety of the current and future facilities of the French Atomic Energy Commission (CEA).

For the first time, based on the Anglo-Saxon model, a report was drawn up at the request of the experts, and analysed in 1962 during the design of EDF's Chinon nuclear power plant (NPP). Presented by the licensee, this document set out an analysis of the risks and means of protection of the installation with the aim of obtaining from the public authorities a construction authorisation and then a commissioning authorisation. The decade of the 1960's saw the development of the graphite-moderated gas-cooled reactors (GCRs) designed by the CEA, referred to as Gas-Cooled Reactors (GCRs) in English. These reactors were officially abandoned in 1969, the year in which a core meltdown accident occurred on the reactor at EDF's Saint-Laurent-des-Eaux NPP.

In the mid-1970's a national nuclear safety organisation began to develop, with the creation of an inspection body – the Nuclear Installations Central Safety Service (SCSIN) within the Ministry for Industry in 1973, and an expert assessment body, the French Institute for Nuclear Safety and Protection (IPSN), created within the CEA in 1976.

In the early 1980's, these bodies began to produce technical regulations, comprising a very small number of good practices guides, technical orders and ministerial guideline notices. These official documents were supplemented by policy documents written by the licensee. These documents jointly constituted the *de facto* regulations.

The emergence of an independent and transparent nuclear oversight body

The Three Mile Island accident in 1979 ***(see p. 12)*** was a real shock for the French nuclear experts and contributed directly to the introduction of a number of modifications on the nuclear facilities. Alongside the technical changes linked to the improvement in safety, the very organisation of oversight underwent changes with the aim of regulating the monitoring of NPPs.

See glossary pages 33 to 36

ASN is undoubtedly the second most powerful nuclear regulator in the world. And few people know the key role that André-Claude Lacoste played in defining the international nuclear safety rules when he chaired the Nuclear Safety Standards Committee at the IAEA.

Ann MacLachlan
Former journalist at Nucleonics week

The Chernobyl accident in 1986 ***(see p. 16)*** underpinned the idea that it was vital to have a regulation system that was more transparent, more independent of the industry players and more robust from the regulatory aspect. 2002 saw the creation of the Institute of Radiation Protection and Nuclear Safety (IRSN), a completely independent public institution of the CEA, resulting from the merging of the French Office for Protection against Ionising Radiation (OPRI) – which replaced the Central Service for Protection against Ionising Radiation (SCPRI) in 1994 – and the IPSN.

The SCSIN, for its part, after several successive extensions to its scope of action, acquired the status of an independent administrative authority in 2006 and became the Autorité de sûreté nucléaire (ASN – French Nuclear Safety Authority). In the same year, the Act on Transparency and Security in the Nuclear Field (the "TSN Act") was promulgated, followed by a series of decrees, orders, statutory resolutions, and a recasting of the corpus of the practical guides, gradually replacing the old regulations. In 2011, in the wake of the Fukushima Daiichi NPP accident ***(see p. 26)***, the safety of the French NPPs was reassessed *via* stress tests, referred to in France as "complementary safety assessments".

Nuclear safety: a global common asset

The emergence of an international awareness of nuclear-related risks is one of the consequences of the major accidents. In his wishes to the press in 2011, André-Claude Lacoste expressed it strongly: *"ASN has an active policy of international cooperation. It considers that nuclear safety must not be a source of competition, but a common asset"*. ASN considers that one of the new challenges of global nuclear safety, particularly in the context of the development of nuclear power programmes in emerging countries, is to develop a safety culture and put in place an independent safety authority (regulator) in each country. Alongside these independent authorities, citizens' associations were created and contributed, with critical and expert positions, to the debate on nuclear-related issues and safety requirements. ■

"I think that the strength of the nuclear sector depends not only on a robust and responsible licensee, but also on a regulator that plays its role in full. This is also what wins the trust of the public, otherwise it doesn't work."

Dominique Minière
Executive Director of the EDF group, in charge of the Nuclear and Thermal Fleet Division from 2015 to 2019

Examples of nuclear accidents and incidents classified on the INES scale

Level 7

1986 – Chernobyl *(Ukraine)*
Further to a series of human errors as well as design faults, reactor 4 suffered core meltdown followed by an explosion which caused the release of nuclear fuel into the atmosphere. The contamination spread across the whole of Europe. *Details p. 16*

2011 – Fukushima-Daiichi *(Japan)*
This accident was the consequence of a tsunami caused by an earthquake of magnitude 9 on the Richter scale, resulting in the total loss of the electrical power supplies and the nuclear reactor cooling systems, and substantial radioactive releases into the environment. *Details p. 26*

Level 6

1957 – Kyshtym *(Russia – former USSR)*
The explosion of a tank of liquid nuclear waste released a radioactive cloud which contaminated an entire region around Kychtym, covering 800 km^2. More than 200 people died, 10,000 people were evacuated and 470,000 were exposed to radiation.

Level 5

1957 – Windscale, renamed Sellafield *(United Kingdom)*
The graphite core of reactor 1 ignited during a routine annealing operation, and fission products – essentially iodine-131 – were released into the atmosphere. No evacuation was required, but the competent authorities took measures such as prohibiting the consumption of locally produced foodstuffs.

1979 – Three Mile Island *(United States)*
Further to an accidental chain of events, the core of unit 2 reactor of the Three Mile Island NPP (TMI-2) suffered partial meltdown, leading to the release of a small amount of radioactivity into the environment. *Details p. 12*

Level 4

1959 – Santa Susana *(United States)*
The experimental sodium reactor at the Santa Susana Field Laboratory near Simi Valley in California suffered partial core meltdown.

1969 – Saint-Laurent-des-Eaux
(Loir-et-Cher département(*)*, France)*
Forty-seven kilograms of uranium dioxide began to melt in GCR 1 during a fuel loading operation. *Details p. 8*

1969 – Lucens *(Switzerland)*
The rupture of a pressure tube caused a pulse of current and the reactor (a small experimental device built in a rocky cavern) exploded. The reactor was totally destroyed. The core underwent partial meltdown. The majority of the radioactive substances were contained within the cavern.

1971 – Monticello NPP *(United States)*
A water tank overflowed, releasing 190 m^3 of contaminated water into the Mississippi River. Radioactive matter subsequently entered into the water intake system of the city of Saint-Paul (Minnesota).

1980 – Saint-Laurent-des-Eaux NPP
(Loir-et-Cher département(*)*, France)*
Reactor core meltdown occurred on GCR 2. A piece of sheet metal obstructed part of the cooling system. The temperature rose sharply, causing 20 kg of uranium to melt and leading to emergency shutdown of the reactor. The accident severely damaged the facility. *Details p. 8*

1993 – Tomsk-7 *(Russia)*
A chain reaction occurred in the Tomsk-7 waste reprocessing plant, causing a large explosion and a significant release of radioactive material into the atmosphere.

1999 – Tokaimura *(Japan)*
Further to a handling error, an abnormally large quantity of uranium (16.6 kg), very much greater than the safety value of 2.3 kg) was introduced into a settling tank, causing a criticality reaction. This accident killed two workmen.

2000 – Indian Point *(United States)*
Reactor 2 of the Indian Point NPP released a small quantity of radioactive steam. This was caused by a steam generator malfunction.

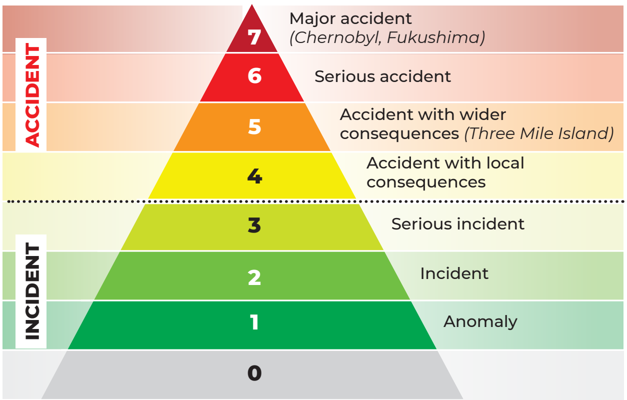
Level 3

1981 – La Hague *(Manche* département(*)*, France)*
A fire broke out in a non-confined radioactive waste storage silo in the reprocessing plant.

** Administrative region headed by a Prefect.*

See glossary pages 33 to 36

INES (International Nuclear Event Scale) **scale for classifying nuclear incidents and accidents**



The need to inform the public of the severity of nuclear events, particularly after the Chernobyl accident in 1986, led to the development of classification scales.

The INES scale was originally put into application on an experimental basis in France by the French High Council for Nuclear Safety and Information (CSSIN), starting in spring 1988. It was strongly promoted by Pierre Desgraupes, vice-chairman of the CSSIN, and was adopted by the IAEA in 1991.

In 2002, ASN proposed a new version of this scale to take account of radiation protection events (irradiation, contamination), particularly events affecting workers, whatever the place of the incident.

Later on, in July 2008, the IAEA published a revised INES scale that allows events occurring in the area of transport or leading to human exposure to radioactive sources to be better taken into account.

1989 – Vandellos *(Spain)*
A fire broke out in the turbine hall of the Vandellos NPP, resulting indirectly in a flood and damaging various systems, including the reactor cooling system. The Spanish government decided to shut down the reactor definitively in November 1992.

1991 – Forbach *(Moselle* département(*), *France)*
Three temporary worker employees were severely irradiated when they entered into an industrial accelerator in operation.

2005 – Sellafield *(United Kingdom)*
Within the Thorp reprocessing plant, 83,000 litres of highly radioactive liquefied fuel containing uranium and concentrated nitric acid leaked into a stainless steel chamber containing 200 kg of plutonium.

2007 – Kashiwazaki-Kariwa *(Japan)*
The power plant was hit by an earthquake of magnitude 6.8 on the Richter scale; the epicentre was situated about 10 km away. The earthquake caused a fire which was brought under control two hours after it broke out, and releases of water containing radioactive elements into the sea.

2008 – Toulouse *(Haute-Garonne* département(*), *France)*
A temporary-contract employee was irradiated by a cobalt-60 source at the French aerospace research centre (Onera).

Level 2

1992 – Sosnovy Bor *(Russia)*
A water intake valve on one of the 1,660 pressure tubes of reactor 3 – a RBMK reactor – closed causing the destruction of the fuel element and the pressure tube.

1999 – Blayais *(Gironde* département(*), *France)*
During the storm that hit France in 1999, the lower sections of reactors 1 and 2, and to a lesser extent of reactors 3 and 4 of the Blayais NPP, were flooded, forcing the shutdown of three of its four reactors.

2006 – Plutonium technology facility of Cadarache *(Bouches-du-Rhône* **département**(*), *France)*
The quantity of plutonium in the containment buildings was underestimated, which significantly reduced the design-basis safety margins established to prevent a criticality accident, the potential consequences of which could be serious for the workers.

2006 – Forsmark *(Sweden)*
The emergency electrical power supply system of the Forsmark NPP reactor 1 failed. The electrical power supply was restored after a few hours, avoiding uncovering of the core.

2007 – Dijon *(Côte d'Or* département(*), *France)*
A radiographer was irradiated during the radiotherapy treatment of a patient.

2008 – Krško *(Slovenia)*
A leak on the reactor primary cooling system caused the reactor to be shut down. The leak was contained in the reactor containment.

2009 – Cruas-Meysse *(Ardèche* département(*), *France)*
Systems cooling was lost, jeopardising the safety of reactor 4.

2011 – Fort Calhoun *(United States)*
The Fort Calhoun NPP was flooded when the river Missouri burst its banks.

Level 1

More than a hundred level-1 events are observed each year in France.

Level 0

More than a hundred level-0 events are observed each year in France.

Saint-Laurent-des-Eaux, two accidents in France

The two accidents at the Saint-Laurent-des-Eaux Nuclear Power Plant (NPP) are the most serious nuclear events ever recorded in France. Retrospectively rated level 4 on the INES scale by ASN, they occurred on graphite-moderated Gas-Cooled Reactors (GCRs), which are currently being decommissioned as this technology has been abandoned.

The GCR reactors

The GCR reactors were the first generation of French nuclear power reactors. They used a natural (non-enriched) uranium fuel, moderated with graphite and cooled by carbon dioxide (CO_2) gas. Just before the 1969 accident, EDF had announced that it was abandoning this type of reactor in favour of the Pressurised Water Reactor (PWR) for economic rather than technical reasons.

The Saint-Laurent-des-Eaux nuclear accident of 1969

On 17 October 1969, five fuel elements melted

An error occurred during a loading operation on GCR A1. This error prevented proper circulation of the carbon dioxide which served as the coolant. This greatly reduced the cooling of the fuel elements present in a channel of the reactor core. The temperature of the magnesium alloy and zirconium cladding of five fuel elements increased, causing their deterioration. The rise in radioactivity in the reactor chamber caused an automatic reactor trip.

