

REPERES

IRSN
INSTITUT DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

SPECIAL ISSUE

Fukushima Daiichi What progress 10 years later?

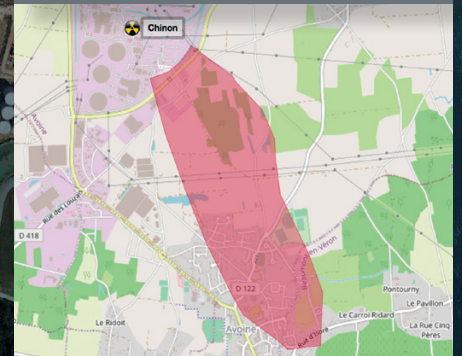
SAFETY



HEALTH



EMERGENCY

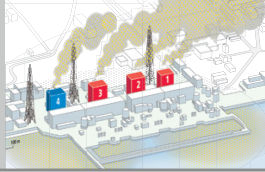


Contents

On the cover: Color-enhanced satellite image of the Fukushima Daiichi nuclear power plant (Japan), September 2013.
An IRSN expert at the Cruas-Meysses nuclear power plant (Ardèche department, France) during the Complementary Safety Assessments in 2011.
Measuring radioactivity using a Safecast device in the Fukushima region.
Estimating post-accident zoning during an exercise in Chinon (Indre-et-Loire department, France), December 2020.

P.4 JAPAN 2011

The accident at Fukushima Daiichi
What happened?



P.6 JAPAN 2021

Ten years later
What is the state of affairs?

P.8 SAFETY

Extreme risks
Enhanced protection for nuclear facilities

Station blackout diesel generator
Assessments made during design

Severe accidents
Ultimate heat sink performance

Tricastin nuclear power plant
Dike reinforcements follow assessment

Research
Innovative materials

P.14 EMERGENCY

Emergency management and recovery
Defining new zoning



P.18 HEALTH

Population protection
What progress has been made in ten years?

P.20 ENVIRONMENT

Environmental contamination
Models are progressing



P.22 IRSN

2011-2021
IRSN's actions

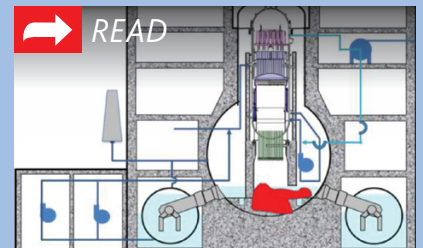
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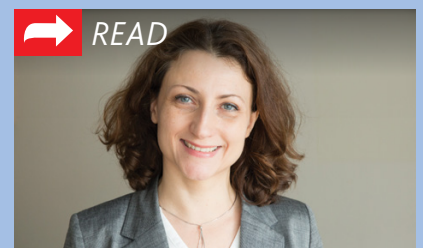
Safety

Local emergency centers to stand firm during extreme situations



Research

Understanding and modeling the accident



Emergency

Three questions for Patricia Dupuy on IRSN's Emergency Center



Emergency

Post-accident management should include social consequences

Dialogue, independence, shared expertise



Emergency

What human resources to call upon in extreme situations?



Environment

A mapping tool to help local stakeholders prepare

About *Repères*

Enhancing nuclear safety is the main driver behind IRSN's every action. As such, the Institute takes its commitment to making the results of its research, studies and reports accessible to all professionals involved in nuclear safety, security and radiation protection, as well as the general public and civil society, very seriously. This is why the Institute publishes a quarterly French newsmagazine, *Repères*, which provides information on IRSN's activities in the fields of research, radiological surveillance, nuclear safety and security, and reflects the broad extent of its expertise. The international significance of the Fukushima Daiichi accident is what has prompted publication of an English version of this special issue focused on the accident and on the lessons learned by IRSN ten years on regarding nuclear safety.

Ten years have passed since the Fukushima Daiichi disaster. This accident, like those before it, has led IRSN to conduct extensive research and take action to enhance safety at nuclear facilities and radiological protection of people and the environment. We must do everything within our power to prevent accidents, even though there are no guarantees that they will not occur. In this special edition of *Repères*, we review the situation.

One of the key findings resulting from the Fukushima Daiichi accident has been that decisions made during the emergency response stage have had a major impact on managing the long-term consequences. To ensure that environmental, social, health, and radiological aspects are factored into decisions made with a view to post-accident management, the wider public—including citizens, elected officials, and associations—must be involved in the choices made; this is especially true since such accidents entail a loss of confidence in authorities and experts. In such a complex situation, it is essential to ensure that citizens have the resources necessary to make their choices, notably, by encouraging radioactivity monitoring initiatives or sharing expertise more widely.

To conclude, I firmly believe that experts' involvement in these types of situations must be based on ethical principles: respect for other people's right to freedom and independence, transparent communication on the risks, and honesty regarding the limits of what we can do and the uncertainties inherent in our knowledge. As experts, we must have faith in citizens.

Jean-Christophe Niel

IRSN Director General



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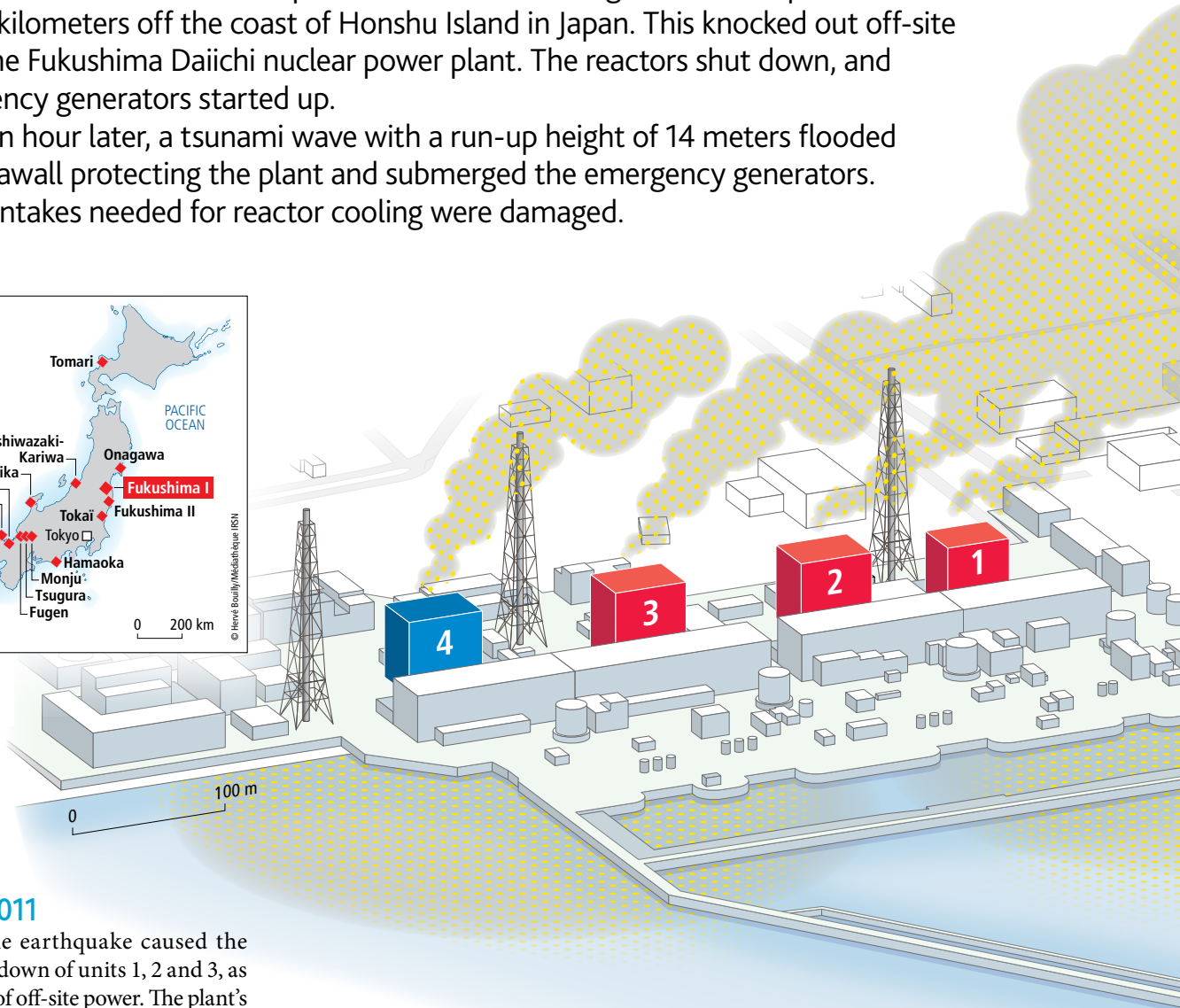
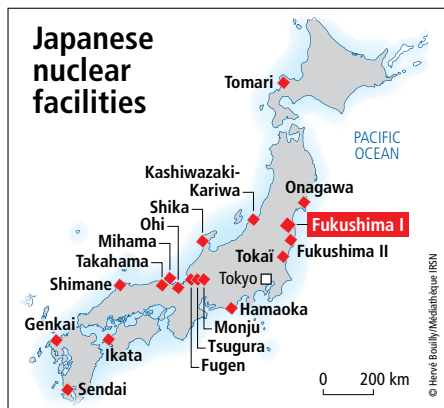
IRSN
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The accident at Fukushima Daiichi

What happened?

On Friday, March 11, 2011, at 2:46 p.m. local time, a 9.0 magnitude earthquake struck 130 kilometers off the coast of Honshu Island in Japan. This knocked out off-site power at the Fukushima Daiichi nuclear power plant. The reactors shut down, and the emergency generators started up.

Less than an hour later, a tsunami wave with a run-up height of 14 meters flooded over the seawall protecting the plant and submerged the emergency generators. The water intakes needed for reactor cooling were damaged.



March 11, 2011

Core melt. The earthquake caused the automatic shutdown of units 1, 2 and 3, as well as the loss of off-site power. The plant's emergency diesel generators took over. Forty minutes later, the tsunami wave triggered by the earthquake reached the coast. The site was hit by seven waves, the highest measuring fourteen meters high. It damaged the seawater intakes and shut down the emergency diesel generators supplying power to units 1 through 4. The unit 2 and 3 emergency backup systems continued to function for a few days, thereby delaying core melt in these reactors. The core damage in units 1, 2 and 3 led to radioactive releases into the environment. The decision was made to vent the reactor containments in order to reduce pressure.

March 12, 2011

Unit 1. An explosion occurred at 3:36 p.m. in the upper part of the reactor building, an hour after containment venting began. Given the loss of cooling systems, the plant manager decided to inject seawater into the reactor coolant system as a last resort.

