The IRSN newsmagazine

Repères

IRSN
January 2012

Special Report

FUKUSHIMA

First lessons learned

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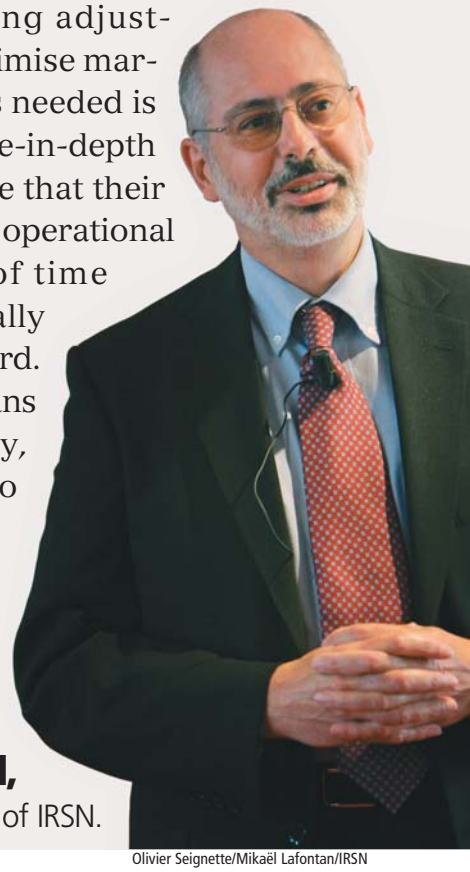
Cover : damaged reactors at the Fukushima Daiichi nuclear power plant after the accident.

DigitalGlobe; Grégoire Maisonneuve/IRSN; Noak/Le bar Floréal/IRSN

The "hardened safety core" inspired by Fukushima

The Fukushima-Daïchi NPP accident was the first occurence showing that an extreme natural event, that generated stress levels far beyond nuclear power plant design-basis values, could lead to a core meltdown accident. It also showed how the massive destruction of a site and of the surrounding infrastructures could delay and complicate all accident management operations. However, the world's nuclear reactors were built without making allowance for risks associated with such events, because of their extremely improbable character.
In order to avoid the re-occurence of such accidents, IRSN considers that checking existing safety margins against these extreme hazards, or making adjustments here and there to optimise margins, is not enough. What is needed is an additional level of defence-in-depth at nuclear facilities to ensure that their vital safety functions remain operational over a sufficient period of time in the event of any physically possible environmental hazard. This is what the Institute means by "hardened core" safety, a notion that it intends to promote internationaly.



Jacques Repussard,
Director General of IRSN.

Olivier Seignette/Mikaël Lafontan/IRSN

About Repères

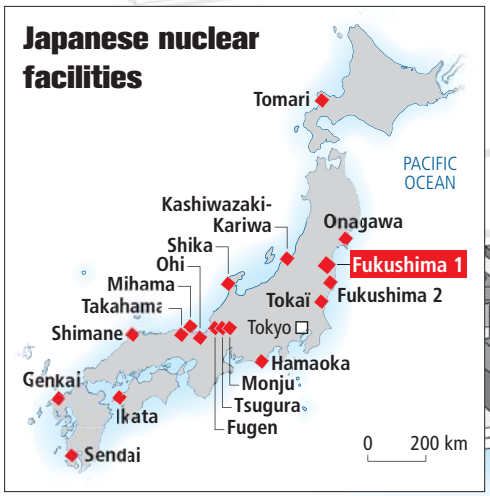
Enhancing nuclear safety is the main drive of every action of IRSN.
Within this scope the Institute takes the commitment to make the results of its research, studies and reports accessible for all professionals involved in nuclear safety, security and radiation protection, as well as the public and civil society. That is why the Institute publishes a quarterly French newsmagazine, Repères, who 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 accident prompted us to propose an English translation of our special issue focused on the accident and on the first lessons drawn by IRSN regarding nuclear safety.