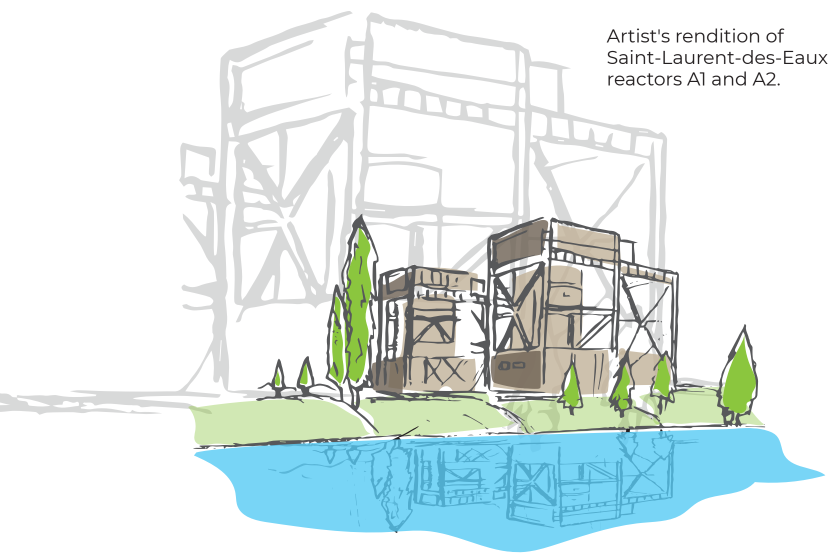
The five fuel elements represented about fifty kilograms of uranium. The radiological consequences were limited: the level of irradiation of the uranium was very low given that the fuel elements had just been loaded into the reactor.

Clean-up operations

About ten days after the accident – the time necessary for the nuclear fuel to cool – the operations to clean up the melted uranium began. On completion of these operations, 47 kg of uranium had been recovered, essentially using remotely-operated equipment. Additional human intervention was nevertheless necessary to recover some of the debris. A full-scale mock-up of the area to clean up was built in order to train the operators tasked with the clean-up.

Technological arbitration

Two nuclear technologies were in competition at the time: the GCRs, considered to be the "French" solution, and the PWRs The President of the Republic at the time, Charles de Gaulle, preferred the GCR technology, whereas Georges Pompidou, his successor in 1969, preferred the PWR technology. Shortly after the accident, the GCR technology was abandoned in favour of PWRs.



Artist's rendition of Saint-Laurent-des-Eaux reactors A1 and A2.

See glossary pages 33 to 36

The Saint-Laurent-des-Eaux NPP is located on the municipality of Saint-Laurent-Nouan in the Loir-et-Cher département[(*)] *on the banks of the river Loire, between Orléans (30 km upstream) and Blois (28 km downstream). The accidents concern only the two old gas-cooled nuclear reactors A1 and A2, which are currently being decommissioned, and the two associated waste (graphite sleeves) storage silos. These two reactors were commissioned in 1969 and 1971 and shut down in April 1990 and May 1992 respectively.*

This NPP also comprises two PWRs, B1 and B2, which have been operating since 1983. They each have a unit power of 915 megawatts.

The Saint-Laurent-des-Eaux nuclear accident of 1980

13 March 1980, two fuel elements melted

A sudden rise in the radioactivity in the reactor pressure vessel led to a reactor trip. The alarms sounded, reactor A2 suffered a partial core meltdown. This meltdown was triggered by the detachment of a piece of sheet metal in the cooling system, blocking a section of it and causing a local rise in the fuel temperature. 20 kg of uranium melted after the reactor trip.
Professor Pierre Pellerin, head of the SCPRI, explained to the NPP surveillance committee that *"the pressure inside the reactor was equivalent to thirty times atmospheric pressure and a few discharges had to be carried out in order to depressurise the reactor pressure vessel"*.
The cumulative discharges of radioactive effluents remained low because a waiting period was observed before depressurising the vessel, knowing that the fuel was irradiated. The small volumes discharged remained below the limits authorised at that time, governed by decree.

Damage and return to service

The quantity of melted fuel was smaller than in 1969 (20 kg as opposed to 50 kg), but the fuel was more radioactive because it had accumulated the fission products and minor actinides during its two years of utilisation in the reactor.

The reactor clean-up and repair operations lasted 29 months and involved five hundred EDF employees and subcontractors. The uranium dust dispersed in the reactor building during the accident represented a contamination risk for a long time.

Several tonnes of lead were brought into the reactor building to provide radiological protection. The clean-up and repair work lasted until 1982. The facility was restarted in October 1983.

The two GCRs A1 and A2 were definitively shut down in April 1990 and May 1992 respectively.

Much later, in 2015, a controversy broke out concerning discharges of plutonium into the river Loire following the accident ***(see next page)***.

The year 1980 was also marked by two noteworthy incidents at the Saint-Laurent-des-Eaux NPP.

- **13 February 1980**
  Further to a very rapid increase in power linked to shortcomings in the operating instructions, the cladding of several fuel elements melted, without the uranium suffering the same fate.
- **21 April 1980**
  A container exploded in a pool storing spent fuel bars removed from the reactor and whose cladding was damaged (pending their transfer off the site). Fission products were released into the pool water.

A fact-finding mission was undertaken in 2015

The two events were subsequently rated level 4 (accident) on the INES scale (*see p. 6*), adopted by the IAEA in 1994 in the wake of the Chernobyl accident. A fact-finding mission carried out at the request of the Minister for Ecology concluded that there had been low-level discharges which did not exceed the standards in effect at the time of the events.


Ministère de l'écologie, du développement durable et de l'énergie
Conseil général de l'environnement et du développement durable

Ministère de l'économie, de l'industrie et du numérique
Conseil général de l'économie, de l'industrie, de l'énergie et des technologies

Les incidents et accidents nucléaires dans la centrale de Saint-Laurent-des-Eaux sur les réacteurs uranium naturel – graphite – gaz

Rapport à
Madame la Ministre de l'écologie, du développement durable et de l'énergie
établi par
Philippe GUIGNARD, Ingénieur en chef des ponts, des eaux et des forêts
Serge CATOIRE, Ingénieur en chef des mines

* *Administrative region headed by a Prefect.*

Steps in the analysis of a sediment on the banks of the river Loire

1. **Identification of the best core-sampling site,** defined by a multidisciplinary team (geochemists, hydrologists, etc.).
2. **Taking of sediment samples** at two different depths every metre.
3. **Gamma spectrometry analysis of the samples in the laboratory.** The tubes are cut in the longitudinal direction and opened. The excess caesium-137 and lead-210 are measured in each section to date them.
4. **The radionuclides are analysed in an IRSN laboratory.** An expert looks for the plutonium, carbon-14 and organically-bound tritium. The analysis revealed peaks of plutonium in the years 1969 and 1980, which correspond to the two accidents that occurred at the Saint-Laurent-des-Eaux NPP.

Core sampling technique for taking and analysing sediments from river banks.

"We must preserve the memory of those who founded ASN and the various organisations that preceded it. Today we are still treading the path towards ever-greater independence and transparency."

Philippe Saint Raymond
Deputy Director of Nuclear Installations Safety (1993 – 2002), then Deputy Director-General of Nuclear Safety and Radiation Protection (start of 2002 to February 2004)

Plutonium discharges into the river Loire

According to the chairman of the NPP surveillance committee: *"Once everything had cooled down, a few kilograms of uranium had melted and been deposited in the bottom of the reactor pressure vessel. These materials were loaded with fission products and plutonium. During the clean-up, a rinsing operation was carried out and liquid discharges were washed into the river Loire"*. The NPP stated that it *"had observed the regulatory discharge authorisation limits applicable at the time, set by the Ministerial Order of June 1979"*.

On 4 May 2015, a documentary entitled "*Nuclear power, the policy of lying?"*, broadcast by the French television channel Canal+, stated that following this accident, EDF made totally illegal discharges of plutonium into the river Loire for a period of at least five years.

A sampling campaign of sediments in the Loire conducted by a university laboratory established the presence of traces of plutonium extending from Saint-Laurent-des-Eaux to the estuary, the origin of which could be attributed to either the accident of 1980 or that of 1969 *(see above)*.

In IRSN's opinion, the majority of these traces were not linked to the accident of 13 March 1980 but to the treatment of water from the reactor A2 pool, which was contaminated when a container enclosing an unsealed fuel element burst on 21 April 1980.

Based on the dosimetric evaluations carried out using the estimated activity discharged at the time, IRSN considers that the plutonium discharges into the river Loire remained sufficiently low for the health and environmental risks downstream of the site to be considered negligible.

See glossary pages 33 to 36

What lessons can be learned from the nuclear accidents at Saint-Laurent-des-Eaux?

Improvements in governance and techniques

The experts from EDF and CEA considered the accident of 17 October 1969 to be exceptional. The analysis of the causes rapidly led to the cause of the accident being diagnosed as a combination between a human error and an error in the automatic loading system.

This event led to improvements in the clad failure detection system of the GCRs and in the fuel handling devices. It was followed up by a group of experts (from the CEA and EDF, as well as the Ministry of Industry) in the months following the event.

With regard to communication, the accident was not concealed but little was said about it.

On 31 October 1969, an article published in the newspaper *Le Monde* reported the accident as an "incident". This caused no particular reaction in France. The events of the accident were nevertheless published in a specialist review, and the Saint-Laurent-des-Eaux NPP produced a film showing the different phases of the repair work.

Three international conferences were held in London, Paris and in Germany between October and December 1970, showing a willingness to make the accident and the methods used to resolve it known to the specialists concerned, in France and abroad.

Capitalising on lessons learned on a global scale

The accident of 13 March 1980 underwent a more formal analysis than that of 1969, given the existence of an oversight organisation within the Ministry of Industry, namely the SCSIN – a forebear of ASN, as well as a public expert attached to the CEA, the IPSN, and an advisory committee of experts. The IPSN drew up two reports, one devoted to the accident of 13 February 1980, which points to organisational and human failures, the other to the accident of 13 March, indicating that there was a design problem.

The IPSN experts also mention the failure to take into account the lessons learned from accidents that occurred in other countries: a precursor incident (tearing off of metal sheets) had occurred in the Vandellos NPP in Spain in 1976, a plant which was sold by France and was an exact copy of the Saint-Laurent-des-Eaux NPP ***(see quote opposite)***.

The IPSN report on the accident of 13 March 1980 points out that: *"this incident escaped attention"*. Likewise, the risk of a projectile causing loss of cooling, which corresponds to the 1980 accident scenario, had not been taken into account when the loss-of-cooling risk was studied in the mid-1970s in France.

Creation of the SCSIN

Created by decree in 1973 following the first accident at the Saint-Laurent-des-Eaux NPP, the Central Service of Nuclear Installations Safety (SCSIN) was responsible for preparing and im-plementing all the technical measures concerning nuclear safety: regulations, coordination of safety studies, nuclear information. It was this lean structure, attached to the Ministry of Indus-try, that was responsible for examining the Basic Nuclear Installation (BNI) authorisation application files. The Service became the Nuclear Installation Safety Directorate (DSIN) in 1991, and was renamed Nuclear Safety and Radiation Protection Directorate (DGSNR) in 2002. ASN was created directly from the DGSNR in 2006.

SCSIN

"**…EDF must be particularly attentive** to the functioning of the various reactors of the same type operating in other countries – especially Vandellos in Spain – in order to draw all the necessary lessons from incident precursor events."

SCSIN
"GCR reactor nuclear power plants, Lessons learned from the incidents on the second plant unit of Saint-Laurent-des-Eaux A", 13 January 1981

Three Mile Island, the first nuclear accident that attracted worldwide attention

The accident involving partial meltdown of the core of reactor 2 of the Three Mile Island (TMI) power plant demonstrated that combinations of human and technical failures could lead to a severe accident. Rated level 5 on the INES scale, the accident was a major turning point for the nuclear industry and gave rise to an overall review of the risks and approach to reactor safety.

Core meltdown

Reactor core meltdown occurs when the nuclear fuel rods which contain uranium or plutonium and highly radioactive fission products start to overheat and then melt. It occurs in particular when a reactors stops being properly cooled. It is considered to be a severe nuclear accident because fissile materials can contaminate the environment with the release of numerous highly radioactive radioisotopes outside the reactor containment.

A year after it was commissioned, reactor 2 of the TMI NPP situated on an island on the River Susquehanna, suffered a technical failure.

The TMI NPP, situated in Pennsylvania in the east of the United States, was commissioned in 1974. In 1979, it was equipped with separate 900 megawatt electric (MWe) PWRs.