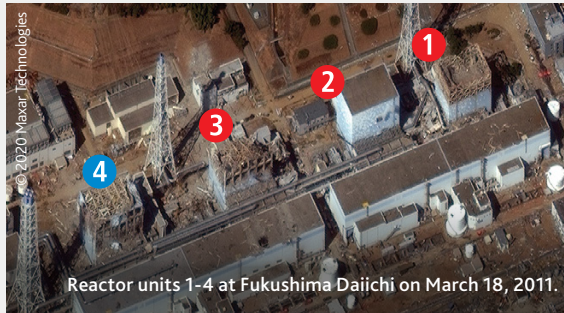
March 14, 2011

Unit 3. The upper section of the reactor building also exploded, even though it had been vented 24 hours earlier. Seawater was injected to cool down the reactor core.

Unit 4. An explosion occurred inside the reactor building, probably caused by an inflow of combustible gas via the pipes shared with unit 3.

Unit 2. The operators failed to vent the containment. On March 15, in the morning, the high pressure level caused a break, resulting in significant radionuclide releases. Seawater was injected to cool the reactor core. ■

The Fukushima Daiichi nuclear power plant

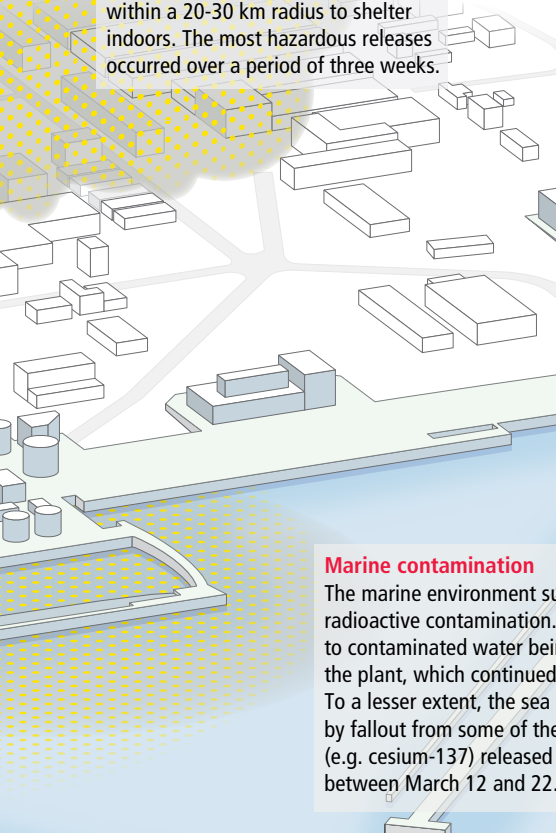


Reactor units 1-4 at Fukushima Daiichi on March 18, 2011.

The Fukushima Daiichi nuclear power plant (Daiichi means "Number One") is made up of six American-designed Boiling Water Reactors (BWRs). Built in the 1970s, it is operated by Tokyo Electric Power Company (TEPCO). Unit gross power capacity ranges between 460 and 1100 MWe depending on the reactor.

Atmospheric contamination

The series of decompressions and explosions resulted in significant releases of radioactive fission products to the atmosphere, such as iodine-131 and cesium-137. In the hours following the accident, the Japanese authorities decided to evacuate 80,000 people within a 20 km radius of the site and ordered those living within a 20-30 km radius to shelter indoors. The most hazardous releases occurred over a period of three weeks.



Marine contamination

The marine environment suffered significant radioactive contamination. This was primarily due to contaminated water being discharged from the plant, which continued up to April 8. To a lesser extent, the sea was also contaminated by fallout from some of the radionuclides (e.g. cesium-137) released to the atmosphere between March 12 and 22.

Units 5 and 6

These reactors were built more recently and as they are situated about ten meters higher up than the other four, they were consequently able to better withstand the external load. One of the emergency generators for unit 6 was used to cool the spent fuel storage pools of units 5 and 6, which were shut down for maintenance.

- Units in operation
- Units shut down for maintenance

Different reactor technologies

Although all nuclear power reactors make use of fission energy* to generate electricity, their design differs. The units at Fukushima Daiichi plant are equipped with boiling water reactors (BWR), whereas the nuclear power plants in the French fleet house pressurized water reactors (PWR). The main difference between these technologies lies in the type of cooling system:

- In a BWR, the water used to cool the reactor core turns to steam at the top of the reactor vessel before being channeled to the turbine. The steam is then condensed to liquid state in a condenser (cooled by sea-water at the Fukushima Daiichi plant) before

being recirculated back into the core.

- The core of a PWR is cooled by a system called the primary circuit in which the water is pressurized so that it remains in liquid form. The heat from this circuit is transferred to the secondary circuit, an independent system in which the water evaporates and drives the turbine. Both of these technologies are equipped with various backup emergency systems which, in the event of an accident, are designed to inject water to cool the reactor core.

* During fission, the nucleus of an atom splits, releasing a very large quantity of energy.

146,520

residents of Fukushima Prefecture were evacuated following the accident in 2011, as ordered by the government.

Source: The Fukushima Nuclear Accident Independent Investigation Commission official report (2012).

State of affairs: Ten years later

Defueling, environmental contamination, return of inhabitants, decontamination... What is the situation now, ten years after the accident? What are the consequences for people and the environment?

■ Lower doses measured in forests

The radionuclides released in 2011 drifted away primarily towards the ocean, and to a lesser extent towards land, depositing on vegetation and on the ground (80% of these terrestrial deposits were on forests). Furthermore, these radionuclides have decayed—between 2011 and 2020, iodine-131 for instance has disappeared, whereas the radioactivity of cesium-137 has decreased by 20%—and were partly absorbed by plants. As early as 2011, IRSN launched the AMORAD research project in collaboration with the University of Tsukuba (Japan) and Andra⁷ (see p. 20). Four field experiments in Japan, examining 5,000 samples from trees and soils, have provided insight into the cesium transfer cycle through the various forest compartments (leaves, branches, bark, wood, roots, humus, litter, soil and mineral). “In 2020, 75% of initial cesium deposit in the forest is now in the

soil, and 5% is still in the trees. As it migrates through the soils, this progressively reduces the exposure of anyone entering the forest,” explained Frédéric Coppin, Geochemist. This research feeds into models used to protect people.

■ Corium in all its forms

The priority for dismantling operations is to remove the corium formed by the molten fuel still inside the reactor vessels or mixed with concrete at the bottom of the reactor buildings. This is also the most complex part of the dismantling program.

Given the radiation levels, far too high for human intervention, the Tokyo-based utility, TEPCO, deploys robots. The robots are used to explore the site and collect samples of the corium, in order to characterize its hardness and granularity, etc. The ultimate goal of this operation is to select the most suitable technology for detecting, cutting and collecting the many tons of this highly-radioactive material. “IRSN, which has devoted extensive work to such severe accidents, is now involved to assess the characteristics of the various forms of corium and minimize the risks of dispersion inherent in cutting them up,” explained Didier Vola, Head of severe accidents department (see p. 11 and 13). The dismantling program is expected to last thirty years.

■ A mountain of waste

To protect the population from exposure, Japan has set an additional dose limit at 1 mSv/year and launched a proactive cleanup program. This has generated around 20 million cubic meters of waste. At the start, this waste was grouped together at temporary storage sites, called *kariokiba*. This waste will be sorted, incinerated or possibly reconditioned, and then transferred to a single temporary storage site in Fukushima Prefecture in the case of waste exceeding 8 kBq/kg. Studies are ongoing to find other solutions for



An interim disposal facility for bags of contaminated soil from Fukushima Prefecture in 2016.



A robot collects the corium from inside the Reactor 2 containment. The aim is to assess its characteristics prior to dismantling.

5%

Landing value of fish and fishery products in 2016, compared to pre-accident figures*.

220 billion euro

The direct cost of the accident**. This figure includes compensation for damage and losses to farming, fishing, tourism, the cost of managing contaminated territories, etc.

* Source: T. M. Nakanishi et al. (eds.), *Agricultural Implications of the Fukushima Nuclear Accident (III)*, 2019.

** Sources: Various: Japan, IAE, EIA.

recycling as well as for sites or disposal facilities outside Fukushima Prefecture. The last remaining *kariokiba* will be emptied by the end of 2021.

Decontamination has now been completed within the Intensive Contamination Survey Area (ICSA). This encompasses the Special Decontamination Area and the municipalities where the estimated annual dose was thought to be between 1 and 20 mSv. *“It will take many more years to manage this waste, and it will be very costly,”* summed up Jérôme Guillevic, an expert in radiation protection.

■ What about the radiation-induced effects?

“Breast cancer, thyroid cancer, leukemia... it’s hard to say that these cancers are caused by radioactive fallout, because the doses received by the population were generally low, just a few millisieverts,” Klervi Leuraud summed up, who specializes in radiation-induced risk. Among epidemiologists, this has been the consensus.

It cannot be denied there have been indirect health effects, including diabetes, kidney and liver failure, obesity and alcoholism, but these are thought to result from disruption to healthcare services and post-traumatic stress. Such stress is decreasing, as its prevalence fell by 19% in men and 27% in women² between 2012 and 2014.

■ Four out of five residents have not returned

Residents began to return to the area as of April 1, 2014. Their return has been slow and partial. At the beginning of 2020, the average rate of return was below 20% for all municipalities that had received orders to evacuate, ranging from 2% to 75%.

■ The importance of “facilitators”

“The measurements made the radioactivity visible.” According to Jean-François Lecomte, an expert in radiation protection, this was one of the key insights resulting from *Fukushima Dialogue*, a project backed by IRSN and that gave a voice to Japanese people affected by the accident since 2011. Citizen initiatives developed to add to the official measurements. A farmer in Suetsugi monitored the radioactivity in his fields, associations sourced the equipment needed to take measurements, and residents called for personal dosimeters. Discussion with experts help everyone to gain a better understanding of the situation. That is how

the idea of co-expertise came into being. Another takeaway was that standards are not enough. They can even be detrimental. From 2011, to reassure the population, the limits relating to the contamination of foodstuffs were lowered. However, some consumers believe that the limit is proof of contamination.

What happened in Japan revealed the importance of “facilitators”, for example teachers and medical or administrative staff who act as intermediaries between citizens and the authorities.

■ Contaminated water, a real headache

In November 2020, there was 1,234,000 cubic meters of tritiated water stored in 1,040 tanks on the nuclear power plant site. This radioactive water results from ten years of cooling the damaged reactors. According to TEPCO, the limit of 1,370,000 m³ will be reached in 2022.