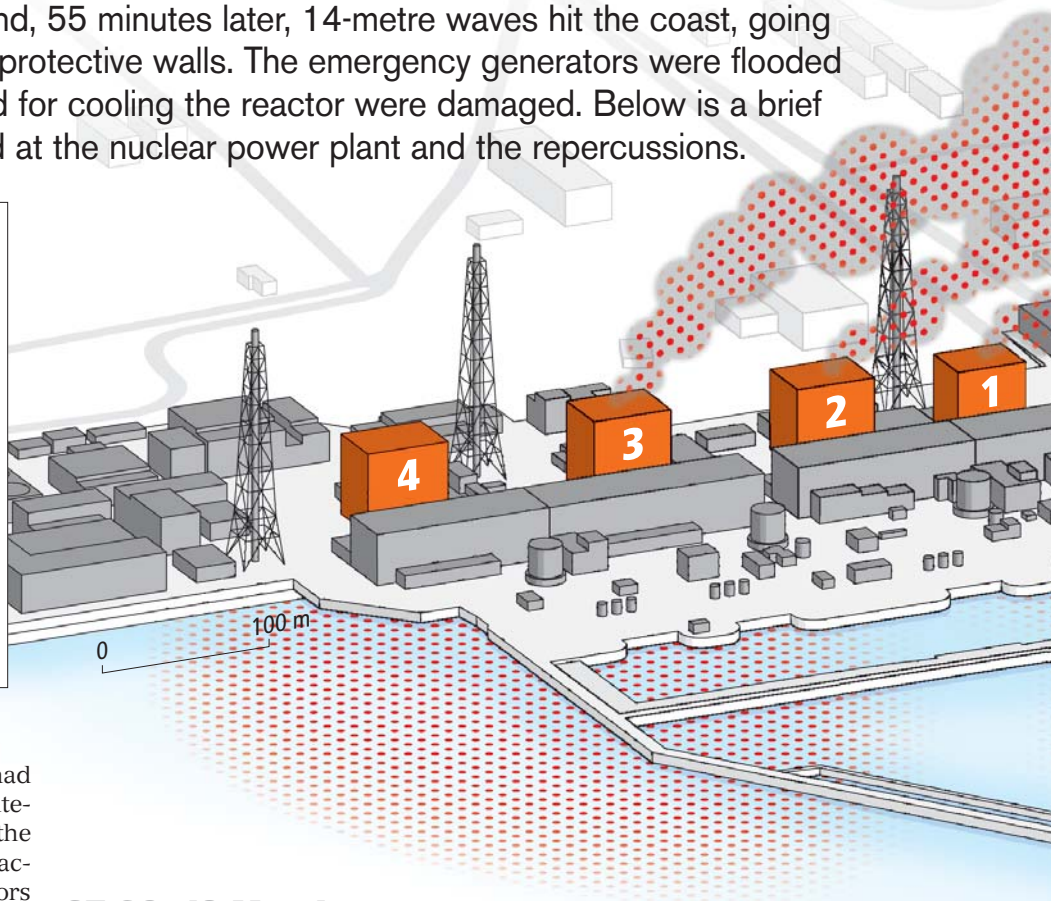
IRSN **Repères** – Published by: Institut de radioprotection et de sûreté nucléaire – 31, avenue de la Division-Leclerc, 92260 Fontenay-aux-Roses – Phone: +33 (0)1 58 35 88 88 – Website: www.irsn.fr – Email: reperes@irsn.fr – **Executive editor:** Jacques Repussard – **Managing editor:** Marie-Pierre Bigot – **Editor:** Catherine Roulleau – **Assistant editor:** Isabelle Cussinet – **Reading committee:** Michel Brière and Jérôme Joly – **Editorial assistance, editing, editing secretarial services, art direction, production:** Emapress – **Illustrations:** Charlotte Heuzé – **Computer graphics:** Hervé Bouilly – **Printed by:** Galaxy (72) – Printed on Cyclus print – **ISSN :** 2103-3811 – January 2012.

Nuclear disaster

Earthquake plus tsunami – a catastrophic combination

On Friday 11 March 2011, at 14:46 local time (i.e. 06:46 in France), an 8.9-magnitude earthquake occurred 80 km off the eastern coast of Japan's island of Honshu, causing a loss of electrical power at the Fukushima Daiichi nuclear power plant. The reactors shut down and the emergency generators took over. The earthquake, however, had also triggered a tsunami and, 55 minutes later, 14-metre waves hit the coast, going over the top of the plant's protective walls. The emergency generators were flooded and the water intakes used for cooling the reactor were damaged. Below is a brief account of what happened at the nuclear power plant and the repercussions.





11 March 2011

Core meltdown. Reactors 4, 5 and 6 had already been shut down for maintenance. The earthquake caused the automatic shutdown of the three reactors still in operation, namely reactors 1, 2 and 3. It also led to the loss of the reactor off-site power supplies, causing the on-site power supplies (emergency diesel generators) to take over. Fifty-five minutes later, a 14 metres tsunami wave damaged the plant's seawater intakes, shutting down the emergency diesel generators of reactors 1 to 4. This was what caused the core meltdown in reactors 1, 2 and 3, leading to radioactive release. The meltdown required venting operations to be carried out to bring down the pressure inside the containment buildings. ■

07:36, 12 March

Reactor 1. An explosion occurred at the top of reactor 1. A few hours earlier, venting had been started to reduce containment pressure. Given the loss of cooling system, the plant manager decided to inject seawater into the reactor core as a last resort. ■

13:00, 14 March

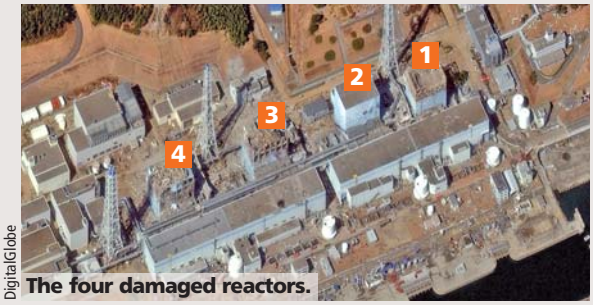
Reactor 3. An explosion occurred at the top of reactor 3. The containment had been vented 24 hours earlier. Seawater was injected to cool down the reactor core. There was also concern about the spent fuel storage pool and on 17 March a helicopter dropped seawater onto it, but with little success. The next day, fire fighting systems were used to make up for evaporation. ■

22:00, 14 March

Reactor 4. A fire of unknown origin broke out in the fuel pool area of reactor 4 (which had already been shut down for maintenance, with the core unloaded). In the evening, another fire broke out, this time in the northwest of