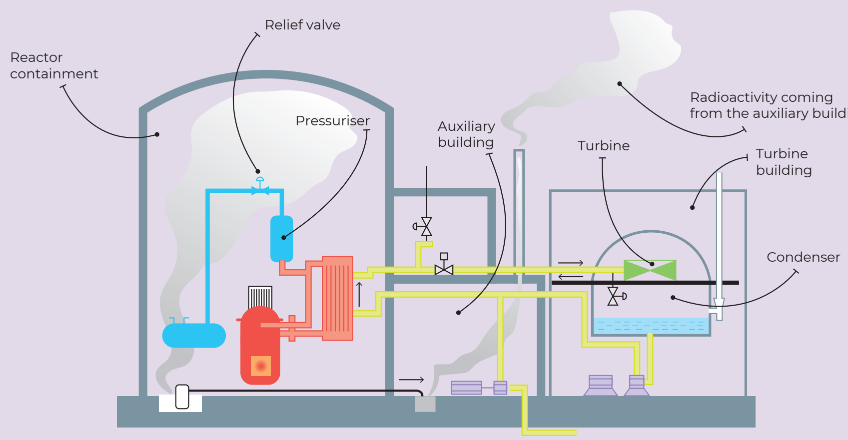
Wednesday 28 March 1979, 04:00 (4 am)

The accident began with a simple operating incident, failure of the main feedwater pumps supplying the steam generator cooling system. The planned safety mechanisms – emergency shutdown (reactor trip) by inserting control rods into the fuel core and activation of the auxiliary feedwater pumps supplying water to the reactor – functioned perfectly.

Succession of failures and negligence

But then a second failure occurred: despite the activation of the auxiliary feedwater pumps, the water did not reach the Steam Generators (SGs) because, due to an operator omission, the valves situated between the SGs and the pumps were closed instead of being open. These valves were reopened manually eight minutes later.

UNIT 2 OF THE THREE MILE ISLAND NPP



See glossary pages 33 to 36

When unit 2 (TMI-2) suffered its accident in 1979, unit TMI-1 was disconnected from the network. It was put back into service in October 1985, despite public opposition, several court injunctions and technical and regulatory complications.
In 2009, its operating license was extended by 20 years, that is to say until 19 April 2034. However, as the site had been losing money for several years, the licensee – Exelon – decided to stop operating it on 20 September 2019.

During this lapse of time, the pressure in the primary cooling system, which was insufficiently cooled, increased to the point where it triggered opening of the pressuriser relief valve, whose purpose is to evacuate the excess steam towards a tank and thereby reduce the pressure in the primary system.

When cooling by the SGs was restored and the primary system pressure reached the pressuriser relief valve closing threshold, **a third failure occurred:** the pressuriser relief valve received the command to close, but remained jammed in the open position, resulting in the loss of primary coolant *via* this valve.

The operators who checked the pressuriser relief valve position indicator saw a "valve closed" indication. But this indication was false. This is because the indicator in the control room reflected the command received by the valve and not its actual position. The loss of primary coolant activated the safety injection system. The operators in charge of operational management of the plant focused their attention on the level of water in the pressuriser to prevent it from filling up.

Faced with the rapid rise in the water level in the pressuriser, and believing the relief valve to be closed, the operators manually stopped the safety injection. The mental picture the operators had of the situation was false; they lacked direct information on the state of the reactor core.

Melting of the fuel, then reactivation of safety injection

Given the emptying of the primary cooling system, the fuel was no longer cooled. This led to degradation of the fuel, with a significant release of fission products from the fuel into the primary coolant. Two hours and fourteen minutes after the start of the accident, the alarm signalling high radioactivity in the reactor containment was activated. From this moment, the operators could no longer ignore that the situation was serious. The pressuriser relief valve was then closed, stopping the emptying of the primary cooling system. At this stage of the incident, new radioactivity alarms were activated, some situated outside the reactor building.

Nine hours and fifty minutes after the start of the accident, a localised explosion of about 320 kg of hydrogen caused a pressure peak of about 2 bars in the reactor building, without causing any particular damage. It took the next twelve hours to purge the primary system of the majority of the hydrogen created by the oxidation of the Zircaloy and the incondensable fission gases released from the fuel during the accident.

Wednesday 28 March 1979, 20:00 (8 pm)

The accident in itself was over. It was nevertheless necessary to let several days go by before being able to exclude the risk of a hydrogen explosion. The damage suffered by the fuel elements was far greater than that imagined for the most severe design-basis accident considered for the installation. It was not until six years later, in 1985, that it was found that 45% of the fuel had melted, taking with it cladding and structural materials, forming what is called "corium". Part of this corium, about 20 tonnes, flowed in liquid form into the bottom of the reactor vessel, fortunately without melting through it, possibly thanks to the forming of a space between the corium and the reactor vessel which would have allowed the cooling water to circulate in the vessel.

Minimal consequences for the environment

Despite the partial meltdown of the reactor core and the large release of radioactivity into the reactor containment, the immediate radiological consequences for the environment were limited. The reactor containment had effectively fulfilled its purpose. The low-level releases into the environment were caused by a system for pumping the primary cooling system effluents, which was kept in service.

How did nuclear safety and radiation protection evolve following the **Three Mile Island** accident?

The TMI accident taught lessons concerning the functioning of the reactors. The lessons from the accident enabled the calculated probability of core melt-down in second-generation PWRs to be reduced by a factor of 10.

International public opinion became aware that nuclear accidents represented a real risk that could materialise at any time. The accident marked the widening of the nuclear safety debate from the sphere of the scientists and industry players to that of the citizens and politicians.

Protect the neighbouring populations by informing them of the risks and the measures to take to respond to them

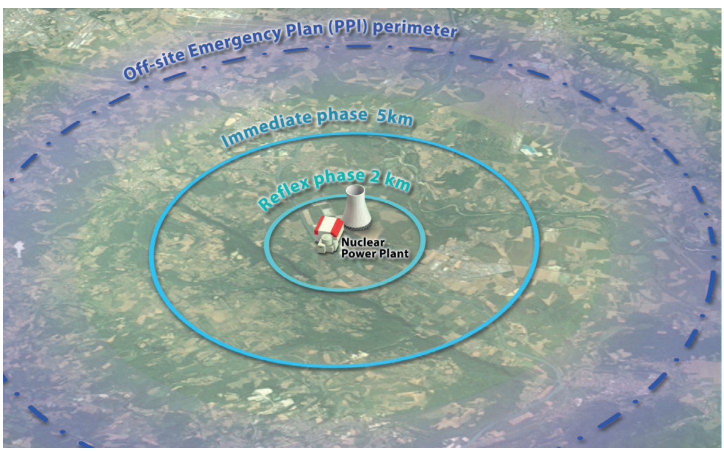
The nuclear safety actors developed extensive information plans for the people living near NPPs. The local authorities, the medical corps and the pharmacists were also directly involved in these actions.

Setting up of emergency plans in France

The TMI accident was partly linked to poor understanding of the situation by the operators. It has been established that it was very difficult for a team to call into question its interpretation of the situation. It thus came to light that setting up an emergency team capable of taking a step back from the situation could be a major improvement. Likewise, the need to better define the role of the different players and the organisation of information circulation in accident situations became apparent.

Emergency plans were developed on these bases. The need for regular training exercises also came to light.

Emergency plans were thus put in place in France in the 1980's. On-site Emergency Plans (PUIs) were developed by the nuclear installation licensees with the aim of controlling an accident insofar as possible and mitigating its consequences, assisting any injured persons on the site and informing the public authorities and the media. The public authorities established Off-site Emergency Plans (PPIs) meeting the general aim of protecting the populations in the event of a severe accident occurring in these facilities. The first emergency exercise was organised in 1980 at the Fessenheim NPP (Haut-Rhin département(*), France).



* *Administrative region headed by a Prefect.*

See glossary pages 33 to 36

Integration of the lessons learned from monitoring the operation of nuclear power plants

The detection of precursor events became a major concern of the licensees and nuclear safety organisations.

The organisation of operation and operating experience feedback thus developed around this new priority.

Modification of certain technical systems

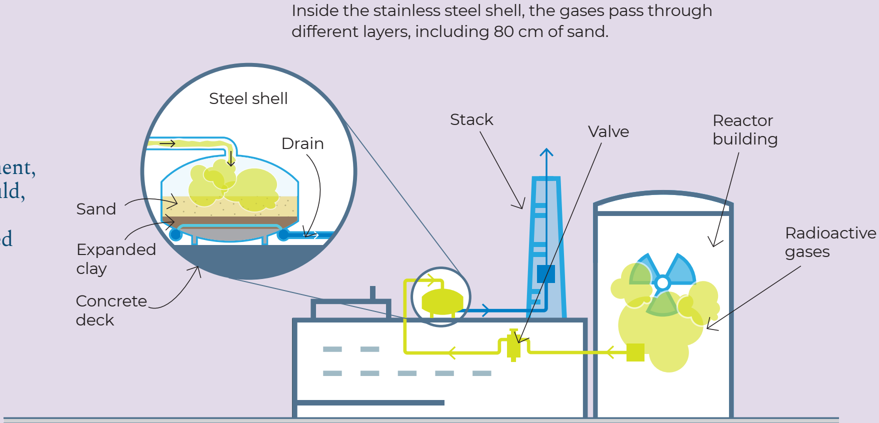
Between 1994 and 2008, ASN sought the opinion of IRSN and the Advisory Committee for Nuclear Reactors concerning technical modifications, of which the main ones adopted are listed below

- **enhanced reliability of commanded opening of the pressuriser relief valves on the 900 MWe** reactors: the aim of this modification was to limit the risks of reactor vessel melt-through, particularly in the event of core meltdown further to a total loss of the electrical power supplies;
- **installation of passive autocatalytic recombiners** on all the reactors (installation completed in 2007);
- **improvement in the closing system of the equipment hatch (TAM)** for the 900 MWe reactors in order to improve the leak-tightness of the TAM, a containment weak point, to obtain a pressure of about 8 bars;
- **installation of hydrogen detection and reactor vessel corium melt-through detection sensors on the 900 MWe reactors in order to have, in the event of a severe accident, information on the how the situation is evolving.**

A major step forward

Filtration of the air in the reactor containment

In the event of an accident, should an increase in pressure threaten to damage the containment, the depressurisation system would, as a last resort, enable the gases in the containment to be released after filtration. The filter is capable of retaining some of the radioactivity and thereby mitigating the environmental consequences of the accident.



Chernobyl, the ultimate disaster

The Chernobyl accident resulted from a convergence of events combining human errors and faults in the design of the NPP. A test sequence on the emergency electrical power supply of reactor 4 was to turn into a major catastrophe and raise worldwide awareness of the risks associated with nuclear power.

The RBMK reactor

This is a Soviet-designed high-power reactor. It is a graphite-moderated reactor that uses boiling light water as the coolant. The fuel is uranium oxide enriched with uranium-235. Each fuel assembly is contained in a "pressure tube" within which the coolant fluid circulates. The major drawbacks of this type of reactor are the complexity of the cooling fluid distribution and collection system, the large build-up of thermal energy in the metal structures and in the graphite, the absence of reactor containment and the difficulty in controlling the reactor core. Eleven RBMK reactors were still in operation in 2023, all located in Russia.

What happened on 25 April 1986 in the building of reactor 4 (RBMK reactor) of the V.I. Lenin NPP situated 18 km from Chernobyl, in Ukraine?

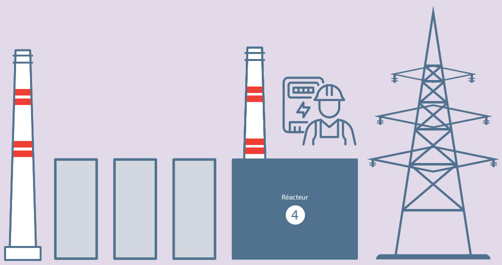
A test was to be carried out to check the possibility of energising the reactor recirculation pumps *via* a turbogenerator set if the electrical power supply failed. This test was to be carried out at about 20% to 30% of the nominal power level.

25 April 1986

The operators started the procedure to lower the power to the level required for the test.

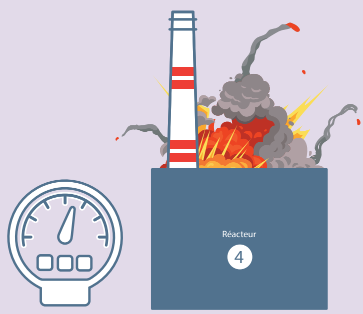
However, at the request of the electrical power distribution centre, the reactor was maintained during the day at a higher power level than that required for the test. At 23:00 (11 pm), the operators started to reduce the reactor power level to attain the test conditions but could not stop the power reduction. They therefore decided to withdraw the control rods, beyond the authorised limits, in order to raise the power level. At 01:00 (1 am) on 26 April, the reactor power stabilised at a level significantly below the required level. The team nevertheless decided to perform the test.

THE ACCIDENT



25 april 1986

Test linked to the electrical power supply of reactor 4. The safety conditions were not observed.



26 april 1986

The uncontrolled increase in power led to an explosion of the reactor and a graphite fire.

See glossary pages 33 to 36

"Chernobyl confirmed that a major nuclear accident could occur with consequences affecting several countries: in this case Ukraine, Russia and Belarus, as well as a large part of Europe. This led to the widespread realisation that it was necessary to have an international approach to nuclear safety issues."