In 2016, Japanese experts were looking at various options. Of these, two are still on the table and being discussed with stakeholders: discharge it into the sea (to dilute it) or vaporize it into the atmosphere (as water vapor). The technical, radiological and sociological advantages and disadvantages of these options are being examined.

According to Japanese authorities, the impact that discharging this water into the sea would have on people and the environment is comparable to the impact of nuclear facilities currently in service. ■

1. The French National Radioactive Waste Management Agency.
2. Fukushima Health Management Survey.

WWW Find out more:
The Fukushima Dialogue Initiative
irsn.fr/Kotoba-EN



Nearly 170 m³ of tritiated water are produced every day.



Using an open data device to measure radioactivity at a storage facility for contaminated soil.



In 2016, people displaced from the municipality of Miharu, in Fukushima Prefecture, were still living in temporary housing. Most of those who remain are elderly, as many young people left the region for good.



Decontamination work on a road in Fukushima Prefecture, October 2016.

SAFETY

Extreme risks

Enhanced protection for nuclear facilities

Following the accident at Fukushima Daiichi, the decision was made to assess the robustness of French nuclear facilities and their resistance to extreme natural events. IRSN experts then developed the concept of the “hardened safety core”, whose aim is reinforcing control of vital safety functions, preventing large-scale releases to the environment and improving emergency response management.

“How on earth could an accident like this happen in Japan, a country renowned for its reliable technology, rigorous organization and robust construction?” recalled Patrick Lejuste, post-Fukushima Project Manager, as he thought back to how stupefied the nuclear community was in 2011. At the time, ASN, the French Nuclear Safety Authority, asked licensees to immediately

undertake Complementary Safety Assessments (CSAs). They had to assess the robustness of the facilities in the event of a major earthquake or extreme flooding event. Seventy-nine CSA reports were drawn up by the licensees. They identified a number of deviations/cases of noncompliance, points for improvement, and presented calculations on the length of time before releases to the environment were likely, etc. In the space

of just a few months, IRSN had conducted a critical analysis of all these reports and examined licensee proposals for making their facilities more robust.

At the beginning of 2012, based on all these data and assessments, ASN concluded that there was no need to close down any of the plants. It did, however, require the operators to check conformity with the safety requirements and decided to raise

FOCUS

What are the first key measures of the hardened safety core?

Preventing accidents with core melt or slowing down their progression, reducing massive releases of radioactivity and making it possible for the operator to manage emergency response—these are the three objectives of the hardened safety core program. It is being deployed across the French nuclear power plant fleet in the wake of Fukushima Daiichi in order to equip it to withstand extreme hazards. Having developed the initiative, IRSN is assessing its design and implementation. After 72 hours, the Nuclear Rapid Response Force (FARN) takes over to assist on-site. Here, we take a look at the first key measures of the concept.

1 Emergency diesel generators (EDG)

These are used to restore **electric power** to the hardened safety core equipment and systems. It is designed to operate for **72 hours without requiring human intervention**.

Implementation expected to be complete in February 2021*

2 Local emergency center (CCL)

This must be designed to withstand extreme natural hazards. It **houses emergency response equipment and can accommodate a staff of about a hundred people** deployed as part of the on-site mobilization plan and mobile response forces. **These teams carry out diagnostics to assess facility condition, evaluate releases and advise public authorities.**

Implementation expected to be complete in 2026

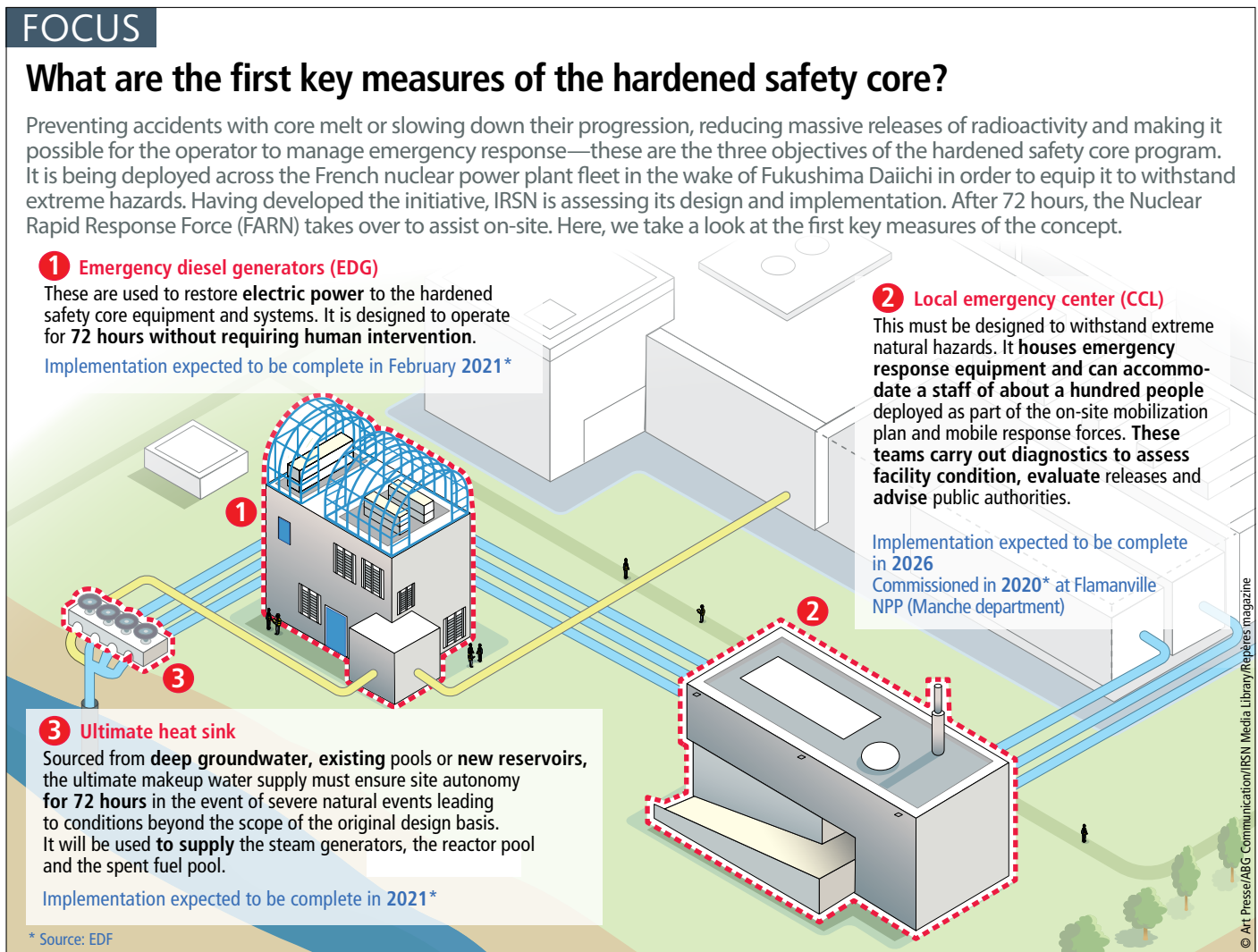
Commissioned in 2020* at Flamanville NPP (Manche department)

3 Ultimate heat sink

Sourced from **deep groundwater, existing pools or new reservoirs**, the ultimate makeup water supply must ensure site autonomy for **72 hours** in the event of severe natural events leading to conditions beyond the scope of the original design basis. It will be used to **supply the steam generators, the reactor pool and the spent fuel pool**.

Implementation expected to be complete in 2021*

* Source: EDF



the required safety baselines relative to natural hazards. IRSN proposed a new concept, that of the hardened safety core. Every facility has since been required to have at its disposal the human and organizational resources and the “last resort” equipment designed to withstand severe hazards that go beyond the design-basis scenarios set out in the safety reference documentation in force.

72-hour autonomy vital on site

Based on feedback from the accident at Fukushima Daiichi—loss of water supply, loss of power, not enough manpower—the aim of the hardened safety core is to “retain control of the situation and, if necessary, be able to contain severe accidents, no matter the circumstances,” Lejuste explained.

The concept relies on two key measures: the Emergency Diesel Generator (EDG) and the Ultimate Heat Sink, designed, respectively, to ensure electric power for 72 hours and makeup water (see p. 10 and 11). Technical dialogue with EDF¹ has been ongoing since 2012. ASN required EDGs to be installed at all reactors by 2018. The design of certain parts of the facilities has also been under review; these must be made more robust to withstand extreme weather events: flooding (see p. 12), lightning, tornadoes, violent winds, etc.

To improve emergency response management, EDF proposed, within the framework of the CSAs, building a Local emergency center (CCL²) on every site, designed to withstand extreme hazards (see webmag). The following year, again on its own initiative, EDF set up the FARN, the Nuclear Rapid Response Force (see opposite).

All new equipment is designed with extreme hazards in mind from the very start. Full implementation of the hardened safety core measures will be completed in line with the ten-yearly reviews, with expected completion set for 2038. ■

1. Électricité de France/French national power company.

2. Centre de crise local.

In what ways has the accident at Fukushima Daiichi changed relations between key players in the nuclear industry and civil society?

YM: The amount of dialogue on technical issues has increased. Local information committees (CLI) hold discussions with the experts at IRSN, the French Nuclear Safety Authority (ASN) and the operators on what are often very controversial issues, such as the anomalies in the Flamanville EPR (Manche department) reactor vessel. IRSN now publishes more information. It consults with citizens prior to conducting assessments instead of toward the end of the process. A good example of this is the project to create a centralized spent fuel pool.

Have the ways in which people can participate changed?

MB: ASN’s standing groups are now open to non-institutional experts. We have gotten involved in a number of these committees, in particular those pertaining to facility safety and waste management.

YM: Such openness serves to enrich the assessment process. We often bring different views to the table. On reactors, we stress the need to stick to the safety margins, keep a close eye on whether the deadlines for implementing ASN recommendations are met, and so on.

What improvements could be made?

MB: Some information should be made public, such as monitoring implementation of commitments made by operators.

YM: We need to get to the point where the concerns of civil society have a real impact on decisions.

What topics are not being discussed?

YM: Security. It’s only natural that certain aspects, like anti-terrorist surveillance, should be classified for defense purposes. But other subjects, such as whether civil engineering structures are robust enough to withstand an aircraft crash, or the ability to maintain cooling after certain types of attack, etc., should be addressed through dialogue with society.

4 questions for...