Infographics: Hervé Bouilly - Source: IRSN

The Fukushima Daiichi nuclear power plant



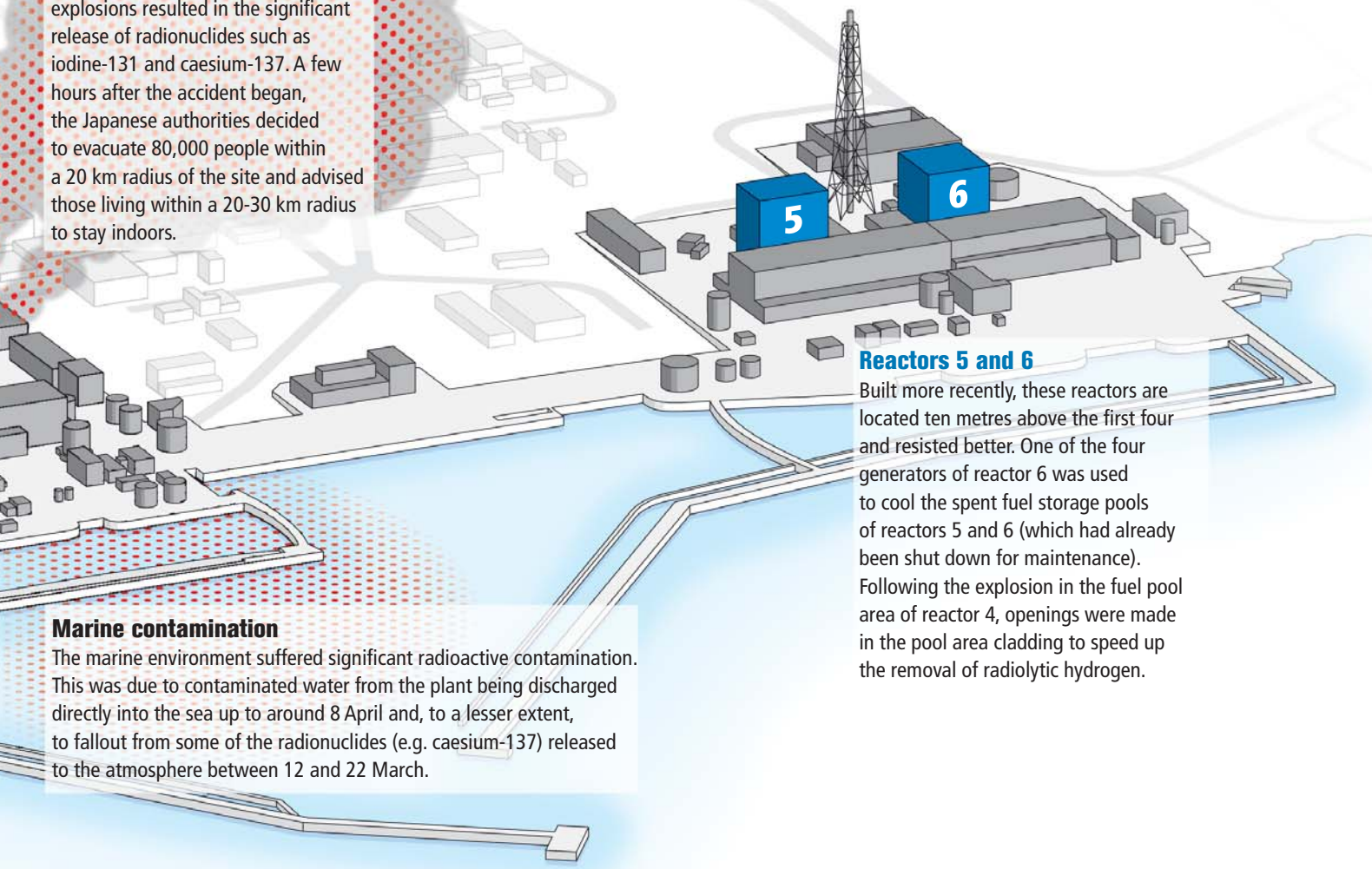
DigitalGlobe

The four damaged reactors.

Fukushima Daiichi (Daiichi means "number one") is a nuclear power plant operated by TEPCO, the Tokyo Electric Power Company. It consists of six American-designed boiling water reactors with a power output of 460 to 1100 MW. The reactors were built in the 1970s.

Atmospheric contamination

The series of decompressions and explosions resulted in the significant release of radionuclides such as iodine-131 and caesium-137. A few hours after the accident began, the Japanese authorities decided to evacuate 80,000 people within a 20 km radius of the site and advised those living within a 20-30 km radius to stay indoors.



Reactors 5 and 6

Built more recently, these reactors are located ten metres above the first four and resisted better. One of the four generators of reactor 6 was used to cool the spent fuel storage pools of reactors 5 and 6 (which had already been shut down for maintenance). Following the explosion in the fuel pool area of reactor 4, openings were made in the pool area cladding to speed up the removal of radiolytic hydrogen.

Marine contamination

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

the building, followed by an explosion in the fuel pool area. Water was poured onto the pool through a concrete pump arm. ■

22:10, 14 March

Reactor 2. An explosion occurred at the bottom of reactor 2. A loss of cooling system had been reported at 8:00 that morning. Seawater was injected to cool down the reactor core. ■

Different reactor technologies

Although all the nuclear power reactors operating in the world today make use of fission energy[1] to generate electricity, their design varies considerably. The Fukushima plant, for example, is equipped with boiling water reactors (BWR). French plants operated by EDF, the national electric utility, have pressurised water reactors (PWR). **There are two major differences between these technologies:**

- The size of the containment building, which is much smaller in BWRs, causing pressure to rise faster;
- The cooling system. In BWRs, the steam generated during core cooling goes directly to the turbine. PWRs, however, have an intermediate system: the reactor coolant system cools itself by transferring its heat to a secondary cooling system that drives the turbine.