Pierre-Franck Chevet
ASN Chairman from 2012 to 2018

26 April 1986, between 1:03 and 1:07 am

Two additional recirculation pumps were put into service. The additional flow caused the temperature in the heat exchangers to rise. At 01:19, to stabilise the water inflow to the moisture separators, the power of the pumps was further increased and exceeded the authorised limit. The system requested an emergency shutdown, but the signals were blocked and the operators ignored the request.

26 April at 1:23:04''

The test began: the turbine steam supply valves were in closed position. The recirculation pumps slowed down and the flow rate decreased.

The core temperature rose, causing – due to the design of the reactor – an increase in the reactivity. The reactor power increased uncontrollably.

26 April at 1:23:40''

The chief operator ordered emergency shutdown. All the control bars started to descend into the core, but produced the opposite effect to that expected. The power again increased uncontrollably.

26 April at 1:23:44''

The power peak was reached, exceeding more than 100 times the nominal power of the reactor. The high pressures in the pressure tubes caused them to rupture. An explosion raised the upper plate of the reactor, weighing 2,000 tonnes.

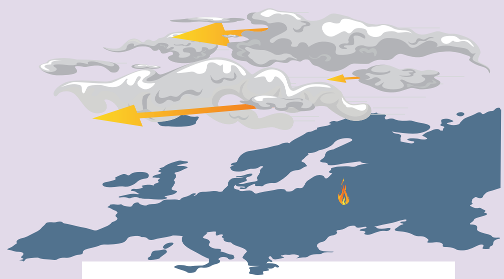
The upper part of the reactor core was exposed to the open air. The graphite caught fire, and several fires broke out in the facility. It took the firemen three hours to put out these fires. The graphite fire restarted. It was not definitively extinguished until May 9.

From 27 April to 10 May 1986

5,000 tonnes of materials (sand, boron, clay, lead, etc.) were transported by helicopter and released onto the reactor with the aim of covering it to reduce the air flow feeding the graphite fire and the release of radioactive emissions.

CONSEQUENCES

The explosion destroyed a large part of reactor 4 and of the turbine hall and intermediate constructions.



A radioactive cloud was released into the atmosphere. Driven by the winds, it crossed part of Europe ***(see box on page 20).***

4,000 people[1]
could ultimately die as a result of radiation exposure further to the accident

116,000 people[2]
evacuated from the zone in 1986 (30 km radius around the NPP)

24,000 years
The lapse of time necessary before humans can once again live in Chernobyl

240,000 "liquidators[2]",
both civil and military, worked on the first sarcophagus and decontamination of the soils in 1986 and 1987.

The causes of the accident, from the power plant design to post-accident management, are numerous and all equally serious.

- **The design of the NPP did not meet safety requirements.**
- **The RBMK reactor is naturally unstable in certain situations.** These situations were not explicitly mentioned in the operating documents. What is more, the emergency shutdown system has adverse effects in certain situations.
- **The test which caused the accident was not conducted in compliance with the planned conditions** and the safety rules were deliberately breached.

The situation was aggravated by the lack of a post-accident management strategy: minimisation of the accident to begin with; late evacuation of the neighbouring populations (116,000 people evacuated in 1986, then 220,000 people in the following years); requisitioning of firemen and "liquidators" (recovery workers), without providing appropriate protective equipment; construction of an ineffective sarcophagus (shelter structure), etc.

Even today, the human and environmental consequences remain difficult to evaluate.

Over and beyond the 30 deaths[3] among the liquidators during the first few weeks, the 6,000 cases[1] of thyroid cancers in children and adolescents, the 340,000 people rehoused[2], the human consequences are difficult to assess with precision and have been the subject of controversy. The toll is very heavy, multifaceted and still forms the subject of numerous studies.

This disaster revealed the weakness of the oversight of safety by the Soviet Union's safety organisations.

There has been no evidence of excess cancers in France due to fallout from the accident.

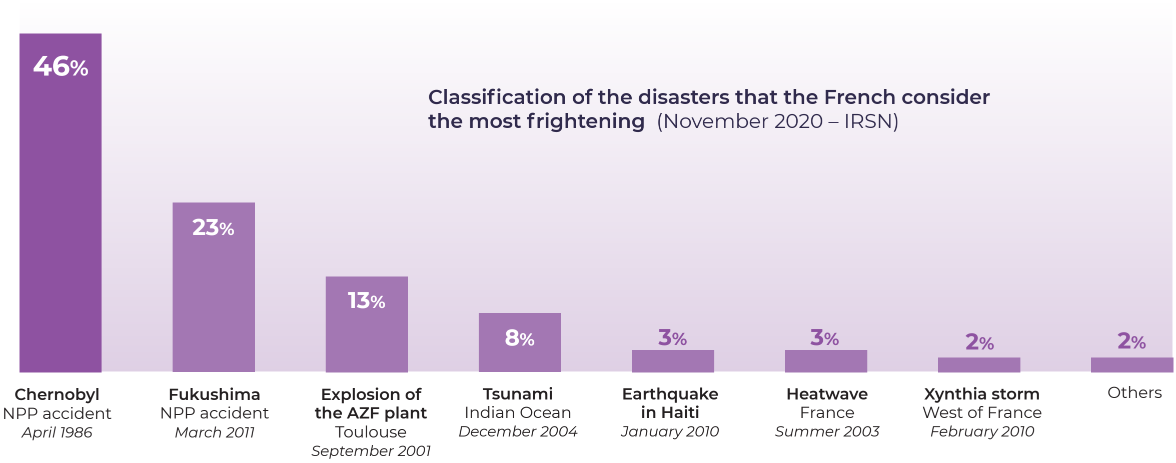
1. Source: AIEA – September 2005 Some NGOs denounce this number which they consider to be below the true figure.
2. Source: IRSN
3. Source: UNSCEAR

ACTIONS TAKEN

25 April – 5 May 1986
Sand, clay and lead were dropped onto the reactor to control the fire and an emergency containment enclosure (first sarcophagus) was installed.

See glossary pages 33 to 36

*The first nuclear accident to be rated at the maximum level on the INES scale, Chernobyl bears its title of **ultimate disaster**, not only because it raised international awareness of the consequences of a nuclear accident, but also because the collective memory – and the French are no exception – classifies it as the most frightening event of all time.*



An unprecedented impact on the public opinion[4].

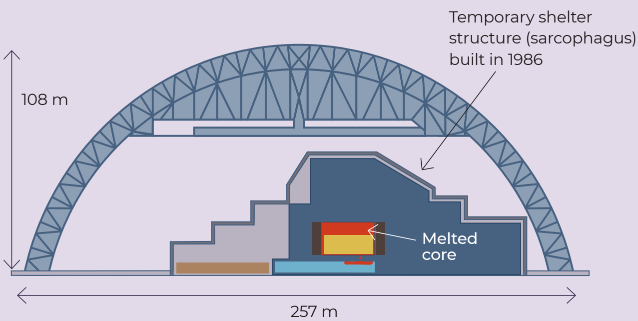
The two disasters that French citizens consider the most frightening are the Chernobyl and Fukushima nuclear accidents. Firstly, as the surveys succeed one another, the predominance of Chernobyl is being confirmed. Secondly, the surveys conducted since 2011 show that as the Fukushima becomes more distant in time, the Chernobyl accident becomes increasingly predominant in the responses.

4. Source: IRSN barometer 2021

In 1987, the Parliamentary Office for the Evaluation of Scientific and Technological Choices (OPECST) published a report on the consequences of the Chernobyl NPP accident.
One of the recommendations in this report was the creation of a national nuclear safety agency. The creation of the High Council for Nuclear Safety and Information (CSSIN) was enacted by Decree on 2 March 1987.

Up until January 2016

Tens of thousands of "liquidators" have worked in the area over the years.



An overall cost of more than 2 billion euros

2018 – 2019

A structure called the New Safety Confinement (NSC) or New Shelter, has been built over the reactor, and was officially commissioned in its final location in July 2019.

How have nuclear safety and radiation protection evolved further to the **Chernobyl** accident?

The purely technical lessons were limited, but the Chernobyl disaster gave rise to the need for information transparency, a safety culture, emergency management preparedness and international concertation.

The Convention on Nuclear Safety was adopted internationally

Adopted on 17 June 1994 in Vienna, Austria, further to the Chernobyl accident, the Convention on Nuclear Safety (CNS) aims to commit the NPP licensees to maintaining a high level of safety by establishing fundamental safety principles to which the States subscribe. The Convention obliges the parties to submit reports on the implementation of their obligations to a "peer review" during meetings held at the head office of the IAEA.

The coordination of the public authorities was improved in France

The measures taken to make nuclear safety progress included: an interministerial circular of 1989[5] organising the coordination of the public authorities in the event of incidents or accidents; the creation of the "Téléray" remote measurements and alert network by the SCPRI (1990); the development of nuclear emergency exercises (1990) and the preventive distribution of iodine tablets (as from 1997) to people living near French nuclear power plants, to prevent thyroid cancers. The PUIs and PPIs were further reinforced and validated by exercises.

Highlighting of the need for transparent public communication

In 1986, the possibility of an accident of the scale of Chernobyl was inconceivable to both the authorities and the public at large. Valentin Faline, director of the Soviet press agency Novosti, explained at the time that *"transparency does not happen overnight. Something very serious has occurred. We had no instructions concerning prevention. Many things were improvised, including in the area of information"*. In France, the Government delegated responsibility for communication to Pr. Pellerin, head of the SCPRI. His communication efforts were clumsy and not very effective. Thus, his press release of 30 April did effectively announce the arrival of the first radioactive fallout in France, stating that its level represented no danger whatsoever, but as the May 1 was a public holiday and the French media were not working, the information was not passed on until 2 May and only by a few media. But he never mentioned a *"cloud that stopped at the border"*.

A cloudy story

The statement "the radiation cloud has stopped at the border" left a deep imprint in the minds of the French and even now, more than 35 years later, there is still a feeling of mistrust regarding information concerning nuclear issues. In truth, no minister, scientist or journalist ever stated or wrote that the cloud "stopped at the French border". Professor Pellerin, responsible for the Government's communication strategy, had declared *"we do not necessarily have the same measurements on either side of the border"*, and this relatively ambiguous phrase was misinterpreted.

5. Circular DGS/PGE/1B No. 1561 of 16 October 1989 concerning information on the administration of stable iodine to the population in the event of a nuclear accident.

See glossary pages 33 to 36

Development of systems for informing the public

The Chernobyl accident revealed the absence of public communication tools in France. The French public had to wait 13 days before learning that France had not been spared by the radioactive cloud. Yet regulatory texts had been drawn up since 1973 and means put in place to inform the public about nuclear safety. The SCSIN was thus tasked with organising informing of the public about safety issues For the Chernobyl accident, it published on France's "Minitel" telematics system a nuclear magazine (3614 MAGNUC), which fulfilled this purpose with limited effectiveness. In 1980, the CEA's IPSN opened a documentation centre on nuclear safety, with the aim of facilitating public access to the information available on this subject. But it was not until 2010 that the French national environmental radioactivity measurement network (ASN/IRSN) opened its website. In 1991, the IAEA introduced the INES scale at international level, while in France, in 2006, the "TSN Act" on transparency and security in the nuclear field allowed the creation of the independent body ASN and the French High Committee for Transparency and Information on Nuclear Safety (HCTISN).

Emergence of independent citizens' monitoring associations

- **The Commission for Independent Research and Information on Radioactivity (CRIIRAD)**

Another consequence of the Chernobyl accident was the creation in May 1986 of the CRIIRAD, an expert investigation commission, stemming from the antinuclear movement and accredited for environmental protection. The association's aim is to produce expert assessments and field measurements independently of the public authorities, as a means of combating what it considers to be information blackouts or disinformation on the subject of nuclear energy.

- **Association for the Control of Radioactivity in the West (ACRO)**

Also created further to the Chernobyl disaster in 1986, ACRO is a citizens' association for providing information and monitoring radioactivity, equipped with an analysis laboratory and accredited for environmental protection.

Management of the emergency and post-accident phases

Following the Chernobyl accident, the response organisation was reinforced, both in the installation itself and in its environment. International emergency exercises are regularly organised. Under the auspices of the IAEA, international conventions have been put in place to rapidly inform other countries of any nuclear accident and to improve the assistance logistics. Finally, the management of the long-term consequences of nuclear accidents (decontamination of the environment, mitigation of exposure of persons) has progressed.

Law TSN, art. 19, I

Any person has the right to obtain from the a basic nuclear installation licensee or, when the quantities exceed thresholds set by decree, from the person responsible for a radioactive substance transport operation or the holder of such substances, the information held by these people, whether that information was received or established by them, on the risks associated with exposure to ionising radiation that could result from this activity and on the safety and radiation protection measures taken to prevent or reduce these risks or exposures, under the conditions defined in Articles L. 124-1 to L. 124-6 of the Environment Code.