Manon Besnard and Yves Marignac

Independent experts at the *Institut négaWatt*
Nuclear and Fossil Fuel Energies Unit



© Coll. part. © B. Runtz



The FARN is staffed by 300 trained employees. Its fleet is composed of 52 all-terrain vehicles as well as air and river transport craft.

© EDF - Bruno Benoit/Sipa

FOCUS

Taking over to deliver a hardened safety core within 24 hours

As an additional safety measure that has been in place since 2013, the FARN (for *Force d’action rapide nucléaire*) provides human resources and equipment in the event of accident. In 2019, IRSN noted in a notice that—for a given accident scenario—the FARN must, without fail, take action within 24 hours

(Notice 2019-00051 on the deployment of ultimate cooling measures). The FARN is tasked with maintaining reactor cooling and ensuring supply of water, power and compressed air. It takes over to deploy the hardened safety core measures to keep the situation under control and prevent core melt or, failing that, mitigate the consequences.

WEBMAGAZINE



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Local emergency centers to stand firm during extreme situations

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SAFETY

Station blackout diesel generator

Assessments made during design

Emergency diesel generators (EDG) constitute one of the pillars of the “hardened safety core”. They supply power to the vital components of the facility in the event that all other sources of electricity are lost. IRSN has evaluated the design of this additional equipment, designed to withstand extreme hazards. EDF¹ has announced that the system will be fully operational for all its reactors by late February 2021.



Safety experts carry out inspections at the Cruas nuclear power plant (Ardèche department) as part of the Complementary Safety Assessments (CSAs) held in the wake of the Fukushima Daiichi accident.

With a relatively small footprint of 288 m², the buildings known as the EDG house the emergency diesel generators and are erected in close proximity to the nuclear island. And with good reason, because in extreme situations, these diesel engines have to take over to power the hardened safety core systems and components to prevent core melt. If this fails, they are needed to mitigate the consequences by preventing large-scale releases to the environment (see p. 8). How were safety experts involved in overseeing the design process?

These bunkered buildings must withstand extreme situations. “Made of reinforced concrete, with 50 centimeter-thick walls,

they built to withstand extreme natural phenomena and the resulting effects, for example lightning, hail, tornados and earthquakes,” explained Marie-Hélène Bonhomme, a civil engineering expert. Beginning in 2016, IRSN examined the reliability of the station blackout emergency diesel generator (SBO-EDG), designed to operate for 72 hours, checking its output capacity to supply the electric power required (3 050 kW). It subsequently published an initial technical report². “IRSN found the initial design-basis scenarios satisfactory,” Patrick Lejoste, post-Fukushima Project Manager shared. The electrical power distribution system for the hardened safety core supplied by the SBO-EDG and the measures implemented to protect it were also assessed³. More recently², they assessed whether the power provided by the diesel generator is adequate to meet the requirements of the equipment it is intended to supply.

Recommendations on earthquake-resistant design

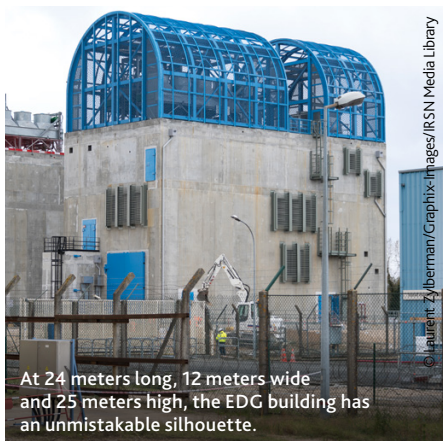
In addition to the generator, the EDG buildings also house lubrication pumps, fuel oil tanks, a ventilation system, batteries, a circuit breaker panel and a fire detection system. No human intervention is required.

In the event of a power outage, the generator starts up automatically. “The anchoring systems on each part of the equipment are designed to withstand the effects of a hardened safety core-level earthquake,” explained Lejoste.

In 2016², IRSN made a recommendation regarding the seismic resistance, assumptions and methods for the design basis of structures housing the EDGs. Operators are required to ensure adequate safety margins.

In 2012, ASN, the French Nuclear Safety Authority set a delivery deadline for the 56 station blackout EDGs for 2018. By the end of 2018, two were operational, both at the Saint-Laurent-des-Eaux site in the Loiret-Cher department. Since then, the other reactors in the French fleet have been equipped gradually. According to EDF, all were scheduled to be operational by February 2021. ■

1. *Électricité de France/French national power company.*
2. *IRSN notice 2016-00187, plus five additional reports on commissioning the EDGs: 2017-00042 (P4 subseries, 1300 MWe plant series), 2017-00131 (CPY plant series), 2017-00318 (P4 subseries, 1300 MWe plant series), 2017-00344 (N4 plant series) and 2018-00109 (Bugey CPO plant series).*
3. *IRSN notice 2017-00058.*



At 24 meters long, 12 meters wide and 25 meters high, the EDG building has an unmistakable silhouette.

Severe accidents

Ultimate heat sink performance

The containment heat removal system, as part of the “hardened safety core”, plays a key role in the event of a severe accident. IRSN has examined its performance and made some recommendations for additional improvements.

How effective is the ultimate containment heat removal system (UCHRS)? That is the question put to the experts at IRSN regarding this part of the hardened safety core system. Its role is to remove residual heat from the containment, including under severe accident conditions. The ultimate containment heat removal system is called upon when the safety injection system and the containment spray system both fail.

It is required in order to prevent any opening of the containment venting and filtration system which would result in significant releases to the environment. Since 2015, IRSN experts have assessed the design, reliability and performance of the system proposed by EDF to mitigate the consequences of an accident with core melt. “The ultimate containment heat removal system injects borated water¹ contained in a tank into the reactor vessel and into the sumps at the bottom of the containment. Once this tank is empty, the system draws water from the sumps to recirculate it and cool it. It is cooled by a UCHRS heat exchanger

connected to the heat sink by the FARN, the Rapid Nuclear Response Force,” (see p. 9) explained Estelle Dixneuf, an expert in the field of safeguard systems design.

According to IRSN’s calculations, that is the potential source of any problems. Julien Chambarel, an expert on severe accidents, explained: “Thanks to our calculations, performed using ASTEC code, we have identified a risk in the event of an accident in which design-basis pressure in the containment is exceeded in the first 24 hours, requiring containment venting. That is precisely the amount of time needed for the FARN to connect the heat sink to the UCHRS heat exchanger.”

This has led to an IRSN recommendation in the event of a severe accident. Now, an additional step must be added to the list of necessary actions, which is to resupply the external borated water tank and inject its contents into the reactor building as quickly as possible. ■

1. Boric acid is added to the water in the reactor coolant system due to its neutron-absorbing capabilities.



The Tricastin plant heat exchanger shown here is the centerpiece of an ultimate heat sink. It measures 7 meters long and weighs around 9 metric tons.

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RESEARCH

Basemat

Creating a more robust basemat

During the accident at Fukushima Daiichi, molten fuel penetrated through the reactor vessels and flowed down onto the basemat. The basemat, made of reinforced concrete, acts as the foundation supporting the reactor containment. To maintain containment integrity, ablation of basemat by the corium must remain limited. How is this risk managed in France? In 2019, IRSN published a notice¹ that addresses this issue. As part of the studies on extending the service life of its 900 MWe reactors, EDF is developing a strategy for managing the flow of corium following melt-through, often referred to as “ex-vessel corium”. The principle behind this entails allowing the corium to spread at the base of the reactor where it is then stabilized under water. The experts at IRSN have thirty years of research on which to base their analysis of this strategy.

Experiments are carried out to study how depleted uranium, replicating the actual fuel, interacts with the types of concrete (limestone or siliceous) used in reactor units. Computer simulation is then used to study conditions at full scale. “When siliceous concrete is used, as is the case in fourteen reactors in France—our experts recommend making the base of the reactor thicker, to minimize the risk of melt-through,” explained Gérard Cénérino, an expert on severe accidents. This research complements other international post-Fukushima projects² (see p. 13 and the Webmag).

1. IRSN/Notice 2019-00051.
2. PreADES, ARC-F and TCOFF, under the auspices of the OECD.

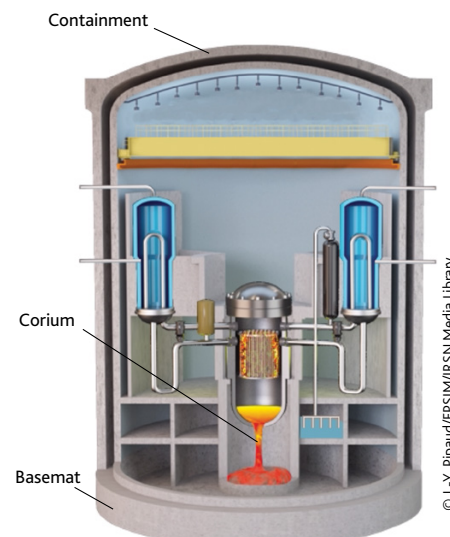


Illustration of a core melt accident with the corium flowing down and starting to interact with the basemat concrete.

© J.-Y. Pipaud/EPSIM/IRSN Media Library

Tricastin nuclear power plant

Dike reinforcements follow assessment

Since the accident at Fukushima Daiichi, nuclear facility design had to be improved to ensure that it withstand exceptional events. This led to the “hardened safety core”, which includes assessing the strength of infrastructure built to protect sites, such as the Donzère-Mondragon canal dike that borders the Tricastin nuclear power plant (Drôme department). IRSN recommended reinforcing it.

“Taking seismic risk into account as it has been up to now is not enough anymore,” explained Olivier Loiseau, Safety expert. He goes on to say that “the accident at Fukushima Daiichi showed us that nature can be much more powerful than the hazard levels used by design engineers in facility design.”

As a result of IRSN’s recommendations, EDF¹ has had to meet higher safety requirements at all its facilities. This applies to a precise list of existing protective equipment and systems, which are part of the hardened safety core, since they are necessary for carrying out safety functions (see p. 8). These new requirements apply to the dike that protects the Tricastin nuclear power plant. Here, we look back at the timeline of events and the assessment conducted. On September 27, 2017, ASN ordered EDF to temporarily shut down all four reactors at Tricastin, in order to reinforce a section of gravel dike measuring a few hundred meters. In the event of an earthquake, it could collapse. EDF conducted additional geotechnical investigations and reinforced the section.

IRSN analyzed the data submitted by EDF and drew up its own design calculations. IRSN believed that the works and the

monitoring plan will ensure that the dike remains stable in the event of a safe shutdown earthquake (SSE). The monitoring plan developed by EDF is based on piezometric² level measurements.