1. Phenomenon in which the nucleus of an atom splits, giving off a very large quantity of energy.

The control room of IRSN's emergency response centre (CTC) at Fontenay-aux-Roses.

The experts in the CTC's health impact unit drafted responses to queries from the French Directorate General for Health.

Mobilisation

Understanding Fukushima from

The Japanese reactor accident required a special organisation of IRSN's emergency response
The 200 trained experts mobilised to address the nuclear crisis rose to the challenge thanks to the

11:00 am, Friday, 11 March 2011. IRSN assembled the members of its emergency response centre (CTC) at Fontenay-aux-Roses as soon as information on the impact of the 8.9-magnitude earthquake that rocked Japan at 6:46 am (Paris time), and the ensuing tsunami, started to trickle in. Although trained in emergency response exercises, little did the CTC's experts know that they were embarking on a four-week marathon during which they would relay each other 24/7. As the crisis played out, the CTC was staffed around the clock by no fewer than 30 experts during the day (three of whom also served as spokespersons) and no fewer than 20 experts during the night. All told, the crisis mobilised 200 of IRSN's 1,700 staff members.

A specially organised CTC...

The Fukushima disaster far exceeded any crisis previously encountered and the emergency response exercises regularly conducted by IRSN, the French Nuclear Safety Authority (ASN) and French nuclear Operators. As a result, the CTC was reorganised to address the specific circumstances of the crisis. The ranks of the CTC were reinforced by a group of engineers skilled in spoken and written Japanese and who worked in rotation over the course of the four-week crisis. *"Ordinarily, the CTC consists of a management unit, a facility assessment unit, a radiological impact unit, a media relations unit, and a secretariat and logistics unit,"* explains Éric Cogez, an emergency situation and emergency response organisation expert at IRSN who is in charge of ensuring the smooth operation of the CTC. *"We immediately added a General Command Post to the scheme."* A health impact unit and an environmental impact unit were set up on the Monday following the quake in order to respond to the avalanche of questions that were rolling in.

Each unit's teams also had to reorganise. *"That Monday morning we understood that not only was this crisis going to last, but that we were going to have to cope with the time difference with Japan. We set up three teams that worked in shifts to ensure they would hold out for the duration of the crisis,"* remembers Franck Bigot, an expert in pressurised water reactors and one of the three key coordinators of the facility assessment unit.

...for a crisis unlike any other

The first concern shared by the experts was how to collect information on an event that was playing itself out 10,000 km away. *"This was a completely new situation,"* remembers Martial Jorel, Director of the CTC. *"Until then, boiling water reactors* (BWR) *were relatively unknown in France. We couldn't contact TEPCO, the Japanese Operator, and information was coming in from various sources and not in real time. We followed the reactor's condition by reading reports that were being published on the websites of TEPCO and NISA*[1] *[...] in order to understand what was happening to the reactors and*

A support unit at the CTC

The need to assess the radiological impact of Fukushima across vast distances rapidly became clear at the emergency response centre (CTC).
To meet this need, Damien Didier, an expert at IRSN, set up a support unit on the radiological impact of Fukushima. *"The tools the CTC uses are designed for calculations over short distances of 50 to 80 km,"* he says. *"As a result, we had to use research and development tools, interface them with available meteorological data for Japan, and build a map and film production environment."* The unit's rapid response made it possible to estimate, as of the first weekend, the trajectory and impact of a possible radioactive plume over Japan.

Photo essay: Grégoire Maisonneuve/IRSN

**Top: the CTC's facility assessment unit.
Bottom: the CTC's radiological impact unit.**

a distance

centre in France.
support of all staff at the Institute.

pools and find out how water was being fed in." In the end, the radiological impact unit is perhaps the unit that worked the most effectively and as planned. It possessed atmospheric release measurements and meteorological data, and was able to calculate deposits left by the plume as well as its trajectories.

Synergy of skills

Despite the difficulties, the experts regularly made diagnosis and prognosis of the situation. Everyone contributed their skills in the race against the clock. One example is the facility assessment team: *"Each of the three key coordinators put their specific skills to work,"* says Franck Bigot. *"Emmanuel Raimond is an expert in the phenomenology of severe accidents such as reactor vessel ruptures or hydrogen releases. Karine Herviou possesses the skills needed to draw connections with radiological impacts on populations. As for me, I was more in a position to analyse the condition of the facility."*

But this was just the beginning: *"Our colleagues volunteered their skills, producing diagrams of the plant for example,"* remembers Martial Jorel. *"And this effort wasn't limited to the CTC. Everyone at IRSN set to work."* Did IRSN's day-to-day operations suffer? *"We always managed to ensure that routine assessments on the operations of facilities in France were carried out,"* says Pascal Quentin, a reactor safety expert who replaced Martial Jorel during the first weekend and was back at his desk the following Monday morning. *"All regular reports for the advisory committees were nevertheless handed in on time."*

IRSN also enlisted the help of partners, such as the French national weather service Météo-France. *"We provided IRSN with forecasts to allow it to anticipate the movements of radioactive elements and with analyses of the past days' weather conditions so that it could retrospectively understand the observations made,"* says Jean-Marie Carrière, director of forecasts at Météo-France. *"We also provided the conclusions of our own forecast calculations on where the plume was heading from Japan in order to combine our results."*

Ultimately, the crisis lasted for six weeks, four of which required round-the-clock vigilance. The CTC was disbanded at 12:00 pm (Paris time) on Friday, 29 April 2011. ■

1. Nuclear and Industrial Safety Agency.

The health and environmental support units

Although not initially part of the CTC, the health impact and environmental impact units quickly proved to be vital. The health impact unit set up base in an IRSN conference room. *"Eight full-time experts, assisted by 16 experts working in rotation, responded to 1,300 requests received in just four weeks from physicians and Occupational Health Physicians, the press and the general public. They were especially busy when the contaminated air masses reached France,"* says Alain Rannou, the health impact unit's radiation safety expert. The unit also scanned 250 people returning from Japan (journalists, expats, airline pilots, etc.) with a whole-body counter to check them for contamination and provided 300 passive dosimeters to people headed for Japan.