"Chernobyl was the catalyst for the creation of CRIIRAD and ACRO.
It is therefore an important development. The Chernobyl accident brought a rude awakening to the reality of nuclear risks and changed the debate on the subject with the rise of the 'green' movements In my opinion it is a change that culminated in 2006 with the TSN Act (editor's note: Act on Transparency and Security in the Nuclear Field)."

Yves Marignac
Consultant on nuclear power and the energy transition within the négaWatt group

Épinal hospital, the risks elsewhere than in nuclear facilities

In 2005, France discovered its most serious ever medical accident involving ionising radiation, when cancer patients undergoing radiotherapy treatment received excessive doses of radiation, with severe clinical consequences. The investigation revealed several dysfunctions in the delivery of the radiotherapy treatment, as well as a lack of understanding of the treatment protocols.

"ASN has ensured the oversight of medical applications of ionising radiation since 2002. After having put in place entirely new regulations in the area of patient radiation protection, ASN realigned its inspection programme on radiotherapy treatment safety as of 2007."

Jean-Christophe Niel
Former Director-General of ASN
Director-General of IRSN

What is dosimetry?

Dosimetry in radiotherapy is the calculation of the radiation doses to apply to the area to treat and the treatment duration. Scientific studies have determined the radiotherapy doses to administer according to the type and stage of the cancer, the organ to treat, the age of the patient and their prior treatments. These are standard doses. The radiation oncologist also specifies the acceptable dose limits for the organs at risk situated near the tumour. As well as determining the types of rays to use and the size and direction of the beams, the dosimetry phase also involves determining, by a computerised study, the distribution of the radiation dose to apply to the area to treat to optimise the irradiation and treatment of the tumour while sparing the neighbouring healthy tissues.

Source: INCa

In early 2005, an unexpected frequency of complications linked to radiotherapy treatments carried out at the Jean Monnet Hospital in Épinal was discovered, concerning in particular 24 patients treated for prostate cancers between May 2004 and August 2005.

This serious accident, rated 7 on the ASN-SFRO scale, was attributed to incorrect utilisation of the treatment planning software: in May 2004, the radiotherapy protocol for the treatment of prostate cancers was modified to get the best out of the possibilities of the dosimetry software. This change also implied modifying the parameters used in the calculation of irradiation intensity, which was not done for some of the patients. Having discovered, as of January 2005, more frequent complications than expected, the use of this protocol was finally stopped in August 2005.

Serious human consequences

Of the 99 patients treated using this protocol between May 2004 and August 2005, 24 received a dose that was 20 to 30% higher than the prescribed dose. Twelve of these patients suffered from severe radiation-induced complications, such as intense pain and radiation necrosis lesions causing fistulas, discharges or haemorrhaging necessitating repeated blood transfusions. Ten of these patents died as a result of these complications. The other patients were affected less severely.

The patients and their families expressed the feeling of having been abandoned, having received no social, economic or psychological support.

The inquiry revealed other dysfunctions leading to significant overdoses.

Between 1989 and 2000, a problem with the parameter settings of another treatment planning software, designed and produced in-house, led to slightly longer irradiation times. Of the 5,000 cancer patients treated at the Épinal hospital centre during this period, about 300 received a dose excess of more than 7%. Two of these patients died as a result of the complications resulting from the treatment. This parameter setting error was corrected in 2000.

Between October 2000 and October 2006, the failure to take into account in the dosimetric calculation the irradiation delivered when taking images to check positioning led to overdoses of 8 to 10% with respect to the prescribed dose for 409 patients. Two of these patients died as a result of the complications resulting from the treatment.

See glossary pages 33 to 36

“The Épinal accidents played a major role in our relations with the medical sector.
Our rigorous intervention enabled us to establish a close collaboration with the French Society for Radiation Oncology (SFRO). Patients died at Épinal, but many of the survivors suffered horrific and often irreversible damage. And this happened in Épinal, barely 60 km from the major radiotherapy centre of Nancy, a very large centre where the Épinal hospital radiotherapists, had they recognised their shortcomings and been organised, could have ‘realigned’ their practices.”

André-Claude Lacoste
ASN Chairman from 2006 to 2012

A chain of dysfunctions

The effects of the accident were minimised by the hospital personnel concerned.

The authorities were not informed of the true nature of the problems within the required time. Moreover, there were no organisational barriers serving to prevent this accident and manage its health consequences.

Radiotherapy uses ionising radiation to destroy cancer cells.
The ionising radiation necessary for the treatments is either produced by an electric generator or emitted by radionuclides in sealed sources.
There are two different techniques: external-beam radiotherapy (the radiation source is external to the patient), and brachytherapy (the source is introduced into the patient and positioned as close as possible to the area to treat).

409 patients
were concerned by the radiation overdoses between 2001 and 2006. They were all treated for prostate cancer and 66 of them suffered severe complications. It is the cohort of 24 patients treated from 2004 to 2005 which was the most severely affected, with ten deaths.

ASN-SFRO scale for classifying nuclear incidents and accidents in the medical field and radiation protection events, developed in July 2007 by ASN in collaboration with the French Society for Radiation Oncology (SFRO). Like the INES scale, the criteria for classifying an event concern not only the confirmed consequences but also the potential effects of the events.

APPLICATION OF THE ASN-SFRO SCALE	EVENTS (unplanned, unexpected)	CAUSES	CONSEQUENCES (grades CTCAE V3.0)
Accident 5 to 7	Death.	Dose (or irradiated volume) very much higher than normal, leading to complications or sequels incompatible with life.	Death.
Accident 4	Serious event jeopardising life, complication or disabling sequel.	Dose or irradiated volume very much higher than tolerable doses or volumes.	Serious, unexpected or unpredictable acute or latent effect of grade 4.
Incident 3	Event causing severe deterioration of one or more organs or functions.	Dose or irradiated volume higher than tolerable doses or volumes.	Severe, unexpected or unpredictable acute or latent effect of grade 3.
Incident 2	Event causing or likely to cause moderate deterioration of an organ or function.	Dose higher than the recommended doses, or irradiation of a volume that can lead to unexpected but moderate complications.	Moderate, unexpected or unpredictable acute or latent effect of grade 2, with minimal or zero deterioration in quality of life.
Event 1	Event with dosimetric consequence, but no expected clinical consequence.	Dose or volume error: for example, dose error or target error during one session, that cannot be compensated for over the duration of the treatment.	No symptoms expected.
Event 0	Event with no consequences for the patient.	For example, patient identification error with a patient treated for the same pathology (can be compensated for).	

If several patients die:
- the minimum level 5 is increased to 6 if the number of patients is greater than 1 and less than or equal to 10;
- the minimum level 5 is increased to 7 if the number of patients is greater than 10.

If the number of patients is greater than 1, a + sign is added to the chosen level (example: 3 becomes 3+).

How has the radiation protection of patients and medical personnel evolved further to the **Épinal** accident ?

In its 2006 report, ASN underlined that *"the importance of the organisation factor in risk prevention is poorly known. Our health system approves people and structures if, on a given day, they satisfy requirements concerning skills and resources, but once these requirements have been satisfied, it shows no further concern for the satisfactory overall functioning. Yet skills are not acquired forever, equipment ages and the use of approximate methods can render costly resources inefficient".*
The tone was set and the measures that were taken radically changed this situation.

"The Épinal events were a catalyst for radiation protection. In a way it was radiation protection's Chernobyl.

Just after the Épinal case, I was astonished that the discussions at the Ministry of Health revolved around legal questions and the financial impact.

The health professionals, who were opposed to anything that resembled an inspection, especially coming from non-medics, adopted a more flexible attitude. They had to face patients who were worried.

It must be pointed out that on average 180,000 people per year follow a radiotherapy treatment, therefore statistically the risk of an incident remains very low.

Remarkable work has been carried out internationally on the notification of events in radiotherapy. We started out with the model used in the nuclear industry, the scale of severity applied in the nuclear installations, namely defence in depth.

The other important event which followed on from the Épinal accident was the seminar organised in Versailles in 2009 ***(see box p. 25)***. We managed to get patients who had been victims to take part in a round table with medical professionals. This exceptional moment of dialogue was a very moving experience. It represented a ground-setting event, in the presence of Roselyne Bachelot who was Minister of Health and Sport at the time."

Jean-Christophe Niel
Former Director-General of ASN
Director-General of IRSN

In November 2007, after the Épinal accident, the Minister of Health and Sport announced national measures to guarantee the safety and quality of radiotherapy procedures. These measures provided a way out of a health crisis and a means of approaching the transition period (2009-2010) before the deadline for bringing all the radiotherapy centres into compliance (2011).

Human resources and training

- Continue the efforts to train and recruit medical physicists in the field of radiotherapy.
- Train a sufficient number of interventional radiology radiographers in the operating theatres for the fluoroscopy guided procedures.
- Render obligatory the presence of a medical physicist from the start to the end of the treatment.

The safety of the facilities

- Render obligatory the installation of a device indicating the radiation dose emitted (feasibility) for the interventional radiology devices put into service before 2004.
- Evaluate the quality of practices at national level, in both radiotherapy and medical imaging; *in vivo* dosimetry (real-time dose measurement); double calculation of monitor units, tighten the methods for checking that the beam delivers the expected dose, and render obligatory this precaution – which already existed at the time of the Épinal issue.

Relations with the patients and the various audiences

- With the patients' associations, continue the information drives on the radiotherapy treatment safety, based on the conclusions of the ASN conference in Versailles (2009).
- Inform the patients about the benefits of medical imaging and the associated risks, and involve them in the decisions.

See glossary pages 33 to 36

"The Épinal accident sent shockwaves through the world of radiotherapy, which until then had been considered very safe. The international conference on patient radiation protection that we organised in 2009 provided the opportunity to review the state of knowledge of the risks associated with radiotherapy. It ended with a moment of intense emotion when the chairman of an association of victims of the Épinal accident gave his testimonial before more than 200 people on the pain experienced by the victims. This was followed by a debate on the informing of patients, which highlighted the shortcomings in the doctor-patient dialogue. The Chairman of the French Society of Radiation Oncology (SFRO) then pointed out that the physicians unfortunately were not well trained in discussing things with patients and each person did the best they could."

Jean-Luc Godet

Director of the Ionising Radiation and Health Department of ASN from 2006 to 2019

The notification of significant events to ASN

Radiation safety oversight is based on incident reports which are sent to the authorities by the health professionals. Two radiation safety oversight systems coexist in the field of radiotherapy:

- medical devices vigilance, which comes under the remit of the AFSSAPS (French Health Products Safety Agency), concerns the incidents or risks of incidents involving medical devices during their use. The Public Health Code now specifies that the persons/entities responsible for a "nuclear activity" are subject to an obligation to notify ASN and the State representative in the département of *"any incident or accident in the area of radiation protection that could jeopardise peoples' health by exposure to ionising radiation"*;
- the obligation for health professionals involved in the treatment or follow-up of patients exposed to ionising radiation for medical purposes, who are aware of an incident or accident linked to this exposure, notify it without delay to ASN and the Director General of the Regional Health Agency – ARS (Act of 21 July 2009).

Quality assurance obligations

The errors committed at Épinal included a lack of preparation of the operators for the change of software and protocol, and failure to inform the public. ASN has tightened the regulations since then by detailing the quality assurance obligations. The aim of the regulatory requirements is to develop the safety culture and the integration, in the organisation of the radiotherapy departments, of management of the risks run by patients. For the radiotherapy centres, the main obligations concern the setting up of a quality management system (QMS), a senior management commitment under the QMS; the accountability of the personnel; the analysis of the risks run by the patients during the radiotherapy process; keeping a record of and addressing adverse situations or dysfunctions, from the organisational, human and material aspects. To accompany these regulatory changes, ASN has published a *Guide to the management of safety and quality of radiotherapy treatments*, and a *Guide to the self-assessment of the risks run by external-beam radiotherapy patients* (available in PDF format on the ASN website).

International conference on patient radiation protection in radiotherapy

With the support of the World Health Organisation (WHO), the IAEA and the European Commission, and the participation of a large number of professional bodies and associations and patients' associations, ASN organised the first international conference on patient radiation protection in the field of radiotherapy, held in Versailles from 2 to 4 December 2009.

Among the major conclusions, the prime position of radiotherapy in the treatment and curing of cancers was reasserted; operator training had to be reinforced and the first utilisations of these techniques should undergo an independent assessment by the professionals. Systems for notifying significant events should be developed with the aim of analysing events and establishing incident learning systems; the involvement of patients and their associations was found to be desirable in the assessment of treatment quality and safety and in the areas of risk management and communication.

A special issue of Contrôle *magazine is available in PDF format on the asn.fr website*

Fukushima, the inevitable disaster scenario

The Fukushima Daiichi Nuclear Power Station (NPS) was equipped with six boiling water reactors (BWRs). An earthquake of exceptional intensity triggered a domino effect leading to the destruction of four nuclear reactors.
The lessons learned from this disaster, rated level 7 – the most severe level on the International Nuclear Events Scale (INES) – contributed greatly to the improvement of the safety of nuclear facilities in France and across the world.