Nonetheless, assessment experts highlighted “the absence of a design margin for an earthquake exceeding the SSE baseline.” They recommended overall reinforcement of the dike. It must now withstand a “hardened safety core design basis earthquake”³. IRSN also stated that the specific features of the

site must be taken into account, primarily because of the soil characteristics.

In 2020, EDF drew up a file detailing its planned measures and works, which will be examined by IRSN. ■

1. Électricité de France/French national power company.
2. Measurements taken of the water level in the dikes.
3. Extreme earthquake used for the hardened safety core design baseline for facilities, as specified following the Fukushima Daiichi accident.

FLOODING

SOFIA simulator

Simulating flooding



Robin Dorel, a specialist in charge of the SOFIA simulator, presents the schematic control panel of the main feedwater system of the steam generator for the 900 MWe reactors.

Is safety assured at the Tricastin nuclear power plant (Drôme department) while work to reinforce the Donzère-Mondragon canal dike is ongoing? To find out, IRSN safety experts used the SOFIA¹ simulation tool. The following critical situation is considered, in which an earthquake has destroyed the weakened part of the dike, the site is flooded and must deal with the total loss of power supply and cooling water. SOFIA was used to model the consequences of such an event with the aim of facilitating analysis of the measures implemented by EDF to manage it². Starting from the initial state of the facility as selected by EDF, which considered residual heat equivalent to that of a reactor in shutdown state for fourteen days, the tool calculated the physical parameters of the reactor in real time. It simulated changes in pressure, core outlet temperature, and the flowrate in the reactor coolant system, etc. These calculations gave an estimate of 37 hours for the steam generators to drain, and the time to core uncovery as 62 hours. That means

that the Nuclear Rapid Response Force (FARN), which can reach the site in 12 hours, has enough time to respond.

More recently³, SOFIA has been used to validate operating a 900 MWe reactor following an extreme hazard. Robin Dorel, who manages the simulator, pointed out that “the new ‘hardened safety core’ equipment and systems must be taken into account. Simulation demonstrated that the facility was strong enough to resist.”

1. Simulator for Observation of Functioning during Incident and Accident.
2. EDF memo dated October 9, 2017 – “Measuring resilience with regard to the conditions considered for shutdown of the four reactors in the event of flooding on the NPP platform.”
3. Supporting the assessment of operating strategies in the event of extreme loads for reactors in service.

WW For more information:
The SOFIA simulator
irsn.fr/sofia-EN

Research

Innovative materials

Research was launched after the Fukushima Daiichi accident in order to better protect the population. Case in point with two programs, MIRE, focused on limiting radioactive releases, and PreADES, which studies the recovery of fuel debris to prepare for dismantling in Japan.

Ten years after the accident, knowledge and safety are improving through numerous research projects undertaken in France and internationally. By bringing to light how vulnerable facilities are to extreme natural hazards, the 2011 accident led to a review of priorities and stimulated preliminary safety research. It is essential that radioactive releases in the form of aerosols or gases be limited during a core meltdown in the event of an accident. Characterizing the chemical species released is also important because their impact on humans and the environment differs according to their physico-chemical form. These objectives are at the heart of the MIRE¹ collaborative project, led by IRSN.

Iodine filtering in containment venting lines

To improve filtration system efficiency in case of containment venting, research is focusing on innovative materials. “Zeolites [minerals mainly composed of aluminum and silica] enriched with silver very significantly improve the trapping of volatile iodine, with good resistance to heat and radiation,” said Laurent Cantrel, Project Lead. He goes on to say, “We are working on the aging of these materials and their performance in severe accident conditions. Our recommendations could be used as input by EDF, whose role is to decide which



The PERSEE facility is devoted to studying iodine traps in nuclear facilities.

solution to deploy to mitigate iodine releases.” Scientists began by deepening their knowledge of the nature of iodine releases with IRSN’s CHROMIA² platform. Then, they compared the trapping capacities of the existing filtration systems on another facility, PERSEE³. Two zeolites were selected for the final studies. When modified, these porous materials can increase their chemical affinities with gaseous iodine to selectively trap it. The addition of silver proved most effective.

Debris analysis

The purpose of the OECD PreADES⁴ project is “to prepare for dismantling Fukushima Daiichi. The Japanese asked us to inventory the debris formed by the accident and their properties,” explained Marc Barrachin, specialist in severe accidents. IRSN provided its knowledge on core meltdown accidents, “acquired through the Phébus PF⁵ program, based on five small-scale core meltdown tests carried out under the program,” he continued. Lessons were learned on the degradation of the core and fission product behavior. Debris analysis campaigns were con-

ducted. PreADES focuses on the boiling water reactors involved in the accident in Japan which “are made of the same materials, but in different proportions. We think we will find more metal in Fukushima Daiichi debris,” Barrachin concludes. Examining the debris will provide useful information to design the robots intended to recover it and the protection needed to evacuate it.

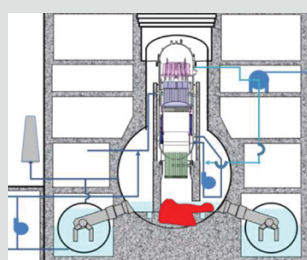
Analysis of the composition of the corium collected, resulting from the core meltdown, will provide information on what happened in March 2011.

With this information and the ASTEC software developed for the simulation of a reactor core meltdown, it will be possible to gain a better understanding of what happened in the accident (see Webmag). ■

1. Mitigation of releases to the environment in the event of a nuclear accident, with the participation of EDF.
2. Experimental platform for fission product chemistry and radiochemistry.
3. Experimental research platform on purification of radioactive effluents.
4. Preparatory Study on Analysis of Fuel Debris, project under the auspices of the OECD, started in 2017.
5. International project (1998-2010) irsn.fr/phebusEN

Find out more:
MIRE project irsn.fr/Mire-EN
PreADES program irsn.fr/news-20180522

WEBMAGAZINE



READ
Understanding
and modeling
the accident

irsn.fr/R48-EN

EMERGENCY



Emergency management and recovery

Defining new zoning

Implementing consumption bans starting from the emergency phase, improving calculation tools that predict the atmospheric dispersion of contaminants... Emergency management is changing, drawing on the lessons learned from Fukushima Daiichi. The goal: better protect the population in the event of radioactive releases.

“We are at a turning point,” Philippe Dubiau, Executive Director for emergency preparedness and response at IRSN affirmed as he described the development of the post-accident (PA) doctrine developed by the CODIRPA¹ chaired by the French Nuclear Safety Authority (ASN). And with good reason, since the new version expected in 2021 will finally incorporate

feedback from Fukushima Daiichi. In this updated version, an important provision has been added to better protect the population. Some measures hitherto reserved for the post-accident phase will be taken earlier. Making recommendations on what is and is not possible to consume cannot wait until the releases have stopped, as has been the case up to now.

The 2012 doctrine was published too early

on to assimilate the lessons learned from managing the accident in Japan. In it, releases are assumed to continue for one to three days, as was the case for Chernobyl. However, in Japan, they lasted for several weeks. “When releases continue for a long period of time, action needs to be taken

immediately. Otherwise, it poses population exposure problems—linked to the consumption of contaminated foodstuffs—and economic issues relating to the conditions of marketing products,” explained Damien Didier, specialist in modeling radioactivity transfers in the environment.

At IRSN, this difference entails operational changes, as from the emergency phase, its experts must assess foodstuff consumption and marketing issues.

Changes to zoning

Zoning is based on modeling future population exposure and food chain contamination. The radiological emergency management platform², C³X, is used, which “combines data from Météo France, the national meteorological service, and that of radioactive releases. It simulates the transport of contamination in the atmosphere and assesses the doses likely

 **WEBMAGAZINE**



READ
Three questions for Patricia Dupuy on IRSN's Emergency Center
[irsn.fr/R48-EN](https://www.irsn.fr/R48-EN)

to be received by humans,” explained Denis Quélo, specialist in atmospheric dispersion models.

Zoning³ contours are also changing. In 2012, there were three zones: a relocation perimeter, a population protection zone and an enhanced territorial surveillance zone.

The doctrine now defines two perimeters: a relocation zone defined according to the ambient radioactivity and a dietary restriction zone which connotes the non-consumption of fresh produce as well as monitoring and management of agricultural production, livestock farming, and consumer goods. “Rather than defining an overall zone, the plan works by sector,” Dubiau added.

Optimized models

Fukushima Daiichi required the C³X platform’s modeling capabilities to be expanded. “This accident shook the scientific and operational community. We have learned from this,” said Denis Quélo. “We realized that our atmospheric dispersion models were insufficient for an initial approach,” he explained. In 2011, they did not include dispersion calculations over long distances; priority was given to the first ten, twenty, or thirty kilometers. However, for this accident, it was crucial to be able to cover greater distances.

Developed in research and development, IdX software overcomes this shortcoming and has been included in the C³X platform. Calculation tools are constantly improved. “We now take better account of the phenomenon of scavenging⁴ of aerosol particles by rain to predict soil contamination. Our models also integrate fogwater deposition,” described modeler Arnaud Quérel.

Measuring more quickly and accurately

In metrology, too, practices are adapting and mobile resources being developed. The Ulysse airborne measurement system, comprising detection devices on board helicopters or aircraft, was launched in late 2011. It provides an initial overall assessment of radioactive fallout in the event of an emergency.

Faster protocols are also emerging in laboratories to allow the analysis of the hazardous nature of the samples taken from the environment to guide decisions. “After Fukushima Daiichi, we realized that we were too slow for the needs of emergency manage-

TECHNICAL TOOLS

Method

Inverse modeling improves understanding of releases

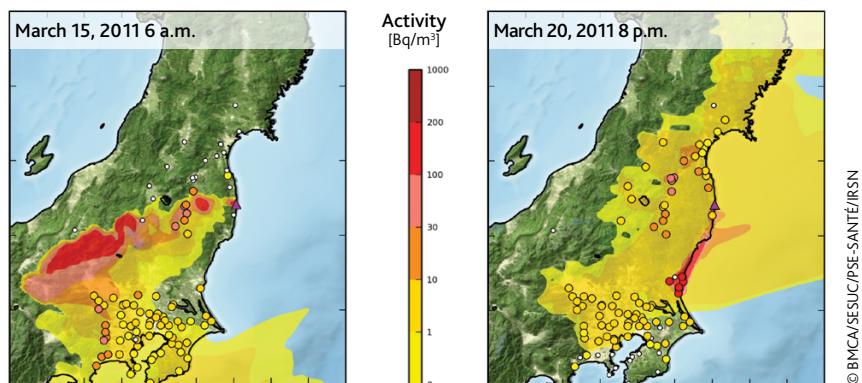
“Inverse modeling [IM] combines measurements made in the environment with atmospheric dispersion models. It helps to accurately deduce a source term [ST], namely the composition of a radioactive release from a facility and its chronology,” summarized Olivier Saunier, specialist in atmospheric dispersion. IRSN was the first to implement an IM method based on gamma dose rate measurements to estimate the Fukushima Daiichi’s source term in 2013*.