The environmental impact unit was set up in Le Vésinet, where the Téléray monitoring room is located. All radiation measurements taken by a network of monitoring stations throughout France are sent to this room, and most of IRSN's sample processing and metrology resources are located there. This network was quickly reinforced. Sensors were sent to France's overseas regions and territories and to the French embassy in Japan, and activated carbon filters were installed to trap iodine-131, a radioisotope that is a by-product of nuclear fission. *"We also increased the sampling frequency by 50%. Over a six-week period we performed 1,200 additional analyses on lettuce, milk and other samples that we asked Météo-France, DGAL[1] and DGCCRF[2] employees across France to send us,"* explains Nathalie Chaptal-Gradoz, one of the people in charge of the unit. *"IRSN's facilities at Cadarache and Octeville helped us to process the extra inflow of samples"* ■

1. French Directorate General on Food Safety.
2. French Directorate for Competition, Consumer Rights, and Protection Against Fraud.

Whole-body scans were performed at the Le Vésinet site.

Noak/Le bar FLoréal/IRSN

Photo essay: Grégoire Maisonneuve/IRSN

1. In the communication unit, Nathalie Kosciusko-Morizet, Minister of Ecology, Sustainable Development, Transport and Housing; Éric Besson, Minister of Industry; Jacques Repussard, Director General of IRSN; and Marie-Pierre Bigot, Director of Communication. 2. Christine Goudedranche, website manager, and Michel Brière, Deputy Director General, in the communication unit. 3. Pascale Portes, Press manager, and two of her collaborators. 4. Press conference led by IRSN spokesman.

> ***"IRSN keeps us informed and we make this information public right away, in a transparent manner."***
>
> **Nathalie Kosciusko-Morizet, minister of Ecology, the 16 March 2011, at a hearing in the French National Assembly.**

Information activity

Taking on the challenge of transparency

During the Fukushima accident, the Institute provided accurate real-time information to local authorities, the media, the public and civil society, mobilising experts and the communication unit.

"In France, we have lived for over twenty-five years with the memory of the Chernobyl 'lie'," recalls Marie-Pierre Bigot, director of communication, who managed IRSN's Emergency Response Centre (CTC) communication unit. Since its creation in 2002, the Institute has led an active information policy. It goes without saying, then, that satisfying the information needs of the local authorities, the media, the population or even civil society was a must during the accident in Japan. *"The nearly ten years of day-to-day work with experts and the mutual understanding of the requirements of our profession have been very helpful during this crisis."*

Informing local authorities

Everything began according to the usual modus operandi. *"We informed the main ministerial offices by telephone, including the Ministry of Ecology and Industry and the Prime Minister,"* recalls Deputy Director General Michel Brière, who was responsible for coordinating IRSN mobilisation during the accident. *"Considering the seriousness of the events, we very quickly activated the CTC and notified more and more political leaders and decision-makers."* IRSN was in fact facing an unprecedented situation. *"With requests coming from all sides, we implemented daily electronic bulletins, summarising our analysis of the state of the Japanese nuclear plants and the consequences for the population and the environment."* Nearly all of the ministerial offices requested to subscribe. IRSN also participated, each morning, in meetings of the interministerial emergency response group, led by the Secretary of the Defence and National Security, service of the Prime Minister. The Institute was called upon by the Parliamentary office of scientific and technological evaluation, which provides information to the parliament and guides its decisions. *"I was called to present the lines of defence of the reactors,"* said Martial Jorel, director of the emergency response centre.

Responding to media in a comprehensible manner

Also in high demand, the communication unit responded to more than one hundred interview requests each day, with mandatory deadlines. *"The French newspaper* Le Monde *loops at 10:30 am: they needed an expert by 9 am at the latest,"* recounts Pascale Portes, press manager. *The radio stations needed regular information flashes, and the television needed content for 1 pm and 8 pm programs."* Three representatives were named rapidly for different fields: facility safety, environment and health. Their greatest difficulty: *"Providing information in real time, while taking*

the time to validate and place into context the elements that were coming to us: What does this measured vessel temperature mean?" summed up Thierry Charles, spokesman for the facilities department. *"We were one of the only institutes to provide so much digested and interpreted information, which undoubtedly explains the progressive wealth of media from China, Japan, Korea, the United States, the United Kingdom and Switzerland."* During this time, Olivier Isnard, an IRSN expert dispatched to Japan, provided on-site interviews for the French living in Japan.