The BWR reactor

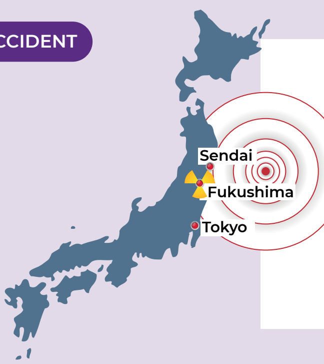
The Fukushima Daiichi NPS was equipped with six BWRs. These reactors owe their name to the fact that the heat released by fission boils the water in which the fuel cladding in the reactor core is immersed. The steam produced expands in the turbines which produce electricity. At the time of the accident, only reactors 1, 2 and 3 were in operation (the others were shut down).

11 March 2011, 14:46 – The event that triggered the disaster: an exceptional earthquake

Japan was hit by the most intense earthquake in its history, with a registered magnitude of 9.1 on the Richter scale. The epicentre was situated out at sea, 130 km offshore of the north-east coast. The electrical power supply of the Fukushima Daiichi NPP was damaged by the earthquake and the backup power supply took over. The three reactors in operation were immediately shut down by the automatic safety systems (reactor trip, emergency cooling), and the cooling procedure began normally.

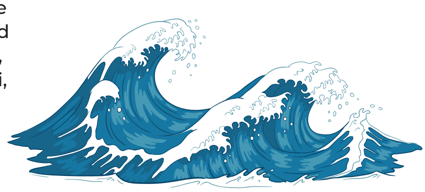
Less than one hour later, at 15:41, the tsunami caused by the earthquake reached the coast and the Fukushima site.
The wave caused by the earthquake reached up to 15 m in height, devastated 600 km of shoreline and travelled up to 10 km inland. The facility, built to withstand an earthquake of magnitude 8 and a 5.7-metre-high tsunami, was entirely flooded. The tsunami damaged the water intakes in the sea, which led to loss of the heat sink and the cooling pumps, thereby depriving the reactors and the spent fuel pools of their normal cooling sources. The water then entered the buildings housing the emergency diesel generator sets and

THE ACCIDENT



11 March 2011

An earthquake, whose epicentre was situated 130 km east of Sendai, followed by a tsunami, hit Japan near the Fukushima Daiichi NPP.



See glossary pages 33 to 36

"There can be no grounds for complacency about nuclear safety in any country.
Some of the factors which contributed to the Fukushima Daiichi accident are not specific to Japan.
A permanently critical approach and the ability to learn from experience is the foundation of the safety culture and essential for anyone working in the nuclear energy sector. Safety must always come first."

These words from Yukiya Amano, Director General of the IAEA from 2009 to 2019, illustrate what inspired ASN's reflection and decisions to improve the safety of nuclear facilities in France.

the electrical switchboards, so these were also lost. Further to the loss of the diesel generator sets and the batteries, the operators no longer had any reliable information on the emergency cooling systems. As time went by these systems stopped functioning: with no means of cooling available, core meltdown was inevitable.

The meltdown of the reactor cores caused explosions due to the hydrogen concentration in the reactor buildings. In effect, owing to the lack of cooling, the water in the reactor vessel turned into steam and the fuel cladding temperature rose to more than 1,200°C. The zirconium making up the fuel cladding then oxidised and this reaction produced hydrogen. On contact with air, the hydrogen under pressure caused violent explosions.

The intentional depressurisation operations undertaken by licensee to limit the pressure in the reactor containments led to the first releases of radioactive substances into the environment. The hydrogen explosions contributed to the release of massive quantities of gaseous radioactive effluents. Then, having lost containment integrity, the contaminated water present in the reactor buildings led to the release of large volumes of liquid radioactive effluents. Managing the effluents and radioactive liquid releases became a major site management challenge.

12 March 2011, explosion in the reactor 1 building

The building housing this reactor collapsed following a hydrogen explosion.

14 March 2011, explosion in the reactor 3 building

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

15 March 2011, explosion in the reactor 2 building, then in the reactor 4 building

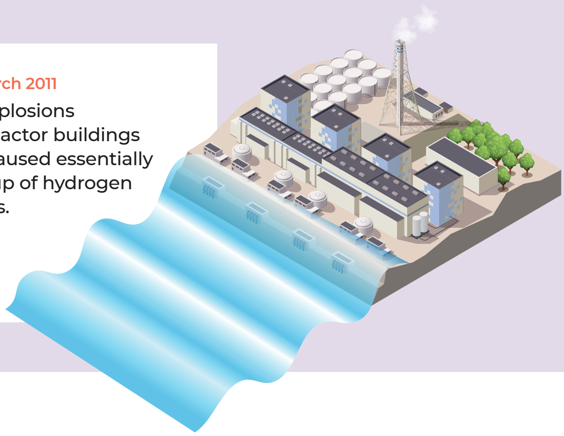
The explosion was once again caused by the hydrogen which had built up in the reactor 2 building. For reactor 4, the roof of the spent fuel pool was blown off, probably due to a hydrogen explosion from reactor 3.

Overheating of the spent fuel pools

Alongside this, the pools of reactors 1 to 4, in which the spent fuel was stored, were no longer cooled due to the failed electrical power supply. As the spent fuel continued to give off heat, the temperature of the water of the reactor 3 and 4 pools continued to rise to boiling point, causing the water level to drop. Despite the explosions and the loss of cooling, the pools and the spent fuel did not suffer any significant damage. It was possible to supply the pools with makeup water.

12, 14 and 15 March 2011

Successive explosions occurred in reactor buildings 1, 3, 2 and 4, caused essentially by the build-up of hydrogen in the reactors.



Fukushima: establishing the final outcome of the nuclear accident is complex

Although no health consequences linked to radioactivity have been observed directly, the toll for the tsunami totals 18,000 deaths and more than 2,000 missing persons. UNSCEAR issues regular reports on the psychological, environmental and financial impacts of the industrial accident.

How have nuclear safety and radiation protection evolved further to the **Fukushima** NPP accident?

Within a few days after the accident, resources were mobilised at national, European and international level to learn lessons from it. In France, 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.

1,500
media queries

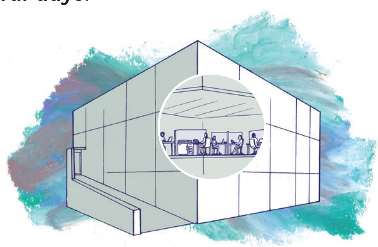
36
press releases

17
press briefings
(between 12 March and 4 April 2011)

700,000
connections to the ASN website

Creation of an operational "hardened safety core"

The aim was to put in place new items of equipment enabling the nuclear facilities to withstand degraded situations and function independently for several days.



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 when designing the NPP earthquake, flooding (including very heavy rain), wind, lightning, hail and tornadoes. This "hardened safety core", which is intended to prevent an accident with fuel melt and to limit 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 1,300 MWe reactors beyond 40 years and the 1,450 MWe reactors beyond 30 years. Some of this equipment is already in place, such as the ultimate backup generating set.

"I am very proud of what ASN has done concerning Fukushima. We had been preparing ourselves for the management of a major crisis for years, and we rose to the challenge. Especially given the fact that the licensee was geographically distant. I immediately declared the incident to be level 6 on the INES scale – whereas the Japanese were still rating it level 3 or 4 – and my assessment was passed on in the media and deemed authoritative by my foreign colleagues. The confidence that my counterparts placed in me in this respect was really very satisfying.

I would add that for me, Fukushima brings back another memory, that of the IRRS mission – which serves to assess the regulatory infrastructure of a country in terms of nuclear safety – I conducted for the IAEA in Japan in 2007,. The mission concluded with report that was critical, but not as critical as I would have liked it to be. It nevertheless asked for an in-depth over-haul of the Japanese authority competent for nuclear safety. The Japanese never requested the follow-up mission which, as its name implies, examines the follow up to conclusions of the report. I learned that the Japanese government itself had decided not to give a follow-up to the report."

André-Claude Lacoste
ASN Chairman from 2006 to 2012

See glossary pages 33 to 36

"The stress tests prove that things can move forward when everyone does their bit. It was a new idea and everyone bought into it. It is all the more miraculous given that it is never easy to reach a consensus in international bodies."

Olivier Gupta
ASN Director General since 2016

Birth of the stress tests concept

The concept emerged during a meeting of WENRA, the Western European Nuclear Regulators' Association, held in March 2011 in Helsinki, a fortnight after the Fukushima Daiichi NPP accident.

The term stress tests was taken from the financial sector, in reference to the bank stress tests following the 2008 financial crisis.

Olivier Gupta was present as Chairman of the WENRA Reactor Harmonization Working Group (RHWG). He recalls the scene: "*The word has just been pronounced by Günther Oettinger, European Commissioner for Energy. Nobody had asked anything of us, but we said to ourselves: it's up to us to give him some intelligent content to try to do something with it. The idea was to say: finally, what happened at Fukushima? They lost all the external cooling sources, what we call the heat sink. They lost all the external and internal power supplies. And there were core meltdowns*".

The incidents at Fukushima were caused by the tsunami and it is highly improbable that this would happen in Europe. It was not a question of thinking about why things happened, but just considering the input data: total loss of electricity, loss of cooling, and core meltdown, as a starting point for the reflection.

There were numerous questions: what would happen in the European NPPs? How much margin do we have? That is to say how far are we from a situation that becomes catastrophic with massive releases? How much time do we have to act? There you have the basic philosophy of the stress tests, these are the questions that one asks.

"I started out with a blank sheet of paper and two words – stress tests, rather like when you sit a philosophy exam. Everything was finished in about three weeks. This "miracle" reflects the context specific to WENRA. Year after year, we have established sufficient confidence between the participants at the difference levels to be able to move forward on difficult subjects such as this one, without conflict in a concerted and constructive manner".

Stress tests

The aim of the stress tests is to determine to what extent the NPPs have safety margins that guarantee their operational safety, even in situations of extreme emergency.

"One of the remarkable things in the wake of Fukushima, was the stress tests episode. After the accident, WENRA held a meeting in Helsinki. Commissioner Günther Oettinger stated: "*We have to conduct stress tests*". He undoubtedly had no idea what they were, but he thought that it was a good way of bothering the others... That was clear. During a WENRA meeting in Helsinki, I proposed to my colleagues to anticipate things by setting up a working group on the spot, to start thinking about what the content of the stress tests could be. It was led by Olivier Gupta (*see opposite*) who started to work that very evening in Helsinki! Fairly rapidly we had a stress tests project. It was subsequently reworked, but it nevertheless served as a basis for the process as a whole. I have warm memories of that period. We reproduced a process somewhat similar to the one created at the start of WENRA, concerning the obligations to be imposed on the Eastern European countries joining the European Union... When you take an initiative, you take it through to its conclusion!"

André-Claude Lacoste
ASN Chairman from 2006 to 2012

Extension of the major advances in safety to all the nuclear facilities in France

The final result of the improvements in the safety of nuclear facilities in France owes a lot to Fukushima. Setting more stringent standards than the level required by Europe, France has maintained a strategy of continuous improvement. Today, the measures taken for all the sensitive sites give an extra margin of three days from the time the accident occurs. This extra margin is crucial.

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 pipes connected to the pool, etc.