How was IM developed? In 2011, this was a research project. When the accident in Japan occurred, the atmospheric dispersion model used failed to accurately reconstruct the contamination. “At the time, this model required input data on the weather, to simulate

the cloud’s path, and the ST,” Saunier explained. These were not sufficiently accurate, as the results did not correspond to the field surveys that poured in during the accident. To improve knowledge of releases and help assess environmental and health consequences, experts use dose rate measurements based on networks of beacons. These are dense and provide fine temporal resolution—10 to 60 minutes in the case of Fukushima Daiichi. Validated during the accident in Japan, IM is now useful in the event of abnormal detection of radionuclides.

In 2020, it helped assess releases from forest fires in the Chernobyl power plant exclusion zone.

*O. Saunier et al. *Atmos. Chem. Phys.*, 2013.



Simulated cesium-137 plume, obtained from the source term reconstructed by inverse modeling, during the two main contamination events in March 2011.

ment,” said Béatrice Boulet, Radiochemist. “You can’t wait six weeks before determining the presence of strontium 90, plutonium, or something else. We have developed protocols that produce an answer in a day,” she added. IRSN is also working on other topics (see p. 16).

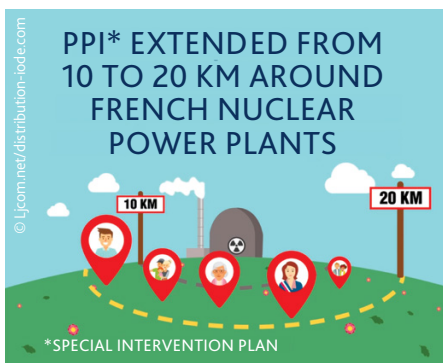
Special Intervention Plans

Following interministerial discussions on feedback from Fukushima Daiichi, the French Prime Minister adopted the new doctrine relating to Special Intervention Plans (PPI) in 2016. By 2022, it should include the French national response plan for major nuclear or radiological accidents. This large-scale plan emerged in 2014, after the accident in Japan, because the public authorities wished to improve the safety

of the population in the event of accidents of exceptional magnitude. “PPIs define an organization that allows to be ready to act in the event of an accident,” summarized Erik Leclerc, specialist in the management of emergency situations. Coordinated by the prefects at the French department level, they provide for three actions to protect the population: sheltering in place and counseling, stable iodine administration, and evacuation. The latter is triggered when exposure forecasts for the population exceed 50 mSv in effective dose for the whole body. “Fukushima Daiichi has changed these measures.”

Among the accident scenarios considered, the possibility of a rapid release was taken into account in the 2000s with the establishment of an automatic shelter-in-place radius,

EMERGENCY



for example, 2 km around power plants. These plans are now supplemented by the possibility of immediate evacuation within a 5 km radius if the rapid releases are long-term, as was the case for Fukushima Daiichi. The disaster in Japan also showed that the impact of an accident can extend over dozens of kilometers. PPIs therefore increased their perimeter from 10 to 20 km around the power plant, within which stable iodine tablets are distributed in advance (see p. 18) and public awareness campaigns are carried out. ■

1. *Steering committee for managing the post-accident phase of a nuclear accident or radiological emergency situation/ Comité directeur pour la gestion de la phase post-accidentelle.*
2. *Calculation of consequences and mapping.*
3. *Predictive modeling of future exposure of the population to ambient radioactivity in inhabited areas and of food chain contamination due to radioactive deposits.*
4. *During precipitation, raindrops carry away the radioactivity collected during cloud formation.*

WWW Find out more:
National doctrine for nuclear post-accident management, October 2012
www.french-nuclear-safety.fr => Information => News releases => National doctrine for nuclear post-accident management

WEBMAGAZINE



READ
Post-accident management should include social consequences
irsn.fr/R48-EN



READ
What human resources to call upon in extreme situations?
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What is IRSN's role within the CODIRPA?

The Institute provides technical information on many topics. It presents accident scenarios including release calculations and dose maps used as input for reflections on the post-accident (PA) doctrine. After Fukushima Daiichi, it studied a serious accident scenario with long-term releases. IRSN also contributes to actions carried out in favor of or in interaction with local stakeholders.

What are the CODIRPA's directions?

We need to assess whether the population protection doctrine, drawn up in consideration of releases from nuclear power plants, is suitable for other facilities. For example, plutonium is

less irradiating than radioactive releases from power plants but can be highly dangerous if ingested. Another issue is releases into aquatic, marine, or fluvial environments.

At Fukushima Daiichi, there were releases into the sea and concerns about their impact. This is a concern in France, too, as its power plants are located on river banks or on the coast.

What about remediation?

Contaminated soil management will be dealt with in more detail. This involves defining contamination reduction strategies and remediation recommendations for the public authorities. This includes managing the waste produced. Decontaminating soil, for example, can involve

removing 10 or 20 centimeters of topsoil. Depending on the desired clean-up target levels, the costs and volumes of waste generated may significantly differ.

We assess the pros and cons of the various options. It is essential that the population and elected representatives be more involved in these issues. The resilience of contaminated areas relies on upstream preparation and stakeholder involvement in the decision-making process regarding the measures to be put in place.



3 questions for...

Philippe Dubiau

Executive Director for emergency preparedness and response

ECONOMY

Cost calculation has improved

Loss of business, devaluation of housing, health-related costs, and contamination remediation expenses, these are four modules that will be added to ARPAGON in 2021. This software program assesses the economic consequences of a nuclear accident. It was created in 2012 by the IRSN's Nuclear Risk Economics Laboratory (LERN). The feedback from 2011 helped identify several improvements in methods and tools for calculating the economic costs of an accident. The Institute provides support in the event of an emergency. Its objective is "to be able to offer the public authorities, at the end of the emergency phase, technical options for managing contaminated areas, including cost assessments," explained Ludivine Pascucci-Cahen, Economist at IRSN. In addition, the costs of accidents are compared with the cost of preventing them.

Another new feature: under the AMORAD research program (improving models used to predict dispersion and assess the impact of radionuclides on the environment) (see p. 20), ARPAGON will estimate the losses of forest and aquatic resources.

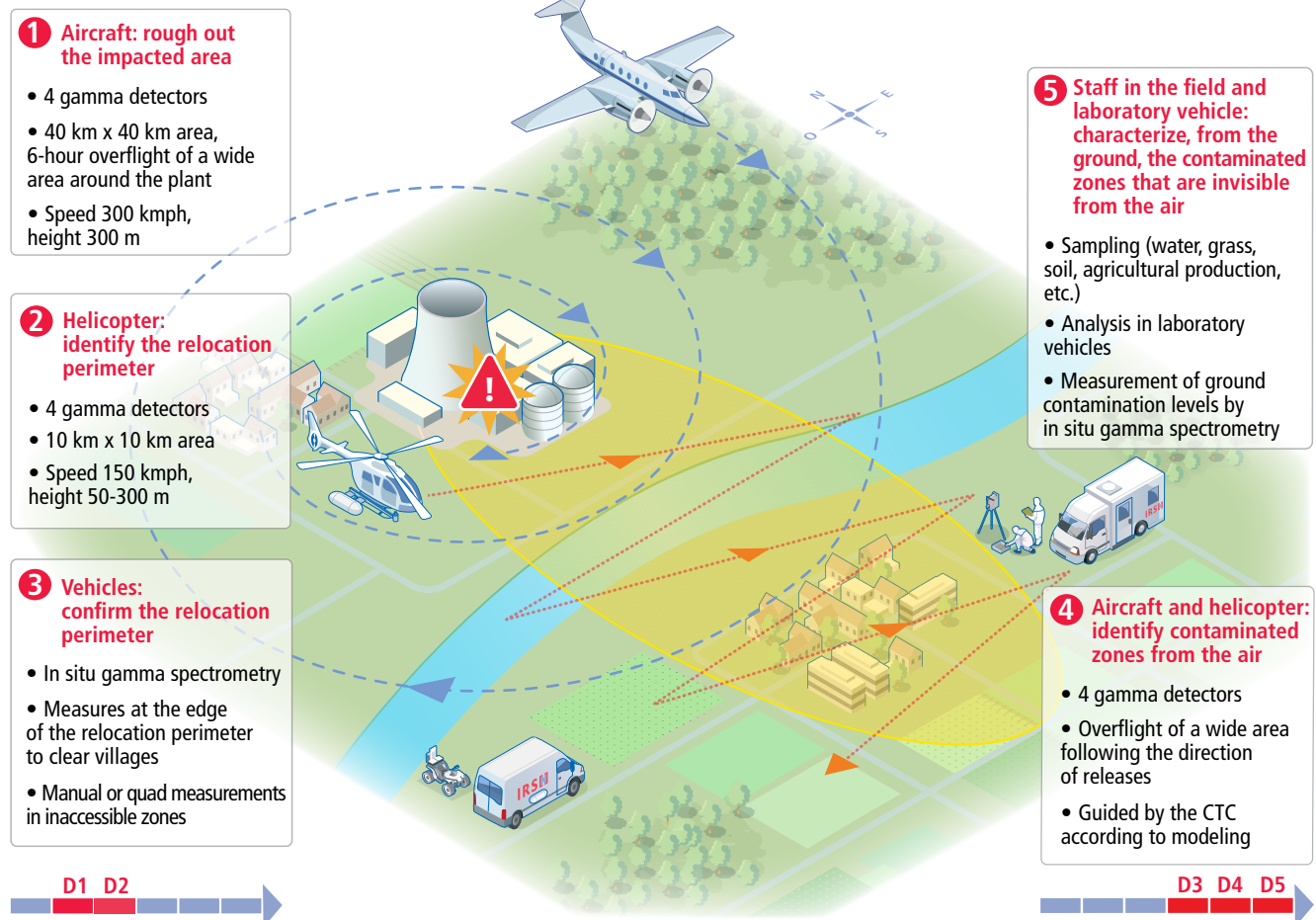


Ludivine Pascucci-Cahen studies the economic consequences of accidents.

MEANS AND PROVISIONS

What means are deployed to map a contaminated area?