In parallel, the press was monitoring the news. *"We learned about the earthquake from AFP and Reuters, and the first information on the power plants came to us from their dispatches,"* explains Pascale Portes. *"We were a relay between the experts and journalists, in both directions."* Journalist Carole Laporte-Mani, scientific specialist at the French radio station RTL, speaks of the Institute's contribution: *"IRSN was very reactive during the crisis, with daily press points, available spokesmen and a press department that was able to manage meetings while respecting journalists' deadlines. It became my main point of contact. We were getting a lot of raw information, at times contradictory, from Japan. IRSN put it into perspective, prudently explaining why the data were reason to worry or not. You could feel the desire of the experts to be as accurate as possible, to the extent of the information they had. They did this while learning to use language that was accurate without being too scientific. The only negative points were the difficulty of reaching the CTC by transportation and always having the same spokesmen. Journalists prefer to vary interviewed experts, as competent as they are!"*

Dealing with increased website traffic

With IRSN very present in the media, the public was quickly informed via the website. *"Starting Saturday, traffic on the irsn.fr site began increasing,"* said website manager Christine Goudedranche. *"On March 23, the plume flew over France; we registered 600,000 visits in one day, compared to the normal 35,000 per month!"* Mirror sites for the visitors were set up to deal with the increase in traffic. The second technical challenge: providing public access to real-time measurements of radioactivity from sensors in mainland France and in French overseas departments and territories. *"Our database Criter was first created for internal purposes. Within a few days' time, we had to go from 2 to 20 servers, and develop a lighter version of the software."*

The frequently asked questions (FAQ) and electronic bulletins published on the website made it possible for both the press and the public to monitor the situation with quality information. *"We know that they were even translated into Japanese,"* said Marie-Pierre Bigot, reporting on information provided by NHK radio.

Relaying information to local information committees

For his part, Michael Petitfrère, in charge of relations with the local information committees, informed their presidents and leaders. *"We sent them our electronic bulletins and we identified the experts of the CTC who could answer their questions on the passage of air over France or the impact of the accident on the health of an expatriate child."* In mid-September, a seminar was held with ANCCLI[1] to discuss issues of safety following Fukushima, and the complementary safety assessments carried out at the French nuclear plants in particular. ■

Efficiency and reliability of information provided

DR

Shohei Sato, director of the department of nuclear systems security of JNES, the Japanese technical safety organisation.

"After the Fukushima accident, JNES collected information from all foreign safety authorities and their technical institutes, to distribute it within our organisation and transfer it to our safety authority, NISA. Of the huge amount of gathered information, that of IRSN was remarkable in quality and quantity. In particular, we followed the simulation of the radioactive plume of Fukushima put online shortly after the accident. The reports on the contamination and environmental effects on land and in the sea were also complete and very important for us."

IN FIGURES

OVER THE FOUR WEEKS FOLLOWING FUKUSHIMA:

5,000 press articles quoting IRSN • **1,365** requests for interviews • **50** electronic bulletins or summary of environmental monitoring of France published • **612,000** visits and **1,500,000** pages viewed on the irsn.fr website on 23 March 2011.

IRSN management, serving the State

The magnitude of the earthquake and tsunami that struck Japan led, from day one, to the mobilisation of French government emergency response groups in support of the French expatriate community, and to the civil security efforts of the Japanese authorities.

As soon as it was clear that this catastrophe was going to be a nuclear crisis, starting the 12 of March, IRSN became directly associated with this mobilisation.

The President and the Director General thus participated in the daily meetings organised by the Secretary General of the Presidency and the Cabinet Director of the Prime Minister, but also in meetings at the emergency response center of the French ministry of Foreign Affairs, and in meetings of the interministerial emergency response committee, chaired by the Secretary General of National Defence and Security. Therefore, the analysis produced by the Emergency Response Centre of the Institute were, practically in real time, passed on to the highest authorities of the State, to help them in decision-making processes.

1. *Association nationale des comités et commissions locales d'information (French national association of local information committees).*

Franco-Japanese activities tailor

How did IRSN help expatriates and companies in France and Japan get thr


DR

Education

"The experts re-instilled confidence in the school community"

Michel Sauzet, principal of the Franco-Japanese high school in Tokyo.

How did you call upon the Institute?

After the event of the 11th of March, a radiation protection expert was sent to the French embassy. Before reopening the establishment, it was of the utmost importance to inform the school community about the environment in which the high school would be functioning on a day-to-day base. The embassy services scheduled meetings with the participation of local IRSN specialists and IRSN specialists from France to respond to the questions of parents and staff.

What type of information was provided to you?

In a context where information was lacking or difficult to verify, and where contradictory rumours were creating stress, the experts provided a lot of peace of mind. As far as organisation of the establishment was concerned, the security procedures implemented were validated by their analysis, and methods for accessing the premises were defined.

How much did this reassure the French community in Japan?

The meetings with the experts reinforced the confidence of the numerous people following them, as did the question section (FAQ) placed online on the sites of the embassy and high school. Even if we had to increase the number of meetings to calm the worries of the population going to the establishment, the quality of dialogue was always emphasized and very appreciated by all. ■

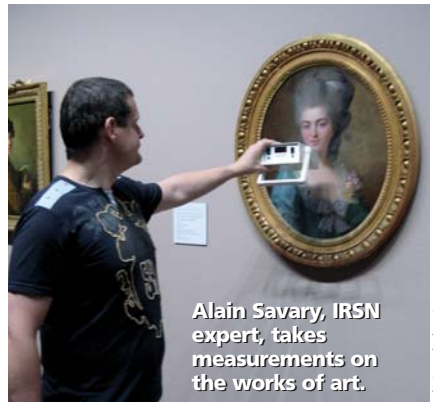
Emergency services. Accompanying a rescue excavation mission

"IRSN accompanied us before, during our rescue excavation mission and after our return," said lieutenant-colonel of the fire and rescue service, Bertrand Domeneghetti, one of the leaders of the national nuclear risk management support mission, of the general directorate of civil security and emergency response[1]. *"In Japan, our dispatch group included IRSN expert Olivier Isnard. Although his main mission was to help the French embassy, he also helped the group maintain contact with IRSN's emergency response centre. Their forecast models were essential to our unit. Upon return to France, the members of the group were subject to external and internal contamination control. The luggage was inspected as well as the heavy equipment. The results were negative for the people, whereas a few objects, like gloves, parkas, shoes and tents, showed positive values of 2 to 5 times the background dose. This return protocol created with IRSN is intended to become a baseline for civil security."* ■

1. *Ministry of the Interior, Overseas Territories and Immigration.*


The French ambassador in Japan welcomes French rescuers at the Tokyo-Narita airport.