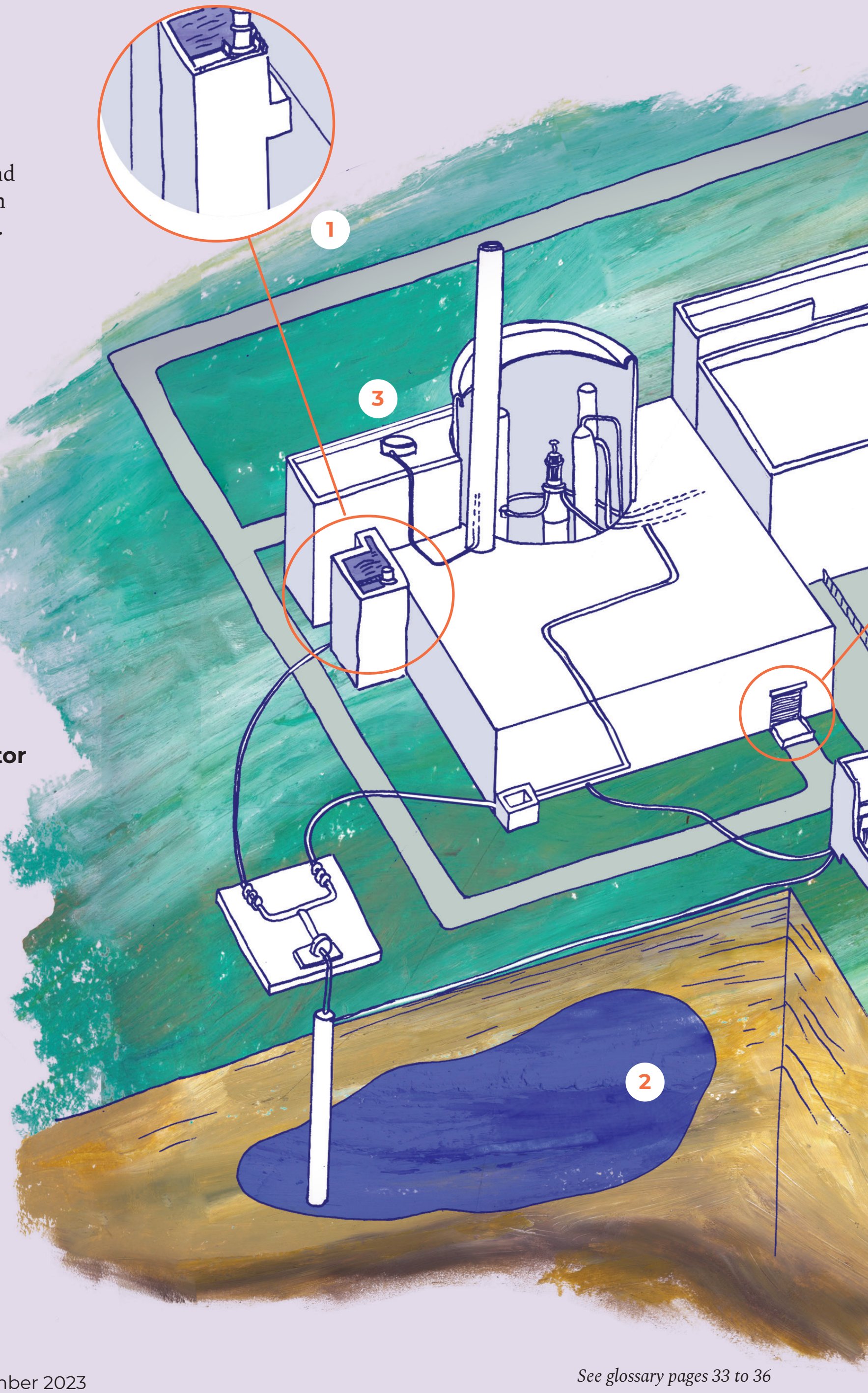
2 Ultimate water source

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 shall be equipped with an ultimate water source. For the last sites, temporary sources have been put in place.

3 Depressurisation of the reactor 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.



See glossary pages 33 to 36

4 **Improvement in site protection against flooding**

The aim is to prevent water entering the buildings of the nuclear platform in the event of extreme flooding. This consists, for example, in installing protective structures in front of the exterior access doors, low reinforced concrete walls, and 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 required it.

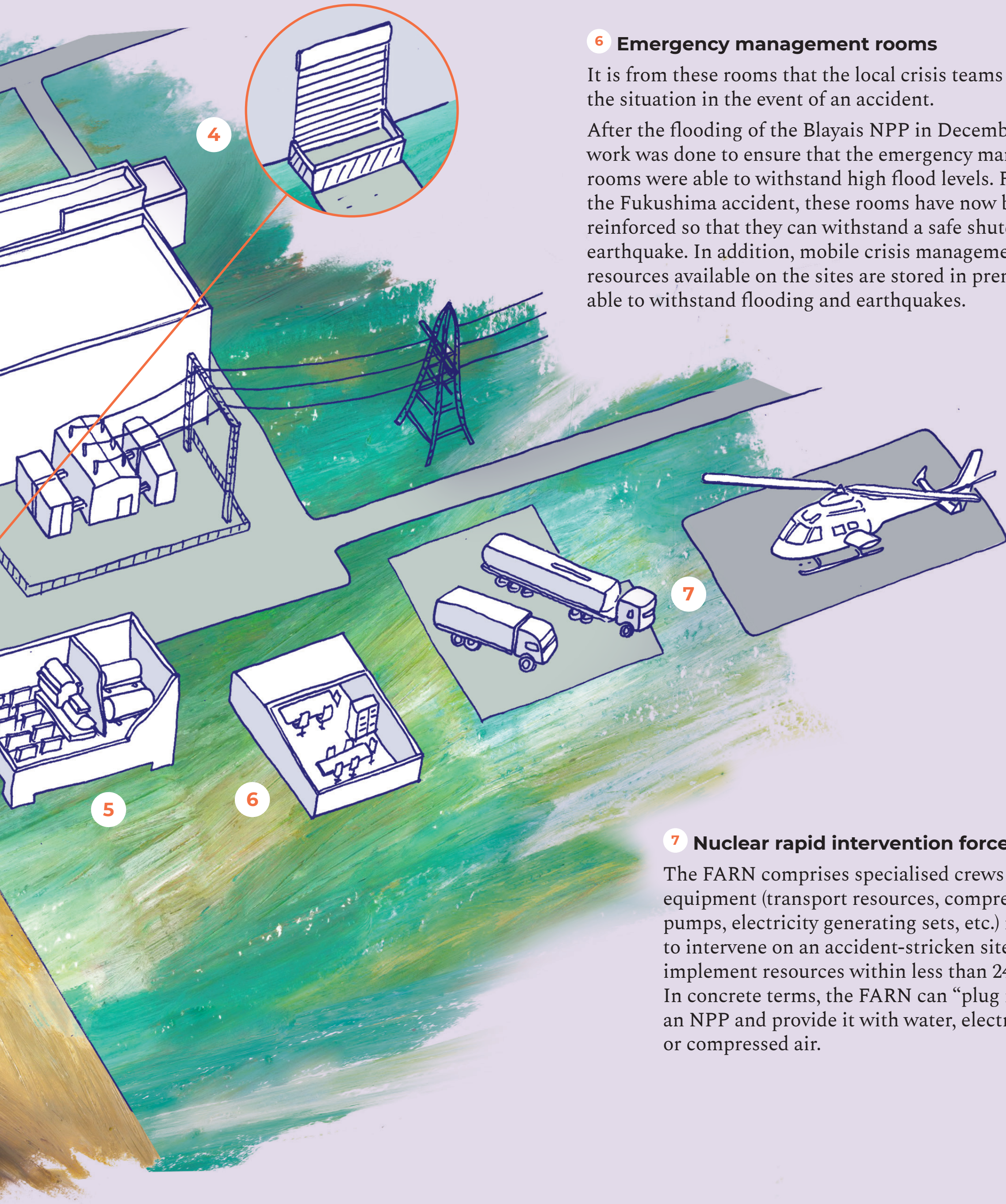
5 **Ultimate backup generating set**

If all the existing back-up electricity resources are lost, the ultimate backup diesel generator set can restore electrical power 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 hazards of extreme intensity (earthquake, flooding, tornado). An ultimate backup generator set is today installed on each EDF reactor in service.

6 **Emergency management rooms**

It is from these rooms that 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. 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.) ready to intervene on an accident-stricken site and implement resources within less than 24 hours. In concrete terms, the FARN can “plug into” an NPP and provide it with water, electricity or compressed air.

POSTFACE

The worst nuclear accident scenario would be to suffer the consequences of the accident and then neglect its causes. Although the collective conscience is now fully aware that there is no such thing as zero risk, prevention and anticipation must better protect us against future accidents, whether major or minor. Prerequisites include the consolidation and adoption by all the stakeholders of a rigorous nuclear safety culture, proportionate to the risks.

The five accidents described and commented on in this publication have all served as lessons which the nuclear regulators and players have used, at national and international level, to create rules, invent new means of protection and innovate in post-accident management.

It is important not to stop at this, but to continually seek to reduce the risks and better inform the public of the means of preventing them and protecting against them. We must therefore remember the past with rigour and remain constantly on the alert. Such is aim of this first issue of the “Cahiers Histoire de l'ASN”.

The ASN History Committee

Glossary

ACRO (Association for Monitoring Radioactivity in Western France) – Created in the wake of the Chernobyl NPP disaster (Ukraine) in 1986, ACRO is a citizens' association for providing information on and monitoring radioactivity, equipped with an analysis laboratory and accredited for environmental protection.

AEC (United States Atomic Energy Agency) – Organisation dissolved in 1974. The regulation functions were then assigned to a new organisation, the Nuclear Regulatory Commission (NRC).

AFSSAPS (French Health Products Safety Agency) – A public institution created in 1999 under the authority of the Ministry of Health, the AFSSAPS set up a health watch and safety system. In 2012, the AFSSAPS changed name to become the ANSM (French Health Products Safety Agency).

AIEA (International Atomic Energy Agency) Intergovernmental organisation created in 1957, with the same legal structure as the United Nations Organisation (UNO), mandated to foster and promote the safe, secure and peaceful use of nuclear technology throughout the world. With 170 member countries, the IAEA is the main forum for cooperation in the field of nuclear activities. Apart from its role in overseeing the commitments made by the countries party to the Treaty on the Non-Proliferation of Nuclear Weapons and assisting its member countries in the use of nuclear technologies, the IAEA produces and keeps up to date a set of nuclear safety standards, encourages their application in the member countries and works to develop international cooperation in order to maintain a high level of nuclear safety and protection of people and the environment against ionising radiation at global level.

ASN (French Nuclear Regulator or "Nuclear Safety Authority") An independent administrative authority (and not a State operator), created by Act 2006-686 of 13 June 2006 on Transparency and Security in the Nuclear Field (the "TSN" Act), ASN ensures, in the name of the State, the oversight of nuclear safety and radiation protection to protect people and the environment against the risks associated with civil nuclear activities.

ASN-SFRO [scale] – (ASN/French Society for Radiation Oncology) – The ASN-SFRO scale is designed for communicating with the public in comprehensible and explicit terms, on radiation protection events leading to unexpected or unforeseeable effects on patients under-going medical treatment by external-beam radiotherapy.

ATPu (Plutonium technology facility) Operated by the CEA (French Alternative Energies and Atomic Energy Commission), the main activity of the ATPu was the production of Mixed Oxide (MOX) fuel, consisting of depleted uranium oxides and plutonium, for nuclear reactors.

BNI (Basic Nuclear Installation) Facility which, due to its nature or the quantity or activity of the radioactive substances it contains, is subject to the Act of 13 June 2006 ("TSN Act") and the Order of 7 February 2012. BNIs must be authorised by decree further to a public inquiry and the opinion of ASN. Their design, construction, operation (when functioning and when shut down) and decommissioning are regulated.

CEA (Alternative Energies and Atomic Energy Commission) – Formerly the Atomic Energy Commission, the CEA is a player in research, development and innovation in the fields of energy, defence, information technology and health. The CEA works in four areas: defence and security, low-carbon energies (nuclear and renewables), technological research for industry, and fundamental research (science of matter and life sciences).

CLI (Local Information Committee) Set up near each French nuclear facility, the CLIs are pluralistic local information and consultation organisations, bringing together the Basic Nuclear Installation (BNI) licensee, ASN, the representatives of the municipalities near the NPP and the local populations, and members of associations. They are tasked with monitoring the impact and the safety of the nuclear power plants and facilities. Each CLI belongs to a federation, the National Association of Local Information Committees (Anccli).

Coolant – Cooling fluid which extracts the heat from the fuel assemblies and transmits it to the turbine as mechanical energy. The coolant used in PWR and RBMK reactors is water, while sodium is used in fast neutron reactors.

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

CRIIRAD (Commission for Independent Research and Information on Radioactivity) Association created under the French Act of 1901, which conducts studies and analyses in the field of radioactivity and is approved for environmental protection.

CSIA (Atomic Facilities Safety Commission) Commission created in January 1960 responsible for examining the safety of the facilities of the Renewables Energies and Atomic Energy Commission (CEA). The CSIA was created in France following an international reflection on the organisation of nuclear safety (counterparts existing in the United States, the United Kingdom and Canada).

Divergence – Start of the chain reaction process in a reactor. Start of the activity of a reactor.

...

...

DGSNR (General Directorate for Nuclear Safety and Radiation Protection) – Created by Decree 2002-255 of 22 February 2002, the DGSNR took over the activities of the Nuclear Installations Safety Directorate (DSIN), the radiation office of the General Directorate for Health (DGS), part of the Office for Protection against Ionising Radiation (OPRI) and the Interministerial Commission on Artificial Radioelements (CIREA). The DGSNR reports to three Ministries: Environment, Industry and Health. It prepares, proposes and implements the government's policy with respect to nuclear safety, with the exception of things concerning defence-related nuclear facilities and activities and radiation protection.

DSIN (Nuclear Installations Safety Directorate) – Entity created in 1991, replacing the Nuclear Installations Central Safety Service (SCSIN), in line with the process to reinforce the oversight of nuclear safety in France. The DSIN was replaced by decree in 2002 by the General Directorate for Nuclear Safety and Radiation Protection (DGSNR).

ECS (*Évaluations Complémentaires de Sûreté* or "Complementary safety assessments", the term used by the French for the stress tests, which they applied with more stringent standards than required by Europe) – Inspection plan decided after the Fukushima Daiichi NPS accident (Japan) in 2011 for the French nuclear facilities, involving an in-depth examination of each facility.