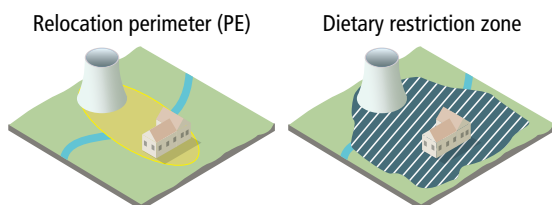
To protect the population in the event of a nuclear accident with releases, the priority is to quickly and reliably identify the affected areas requiring protection measures, in order to advise the authorities. IRSN's strategy is based on the successive deployment of measurement resources in the field, in constant contact with its Emergency Center (CTC) in Hauts-de-Seine department. Some means have been developed as a result of the Fukushima Daiichi accident.



The IRSN Emergency Center (CTC) in constant liaison
 IRSN's CTC is based in Fontenay-aux-Roses (Hauts-de-Seine department).

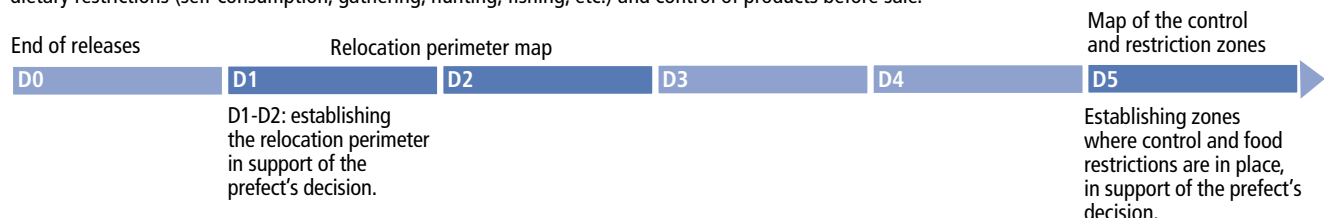
- It provides technical information on the accident (type of release, approximate quantity, weather conditions, etc.).
- It uses the measurements taken in the field and establishes a diagnosis of the effective doses in the impacted zone in the form of a map to refine modeling.
- It provides the authorities with the information required to protect the population.

Two types of zones impacted by protection measures
 By comparing the measurements and the results obtained from modeling, IRSN defines the zoning.



The population is informed on a daily basis

The authorities, informed by IRSN, decide on protection measures: sheltering in place, relocation of the population, dietary restrictions (self-consumption, gathering, hunting, fishing, etc.) and control of products before sale.





An IRSN Emergency Response Officer reassures a person and collects information while screening for internal contamination with X- and gamma-emitting radionuclides.



Following a nuclear accident, people may have ingested or inhaled radioelements. Whole body counting measures internal contamination.

Population protection

What progress has been made in ten years?

Preventive iodine intake, health monitoring... Radiation protection measures in the event of a nuclear accident are implemented since 2011. In addition, one major recommendation for health surveillance is that national cancer registries be maintained for all categories of the population.

Preventive intake of stable iodine, in the form of potassium iodine (KI), is one of the population protection strategies used during the emergency phase of a nuclear threat or accident with releases. By saturating the thyroid with stable iodine, this countermeasure prevents the gland from uptake and fixation of radioactive iodine, and limits the occurrence of thyroid cancer.

Its implementation in France has been recommended since 1997. As soon as there is an alert, an adult should take two 65 mg tablets. Intake may be repeated once if exposure exceeds 24 hours. The dosage for children is adapted according to their age. Fukushima Daiichi showed that this measure is insufficient for people awaiting evacuation or who cannot be evacuated in the event of prolonged or repeated releases. In 2014, the Institute initiated the PRIODAC¹ project, funded by the French Investments for the Future Program (PIA). “We needed

to find a KI dosage allowing repeated intake and verify its effectiveness and safety,” explained Marc Benderitter who specializes in radiopathology. He has been in charge of this major project, which includes pre-clinical studies of pharmacokinetics, therapeutic effectiveness, and toxicology. Rat pups model newborns, while female rats in gestation represent pregnant women, and young, adult, and aged rats cover the rest of the population. Preclinical regulatory toxicology studies complete the program. PRIODAC aims to change the KI dosage for repeated intake by all categories of the population and to modify the marketing authorization by 2022.

Questioning screening practices

How can the risk of thyroid cancer be assessed in the event of releases? Japan opted for systematic screening. “*The World Health Organization (WHO) now advises against this type of monitoring,*”² reported

Dominique Laurier, expert in the biological effects of radiation. This recommendation follows on from long-term feedback.

After the Chernobyl accident, studies showed an increase in thyroid cancer, especially in young people exposed to releases. In 2011, Japan wanted to reassure its population. Without precise estimates of the extent of the accident, that summer it launched a vast screening campaign using ultrasound scanning, a very sensitive technique. Three hundred thousand boys and girls were screened. The fifth screening campaign is currently underway. What are the results? For every thyroid nodule discovered, a biopsy is taken. In case of malignancy, the gland is either fully or partially removed. In ten years, two hundred surgical procedures have been carried out. Is this world record due to the accident or a result of this uncommon strategy of operating even before symptoms appear, criticized more and more? “*This screening*

gives the impression that there are more cases and that they are due to radioactivity. The occurrence of cancer is actually stable. Most of these nodules are not radiation-induced,” explained Laurier.

This proactive choice is gradually revealing its flaws. Screening leads to overdiagnosis, causes worry, causes more ablation, and exposes people to unnecessary hormone therapy. Ultimately, there is no clinical benefit; therefore, the experts issued new recommendations. There is now consensus on waiting and monitoring the tumor nodule without operating on it. Japan is adopting this strategy for its final screening campaigns. Japan’s experience is instructive. In 2011, the Fukushima prefecture did not have a cancer registry. If it had had one, it could have used it to identify a possible resurgence of thyroid cancer. France has a national childhood cancer registry but does not cover the entire country for adults. Such registries help to evaluate the health risk and develop dialogue with civil society. The Shamisen project recommends implementing them (see opposite). ■

1. Repeated prophylaxis with stable iodine in an accident situation/Prophylaxie répétée par l'iode stable en situation accidentelle.
2. WHO (2018), *Thyroid Health Monitoring after Nuclear Accidents*.

WWW Find out more: [PRIODAC irsn.fr/priodac-EN](http://PRIODAC.irsn.fr/priodac-EN)

INTERNATIONAL

Shamisen project

In favor of a radiation protection culture



The Shamisen project recommends developing a radiation protection culture. In Tokyo, local authorities received training on iodine tablet distribution to residents in 2014.

Twenty-eight recommendations to improve dosimetric, health, and epidemiological surveillance after a nuclear accident are the takeaways from the European Shamisen project initiated in 2015 that included IRSN as a participant. One principle conditions all the others: to do more good than harm. Health surveillance must respect the independence and dignity of populations. The project encourages training of personnel—medical or not—according to the different phases of an accident, developing evacuation and shelter-in-place protocols,

and supporting populations who desire to take their own measurements of radioactivity in the environment, in food, etc. The authors recommend developing, with the help of experts, mobile applications and easy-to-use dosimetry devices. Nineteen European and Japanese partners are involved in Shamisen, representing around sixty specialists in radiation protection, dosimetry, sociology, medicine, psychology, and more.

WWW Find out more: [Shamisen irsn.fr/Shamisen-EN](http://Shamisen.irsn.fr/Shamisen-EN)

IN A NUTSHELL

Internal contamination: measuring equipment that adapts to everybody

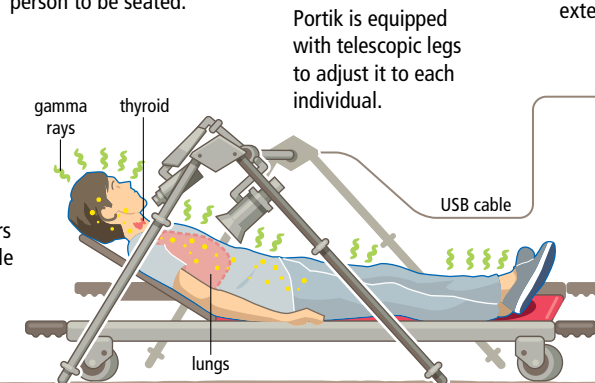
The Portik detector is suitable for both a child and a wheelchair user and measures internal contamination. This portable* whole body counter can be deployed quickly to a disaster area so that people requiring medical attention are identified without delay.



The Portik detector is transportable
Disassembled for transport, it can be ready in just a few hours to round out the array of mobile resources already on site: lab trucks and light whole body radiometry vehicles (boxers).

* IRSN patent FR3050281

Versatile
Portik works in all positions, unlike boxers that require the person to be seated.

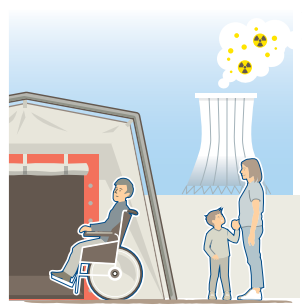


Freestanding
Combined with a laptop computer, it can be used without an external power source.



Spectrometry software acquires and analyzes gamma spectra.

Rapid triage
Set up as close as possible to operational emergency centers to facilitate prompt treatment of contaminated individuals, who are placed in private rooms or a tent.



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ENVIRONMENT

Environmental contamination

Models are progressing

When an accident occurs, forests, marine and agricultural environments are contaminated. The long-term effects of this contamination are being studied. In ten years, research has provided knowledge on the transfer of radionuclides to ecosystems, the quantification of uncertainties in models, etc.

How can the medium- and long-term consequences of a radioactive release on humans and the environment be assessed? They can be assessed by optimizing the models that predict their dispersion and estimate their dosimetric impact. Coordinated by IRSN, the AMORAD¹ project is developing three lines of research: the cesium² cycle in forests, erosion-runoff flows from watersheds to rivers and then to the sea, and the impact of releases on the marine environment (water, sediments, organisms).

Cesium transfer in forest ecosystems

As a vulnerable biotope, forests capture more atmospheric contamination than agricultural and urban environments. They then contaminate other environments, via erosion, runoff, fires, etc. It is therefore essential to predict the evolution of contamination in the various compartments—soil, tree and forest understory. In 2011, the existing empirical model proved insufficient, as it had not been well tested, due to the lack of data immediately following Chernobyl.

With AMORAD, cesium transfer is specified after validation of the new TREE4 model on data from forty Japanese forest sites. *“TREE4 calculates the levels of contamination and predicts their short- to long-term evolution, from several months to thirty years,”* explained Marc-André Gonze, terrestrial ecosystem modeling and risk assessment expert.