Yoshikazu Tsuno/AFP


Alain Savary, IRSN expert, takes measurements on the works of art.

Olivier Chabanis/IRSN

Museum. Controlling radioactivity in art

Dalí, Miró and Picasso must be saved! At the time of the Fukushima accident, 170 artworks from the Centre Pompidou in Paris were on exhibit at the National Art centre of Tokyo. The management of both the centre and the modern art museum are taking the necessary measures to recover the collection loaned for the exhibit. In May, curator Brigitte Léal travelled to Japan, accompanied by two organisers and the manager of the loans department.

"As soon as we were informed of the risk of contamination, we contacted the IRSN emergency response centre," recounts the curator. *"We were very worried; it was the first time we were faced with such a situation. We didn't know whether the pieces were liable to be damaged or irradiated, or whether it was possible to handle them without risk for the museum staff. We were worried that upon return the pieces would contaminate the whole museum... Very quickly, IRSN specialists analysed the artworks, transportation crates and exhibit halls. The results, which were detailed in a precise report, made it possible to reassure everyone. Today, the pieces are back in their storage areas or rooms at the museum. As a precautionary measure, and especially to relieve any doubts, the crates were destroyed."* ■

ed to the emergency

ough the Fukushima nuclear crisis? Testimonials.

Airline company. Reassuring aircrews

"*We have worked with the IRSN emergency response centre,*" recalls Gérard Desmaris, Occupational Health Physician for Air France and radiation protection specialist. At Le Vésinet (Yvelines), *"36 whole body counts*[1]*, all negative, were carried out for the aircrews returning from Japan. The measurements reassured our aircrew and professional organisations."* The company itself has transported radiation protection material, iodine, Téléray sensors... in Japan and in the French overseas territories to help with environmental monitoring. *"Our workers remain worried, about water and food in Japan in particular,"* said the doctor with regret. *"I took water from the Tokyo network and food samples to have them tested by IRSN. The results should calm the fears, but there is a lot of educating to be done."* ■

1. Examination of the evaluation of received doses.

The cable ship that carried out the repair.

Louis Dreyfus Armateurs

Navigation. Assessing risks

"*Before sending workers into a zone that may be contaminated, it is crucial to evaluate the situation and make sure there is no risk,*" stressed Alain Coatanhay, fleet general manager of the Louis Dreyfus Armateurs. When one of its ships had to repair an underwater fiber optic cable that was damaged by the earthquake 120 km east of Fukushima, he turned to the Institute. *"The information provided was essential for reassuring the team. The experts helped us to present the radiological situation and to set up a monitoring system, including individual dosimeters and radiation meters for the boat. One expert accompanied the ship to the work zone. Fortunately, there was zero exposure there!"* ■

Media. Indicating the measures to be taken

Two technicians and four journalists from Radio-France were covering Fukushima in Japan. Sent abroad to follow the story of the earthquake and tsunami, they were not protected against radiation. Marie-Pierre Meteau, nurse, had to replace the absent company doctor. *"I called IRSN and the Quai d'Orsay's emergency response centre. IRSN told us the measures to take. Upon their return, our teams went to the Vésinet analysis laboratory* (Yvelines)*, and the equipment was put in storage before inspection. As one of the recorders had already been brought back in the newsroom, IRSN specialists went there to take measurements. No contamination was detected."* ■

Dosimeter supplier. Maintaining quality

The main supplier of radiophotoluminescent dosimeters to IRSN is Japanese. Makoto Imai, director of the company, explains how Chiyoda Technol, in Tokyo, managed the situation. *"As soon as the accident took place, we described the state of our facilities and our production capacity during videoconferences with IRSN. IRSN had ordered 30,000 dosimeters long before the accident. As a precaution, the delivery date had been moved up. And to avoid any risk of contamination, the dosimeters are manufactured in regions far away from Fukushima. They are also inspected by IRSN upon arrival."* ■

French Embassy
Explaining the situation to French expatriates

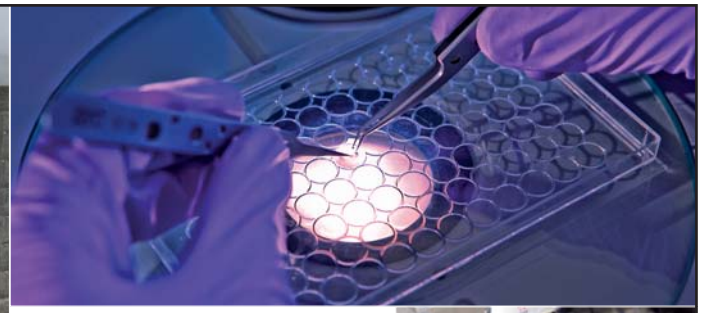
IRSN sent Olivier Isnard, a specialist in nuclear crisis situations, to the French embassy in Tokyo. He stayed five weeks with expatriates, French companies and also with the ambassador Philippe Faure. Ambassador Faure praised the work accomplished by the expert and his commitment to French citizens. He emphasized "*his pedagogical talents for explaining the situation and the precautionary steps to be taken*" during this trying period.