EDF (*Électricité de France* – French Electric Utility) – Licensee of the French nuclear power fleet, producing electricity, ensuring the operation and maintenance of its power plants, and distributing the electricity.

EPR (European Power Reactor) – New type of nuclear reactor incorporating numerous improvements in terms of safety, fuel use and reduced operating costs.

FARN (Nuclear Rapid Intervention Force) Organisation set up further to the lessons learned from the Fukushima Daiichi NPP accident (Japan) of 11 March 2011. It provides external support to sites in difficulty. Its aim is to intervene in the areas of operational control, maintenance and logistics on a site in a severe accident situation, to restore water and electricity supplies in less than 24 hours, with the start of intervention within 12 hours, in order to:
– limit the deterioration of the situation;
– avoid core meltdown if possible.

Fast neutron reactor – Designed to use fissile material (uranium and plutonium) as the nuclear fuel, more completely than in the thermal-neutron reactors. The cooling fluid can be a liquid metal such as sodium or helium. It has the advantage of being able to produce fissile material (breeder reactor) or, on the contrary, incinerate long-lived waste (actinides).

HCTISN (High Committee for Transparency and Information on Nuclear Security) An independent body created by the Act of 13 June 2006, the HCTISN is the cornerstone of the nuclear security transparency to which the public are entitled. The HCTISN is a pluralistic body comprising all the stakeholders of the world, in all its diversity: nuclear facility licensees, the French nuclear regulator (ASN), the French Institute of Radiation Protection and Nuclear Safety (IRSN), State services, Local Information Committees (CLI), associations, syndicates, parliamentarians and qualified personalities.

INCa (French National Cancer Institute) State health and scientific agency tasked with coordinating the actions to fight cancer. Created by the Public Health Act of 9 August 2004, INCa is placed under the joint authority of the Ministry of Social Affairs and Health and the Ministry of Higher Education and Research.

INES [scale] – (International Nuclear and Radiological Event Scale) – Following the Chernobyl NPP accident in 1986 (Ukraine), and in order to help the public and the media understand the severity of a nuclear incident or accident immediately, a scale of severity was created, similar to the Richter scale which indicates the intensity of earthquakes. Used internationally since 1991, the INES scale comprises 8 levels from 0 to 7. Levels 1 to 3 correspond to "incidents and levels 4 to 7 to "accidents". The INES scale applies to any event occurring in the civil and military Basic Nuclear Installations (BNIs), and in the transport of nuclear materials. Application of the INES scale to BNIs is based on three classification criteria:
• the consequences of the event outside the site, that is to say the radioactive releases which can affect the public and the environment;
• the consequences of the event within the site, which can affect the workers and the installation itself;
• the deterioration of the installation's lines of "defence in depth", that is to say the successive means of protection (safety systems, procedures, technical controls, etc.) put in place within the installation in order to mitigate the effects of an incident or accident and to guarantee containment of the radioactivity.

IPSN (French Institute for Nuclear Safety and Protection) – Institute created in 1976 (by combining the CEA's Risk Control Department and the Nuclear Installations Central Safety Service – SCSIN), the IPSN is tasked with conducting nuclear safety studies. Providing technical support to the SCSIN of the Ministry of Industry, it became the Institute for Radiation Protection and Nuclear Safety (IRSN) in 2002 when it merged with the Office for Protection against Ionising Radiation (OPRI).

IRRS [missions] – (Integrated Regulatory Review Service) – The IRRS missions of the IAEA are designed to improve and reinforce the efficiency of national nuclear regulatory frameworks, while recognising the ultimate responsibility of each State to ensure safety in this field. These missions take account of regulatory, technical and strategic aspects, make comparisons with IAEA Safety Standards and, as applicable, take account of best practices observed in other countries. These audits are the result of the European Nuclear Safety Directive which requires a peer review mission every ten years.

IRSN (Institute of Radiation Protection and Nuclear Safety) – Founded in 2002 further to the merging of the Institute for Nuclear Safety and Protection (OPRI) and the Office for Protection against Ionising Radiation (OPRI), IRSN is a public institution of an industrial and commercial nature which functions under the joint authority of the Ministries responsible for Defence, the Environment, Industry, Research and Health, and Labour. IRSN provides ASN, the French nuclear regulator, with technical expertise.

MWe (Megawatt electric) – Unit of electrical power.

NRC (Nuclear Regulatory Commission) Federal agency created in 1974 which is independent of the United States Government and is responsible for regulating nuclear safety in the USA and ensuring compliance with the regulations. It ensures the safe use of radioactive materials for civil purposes, while protecting people and the environment. On this account the NRC is responsible for regulating the commercial nuclear power plants and other uses of nuclear materials (such as in the medical field) by granting licenses (design, construction, operation), conducting inspections and ensuring compliance with its requirements.

Nuclear safety – All the technical provisions and organisational measures implemented with a view to preventing accidents or mitigating their consequences. They concern the design, construction, functioning, shutdown and decommissioning of basic nuclear installations and the transport of radioactive substances. Nuclear safety is a component of nuclear security which comprises radiation protection, the prevention and combating of malicious acts, as well as civil protection actions in the event of an accident.

Nuclear security – Nuclear security covers civil protection in the event of an accident and the protection of facilities against malicious acts, nuclear safety, that is to say the safe functioning of the facility and radiation protection which aims to protect people and the environment against the effects of ionising radiation ("TSN Act" of 13 June 2006).

OPECST (Parliamentary Office for the Evaluation of Scientific and Technical Choices) – Created by the Act of 8 July 1983, its duty is to inform Parliament of the consequences of the scientific and technological choices in order to inform its decisions. It collects information, implements study programmes and carries out assessments.

OPRI (Office for Protection against Ionising Radiation) – A public State institution which took over from the Service of Oversight of Protection against Ionising Radiation in 1996, OPRI merged with the Institute of Nuclear Safety and Protection (IPSN). It is now part of the Institute for Radiation Protection and Nuclear Safety (IRSN).

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

PUI (On-site emergency plan) – This plan is drawn up and implemented by the industrial operator responsible for a nuclear installation. The aim of the PUI is firstly to protect the personnel working on the nuclear site in the event of an incident or accident, and secondly to mitigate the consequences of the accident outside the bounds of the nuclear site to the maximum extent possible.

PWR [reactor] – (Pressurised Water Reactor) Reactor that uses light water both as a moderator (to lower the energy of the neutrons to a level that increases fission efficiency) and as a coolant (to transfer the heat from the core to the steam generator). The French nuclear power reactor programme is based essentially on the development of this technology (with reactors of 900 MWe, 1,300 MWe and 1,450 MWe), which counts the largest number of units in service in the world.

QMS (Quality Management System) Inspired by the international standards of the International Atomic Energy Agency (IAEA) and the International Organisation for Standardisation – ISO), this system is based on:

- an organisation manual containing organisational notes and procedures defining rules for the conduct of each of its missions;
- internal and external audits to ensure that the system's requirements are strictly applied;
- listening to stakeholder feedback;
- performance indicators for monitoring the effectiveness of action taken;
- a periodic review of the system, to foster continuous improvement.

Radiation protection – Radiation protection aims to prevent or reduce the health risks linked to ionising radiation, on the basis of three broad principles: justification, optimisation and limitation of radiation doses. To apply these principles, radiation protection implements regulatory and technical means adapted specifically to three categories of persons: the public, patients and workers.

RBMK [reactor] – (*Reaktor Bolshoy Moshchnosti Kanalnyi* / High-powered reactor with pressures tubes) Soviet-designed nuclear reactor, used notably in the Chernobyl NPP (Ukraine).

RHWG (Reactor Harmonization Working Group) – Mandated by WENRA to develop a harmonised approach to the nuclear safety of in-service nuclear power plants, the RHWG developed the WENRA safety reference levels for the existing power plants. These reference levels are approved by the association members. They reflect the practices which must be implemented in the WENRA member countries.

SCPRI (Central Service for Protection against Ionising Radiation) – A former French public body created in 1956 and attached to the Ministry of Health, the SCPRI's mission was to protect the public and nuclear industry workers against the dangers of ionising radiation. It was replaced on 19 July 1994 by the Office for Protection against Ionising Radiation (OPRI).

SCSIN (Nuclear Installations Central Safety Service) – Created by decree within the Ministry of Industry in 1973, the SCSIN was responsible for preparing and implementing all the technical actions relative to nuclear safety: regulations, coordination of safety studies, nuclear information. It was also responsible for examining the authorisation application files relating to basic nuclear installations. It was replaced by the Nuclear Installations Safety Directorate (DSIN) in 1991.

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SFRO (French Society of Radiation Oncology) – Created in 1990, the SFRO meets the need to bring together the radiation oncology professionals, whose training, diplomas, professional interests and conditions of practice differ from those of their radiologist colleagues.

Socatri (*Société auxiliaire du Tricastin*) Company operating a clean-up and uranium recovery facility in Bollène in the Vaucluse département.

Stress tests – Two weeks after the accident at the Fukushima Daiichi NPP (Japan), the European council meeting of 24 and 25 March 2011 decided to perform stress tests on the European nuclear power plants in order to take into account the first lessons from the accident in Japan. In France, the stress tests were baptised *"Évaluations complémentaires de sûreté"* (ECS) (Complementary safety assessments) of the nuclear facilities in the light of the Fukushima Daiichi NPP disaster. By comparison with the European framework, the French exercise was extended to include all nuclear facilities and enhanced by incorporating Social, Organisational and Human Factors (SOHF).

TAM (*"Tampon d'Accès du Materiel"* – Equipment hatch) – Large-diameter penetration in the reactor containment used to introduce the necessary equipment and materials during reactor outages.

TMI (Three Mile Island) – NPP situated in the east of the United States and definitively shut down on 20 September 2019. Commissioned in 1974, the Three Mile Island NPP suffered an accident on 28 March 1979. This accident was rated level 5 on the International Nuclear Events Scale (INES). The plant comprises two separate reactor units, TMI-1 and TMI-2. It was in TMI-2 that the Three Mile Island nuclear accident took place in 1979.

TSN [Act] – (Act on Transparency and Nuclear Security) – Act of 13 June 2006 on Transparency and Security in the Nuclear Field, which lays down the legislative bases of the nuclear safety system through application of the principle of "precaution" in the nuclear field.
The "TSN Act" lays down the procedures for guaranteeing that the public are informed about nuclear activities and the structures for holding consultations and debates on the subject. It defines all the legal acts applicable to these activities, from the creation authorisations to the inspections carried out by the inspectors and the penal enforcement actions, through to decommissioning.

UNGG [reactor] – (Gas Cooled Reactor, known as "UNGG", the French acronym for Natural Uranium-Graphite-Gas) – EDF's first-generation nuclear reactor, functioning with natural uranium.
The first GCR reactor was commissioned at Chinon (Indre-et-Loire *département*) in 1963. A total of six reactors of this type were built in France. These reactors were shut down between 1973 and 1994, when this technology was abandoned in favour of the pressurised water reactors (PWRs).

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) – Scientific committee of the United Nations for studying the effects of ionising radiation). Created in 1955, this committee brings together experts from 27 countries and reports to United Nations General Assembly. It is a scientific body which validates and endorses the results of national or international studies on the effects of ionising radiation on man.

WENRA (Western European Nuclear Regulators' Association) – Created in 1999 on the initiative of André-Claude Lacoste, who was head of the DSIN at the time and became the first chairman of the association. WENRA brings together the heads of the nuclear regulators of 18 European countries: Germany, Belgium, Bulgaria, Spain, Finland, France, Hungary, Italy, Lithuania, Netherlands, Czech Republic, Romania, United Kingdom, Slovakia, Slovenia, Sweden, Switzerland and Ukraine.

WHO (World Health Organisation) Specialised agency of the United Nations Organisation (UNO), created in 1948. It depends directly on the Economic and Social Council of the United Nations.

Zircaloy – Group of zirconium alloys. Zircaloy is used primarily in the nuclear industry as a fuel cladding material (first containment barrier) due to its neutron absorption characteristics.

Editor: Autorité de sûreté nucléaire (ASN)
15-21, rue Louis Lejeune, 92120 Montrouge

Publications Director: Olivier Gupta, Director-General of ASN, the French Nuclear Safty Authority
Chief Editor: Marie-Christine Bardet

This issue was written and produced in collaboration with the members of the ASN History Committee: Pierre-Franck Chevet, Marie-Pierre Comets, Daniel Delalande, Alain Delmestre, Jean-Luc Godet, Olivier Gupta, André-Claude Lacoste, Jean-Christophe Niel, Philippe Saint Raymond

ASN Commissioners: Sylvie Cadet-Mercier and Géraldine Pina also contributed to this issue

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AUTORITÉ
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15-21, rue Louis Lejeune – 92120 Montrouge – Tel.: +33 (0)1 46 16 40 00