The tool makes it possible to estimate, in microsievert per hour ($\mu\text{Sv/h}$), how the resulting external dose rates evolve over time in a forest environment and to assess the efficiency of decontamination efforts like removing part of the soil, tree felling, etc. *“How quickly will we be able to restart forestry? How can we shorten this time?”* Gonze comments. He goes on to say, *“If a nuclear accident were to occur in France, these*



IRSN researcher Sabine Charmasson takes samples and cores on the coast and at sea to assess the contamination of water and marine sediments along the coast, north of the Fukushima Daiichi plant.



Sampling campaign in French forests as part of Dina Okhrimchuk's thesis. Pierre Hurtevent, Engineer, takes samples from the roots of a beech tree.

calculations would help decision making.” The model, parameterized with the Japanese dataset, needs to be transposed to the French context, according to the nature of its vegetation, soil, and climate. A thesis is currently exploring this issue³.

Taking an ecosystem-based approach

Marine models also revealed shortcomings in 2011. Improvements must be made in radionuclide dissemination predictions and simulations of transfers to fish and shellfish consumed by humans. After ten years of research, dispersion modeling, based on marine current calculations, is operational and ready to be used by the IRSN Emergency Center (see *Webmag*). Another model, regarding transfer to biological species, has also been perfected. “In the event of an emergency, the tools must make it possible to quickly issue recommendations: bans on fishing, consumption, etc. Based on the estimated levels in the water, they assess the radionuclide concentrations expected in fish,” explained Céline Duffa, specialist in radionuclide transfer in marine systems. “The accident in Japan shows that species contamination varies according to habitat and diet. Benthic organisms—living on the seabed, such as the olive flounder—are the most affected. Their diet is linked to sediment, which traps radioactivity,” she added.

AMORAD offers a new ecosystem-based approach and considers transfers across the entire trophic chain. It considers the relationships between various organisms according to their eating habits.

Quantify uncertainties

In the agricultural field, post-Chernobyl models on market gardening (cabbage, spinach, etc.), field crops, and livestock products (milk, meat, etc.) were already present in operational tools like Symbiose⁴, and these remain valid. The lack of a model for orchard fruit (apples, cherries, etc.) has been remedied thanks to data acquired by the Japanese authorities.

The Fukushima Daiichi accident highlighted the need to know how to quantify the level of accuracy of forecasts and their uncertainties. “Post-accident zoning [see p. 14] is defined by comparing predicted values with a benchmark. For safe zoning, we seek to quantify the uncertainties of models,” concluded Marie Simon-Cornu, specialist in risk assessment. ■

EUROPE

Territories project

Managing the post-accident phase at the local level



The local nuclear information commission (CLIN) of the Gironde department hosted a delegation of Japanese and Belarusian stakeholders as part of the Territories program in December 2018.

How can land affected by long-term contamination be managed? This question is at the heart of the Territories project led by IRSN. “We make thirteen recommendations on how to model the long-term evolution of contamination, include uncertainty in decision-making, develop co-expertise in radiation monitoring, and so forth. Citizens, experts, and institutions all work together on this project,” said Marie Simon-Cornu, coordinator of the project involving eleven European partners.

Ties with Japan are strong. In late 2018, during a workshop with Le Blayais (Gironde department) local nuclear information commission (CLIN), several Japanese stakeholders shared their

experience with wine makers. The testimonial from a persimmon producer was particularly memorable. “He explained how the trees and fields were cleaned and how each piece of fruit was monitored for radiation,” recalled Xavier Paulmaz, Project Manager for the CLIN. A fictitious accident was envisaged, and consideration was given to the following questions: How could business be revived? Should the vines be pulled up? What financial support would be available? Since then, a working group has made local stakeholders aware of these issues.

WWW Find out more:
Territories.eu

1. Improvement of models for predicting the dispersion and assessing the impact of radionuclides in the environment.
2. Radioactive cesium isotopes are among the major radioelements in accidental releases from power plants.
3. Study of the long-term behavior of atmospheric fallout of cesium-137 in French forests, Dina Okhrimchuk, in progress.
4. Platform for simulating the transfer of radionuclides to ecosystems and calculating the dosimetric impact on humans.

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AMORAD
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WEBMAGAZINE



READ
A mapping tool to help local stakeholders prepare
irsn.fr/R48-EN

2011-2021: IRSN's actions

The Institute has monitored developments in Japan since March 11, 2011. It has deployed its multi-disciplinary expertise to assist in guiding national and international discussions on safety, and supports civil society by responding to their questions and concerns.

■ 2011: Handling the emergency in Japan and France

From March 11, IRSN deployed its Emergency Center (CTC) based in the Hauts-de-Seine department (*see Webmag*). Expert Olivier Isnard accompanied the French civil security rescue mission seconded to Japan.

Through dose rate measurements, he ensured that there was no radiological risk for the team members. *“The Institute supported us before, during, and on our return from our clearance mission,”* attested Bertrand Domeneghetti, lieutenant-colonel of the fire brigade at the General Directorate for Civil Protection and Emergency Management, in 2012. With around twenty rescuers, IRSN conducted a radiological risk assessment at the *Lycée Français* in Tokyo and then informed parents and staff.

The expert stayed in Japan for five weeks, analyzing the situation and the stakes. A daily news bulletin was published on the embassy’s website. At the Pompidou Center’s request, he screened the 170 works exhibited at the National Art Center, Tokyo, for contamination before their return to France.

In France, the Vésinet Center (Yvelines department) deployed specialists in radiological measurements. They carried out whole-body counting on personnel returning from Japan, from Air France and Radio France as well as Cybernetix, who dismantled a power plant south of the damaged one.

At the end of 2011 and then in April 2012, the Institute took part in contamination measurement and mapping campaigns near Fukushima Daiichi. Its specialists carried out in situ readings and measured the dose rate in cars, using the Ulysse system (*see p. 17*). Over 100,000 gamma spectrometry measurement points were read, including in the evacuated zone.

■ Four weeks of non-stop work at the CTC

The Institute’s CTC was very involved in handling the accident in Japan. For four weeks straight, its experts were constantly at work. A force of at least 30 experts were on hand during the day and 20 at night, totaling 200 of the Institute’s 1,700 staff at that time.

It’s the full breadth of IRSN’s expertise, in support of this team of experts, which made it possible to provide estimates of the consequences in Japan and France.

■ Thriving safety policies in action

In the aftermath of the accident, the Institute got organized to respond to the Prime Minister’s request for complementary safety assessments on nuclear facilities to examine their resistance to high-intensity loads. Karine Herviou, Safety Expert, remembered that *“although we had not finished managing the emergency, we were already getting organized to make a decision as to how to manage the impact on French facilities. The request for a ‘hardened safety core’ is the result.”*

■ Analysis and explanations

A few months after the accident, the French High Committee for Transparency and Information on Nuclear Safety (HCTISN¹) and several local information commissions (CLI) asked the Institute for an interpretation of the events that occurred at the Japanese plant. Between September 2011 and January 2012, IRSN and the French National Association of Local Information Committees and Commissions (ANCCLI²) co-organized three seminars to monitor complementary safety assessments and present IRSN’s conclusions from them. This would include introducing the hardened safety core concept which aims to improve the safety of facilities in the event of exceptional hazards (*see p. 8*).





In February 2013, IRSN measured the contamination level of a school that was evacuated and then decontaminated in Kawamata, Japan.



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2018 saw the renewal of the IRSN and IAEA cooperation agreement. Jean-Christophe Niel, the Institute's Director General (left), and Juan Carlos Lentijo, IAEA Deputy Director General and Head of the Department of Nuclear Safety and Security (right).



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Gilles Compagnat at the ANCLI-IRSN seminar on post-Fukushima safety issues.

■ An international presence

The Institute participated in the peer review of the conclusions of European stress tests, an international action similar to France's complementary safety assessments. It also participated in several IAEA³ activities. In 2013, a request was made to IRSN to organize a seminar in Japan on serious accidents, during which it presented the French hardened safety core initiative. It took part in ETSO⁴ network safety discussions.

"We are present in all the major international organizations to share our experience on the accident, the lessons learned, and to compare safety improvements," Herviou concluded.

■ Ten years of monitoring...

Since 2011, the Institute has been involved in monitoring developments in the situation in Japan, ranging from emergency management, impacts on the environment and health to facility condition, dismantling, social consequences, and so on.

Eight annual news bulletins have been published on *irsn.fr*. Locally, IRSN is involved in several technical projects such as dismantling, as well as community projects, such as the *Fukushima Dialogue* initiative (see p. 6).

■ Vigilant local commissions

Since the Fukushima Daiichi accident, the Golfech (Tarn-et-Garonne department) CLI's actions have been inspired by the feedback from it.

When the special intervention plans (PPI⁵) were applied to a radius of 20 km around French power plants, an awareness campaign was organized, targeting 130,000 additional residents. Weekly ambient radioactivity measurements are carried out using the *OpenRadiation* sensor supplied by IRSN. This tool, connected to a smartphone, allows volunteer citizens and communities to share these measurements on a website thereby contributing to improving knowledge on the local environment.

Regarding safety, *"commission members have been visiting the Golfech power plant since 2016 to monitor the deployment of the hardened safety core,"* (see p. 8) reported Véronique Auguste, Project Manager for this CLI. This level of vigilance was put

into place following commission member Gilles Compagnat's trip to Japan in 2014. During his stay, he met with the former director of the Fukushima Daiichi plant, located 11 km south of the damaged facility, where the disaster was averted. *"Employees managed to pull 9 km of electric cables to restart the pumps. This prevented the hydrogen from exploding,"* he explained. In 2015, CLI set up a technical commission on organizational and human factors, which studies all significant safety events from this perspective. ■

1. Haut Comité pour la transparence et l'information sur la sécurité nucléaire.
2. Association nationale des comités et commissions locales d'information.
3. International Atomic Energy Agency.
4. European Technical Safety Organization Network.
5. Plan particulier d'intervention.

WWW Find out more:
 Involvement: Understanding Fukushima in France irsn.fr/fuku-lessons
 Complementary safety assessments: The condition of nuclear facilities post-Fukushima irsn.fr/ECS-EN
 IRSN briefs on the Fukushima Daiichi accident irsn.fr/fukushima-EN
 OpenRadiation openradiation.org/en



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Two IRSN experts measure radioactivity during an IAEA exercise near Fukushima Daiichi.

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We hope that you have enjoyed reading this special issue of Repères devoted entirely to the Fukushima accident and its aftermath. Would you like to learn more about managing severe accidents, the complementary safety assessments performed in France, the Fukushima Dialogue initiative and other topics related to nuclear safety and radiation protection research?

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