Robotics
Protecting workers

Operation in hostile environment using a robotic cutter.

JAPC/E-Energy/Cybernétix

"There's a big difference between performing an operation in a confined radioactive environment on a worksite and in an open environment liable to be contaminated and with which we're not familiar," stated Olivier Bernard, engineer and radiation protection specialist at Cybernétix. At the moment of the earthquake, this company, which specialises in robotics for operations performed in a hostile environment, was participating in the dismantling of steam generators at the Tokai-Mura site south of Fukushima. *"From the 11th of March, we asked IRSN for information on the situation. The difficulty was characterising the risk, dispersion of radioactive elements and the level of contamination. We decided to repatriate our two workers. Upon arrival, they went to Vésinet* (Yvelines) *for whole body counting. The results were negative. Before sending workers back to Japan, the Radiation Protection and Health Department of the Institute helped us to quantify the risks and determine the measures to take. Our workers carried dosimeters, radiation protection suits and counters."* ■



- Emergency response
- Research

- Nuclear safety

- Radiation protection and Health
- Environmental monitoring

Sophie Brandstrom/EDF; Noak/Le bar Floréal/IRSN; Arnaud Bouissou/MEDDTL/IRSN; Laurent Vautrin/EDF; Grégoire Maisonneuve/IRSN; Toma Mark-M Way

Increased safety after Fukushima

You have to imagine the unimaginable, Fukushima has taught us. In France, evaluations are made to validate facility compliance and calculate their resistance to disasters. New pathways for progress are taking shape, notably with the design and construction of equipment capable of withstanding the worst stresses. Research is underway to predict the future of radionuclides released by Fukushima, and also to improve monitoring and radiation protection in France.

Photos: Grégoire Maisonneuve/IRSN

Complementary Safety Assessments

Analysing the resistance of French facilities

The acronym CSA refers to the Complementary Safety Assessments. A complete inventory of French nuclear facilities that required extensive work.

The Three Mile Island (United States) accident and Chernobyl (Ukraine) accident were caused by internal failures. However Fukushima was provoked by extreme natural hazards. The latter led to an assessment of the resistance levels against earthquakes and floods for the European nuclear plants, and those in France in particular. It was also necessary to determine the lengths of time before radioactive releases into the environment would occur in the event of total loss of electrical supply or heat sink. This was the subject of the complementary safety assessments (CSA) requested from the French plant Operators by the Nuclear Safety Authority (ASN) on the 5th of May 2011.

The CSA procedure satisfies two requests: that of Prime Minister François Fillon from 23 March 2011, to perform an audit of the safety of French facilities, and that of the European Council, from 24 and 25 March, to perform stress tests. *"The two requests were comparable,"* said Karine Herviou, IRSN expert in charge of preparing the CSA documents. *"The French specifications were written mainly based on the specifications written up by the European Association of Nuclear Safety Regulators, Wenra."*

The inspections on the operator's premises (here the Cruas plant) are carried out by ASN inspectors accompanied by IRSN experts.

79 priority facilities

There are some differences between the European stress tests and the French CSAs. They required two reports that are different in format, even if the content remains the same: *"The scope of the French assessments is broader. They cover not only the reactors, but also the research facilities and fuel cycle facilities. A section dedicated to contracting has been added at the request of the High Committee for Transparency and Information on Nuclear Safety,"* explained Daniel Quéniart, Senior Advisor to the Director General of IRSN, who participated in the development of the critical analysis report of the Operator documents.

Nearly all of the French facilities are covered in the CSAs. This corresponds to 58 pressurized water reactors, the EPR under construction, the research facilities and the fuel cycle facilities. Seventy-nine facilities are considered priorities by the ASN, including the reactors that were covered in reports submitted by the Operators on the 15th of September 2011. For the others, the facility operators have an additional year to comply with the request.

In practice, the different facilities to assess are numerous; however there are only a few Operators, namely, EDF, the French Alternative Energies and Atomic Energy Commission (CEA), Areva and Laüe-Langevin Institute (ILL).

In order to facilitate the CSAs, an intermediate step was observed. *"In the beginning of June, the Operators submitted a document summarising*

CLOSE-UP

The assessment documentation has eight chapters:

- **1.** Site presentation;
- **2.** Earthquake;
- **3.** Flooding;
- **4.** Extreme natural phenomena (hail, lightning, tornado);
- **5.** Loss of heat sink/ electrical power supply;
- **6.** Severe accident management;
- **7.** Service provider companies;
- **8.** Summary of the site and associated action plan.

the procedure they planned to use to perform the CSAs," explains Caroline Lavarenne, expert from the Institute and head of CSA document preparation. *"Based on an IRSN analysis of these documents, the Nuclear Safety Advisory Committees – who provide technical support to the ASN - judged the procedures satisfactory, with certain points for caution noted. Next, the Authority required the Operators to consider the impact of any high-risk facilities, such as chemical facilities, located near a plant."*
Over the summer, the Operators of the 79 priority facilities thus got down to the task in order to submit their final report on the 15th of September. *"Simultaneously, we at IRSN have identified the compliance gaps and points for improvement in the facilities, calculated the periods available before radioactive release, and re-examined the seismic risks of each site... so as to develop an analysis template of the CSAs"* explains Karine Herviou. A month and a half after receiving the Operators' reports, IRSN was able to present a synthesis and critical analysis of their proposals before the Nuclear Safety Advisory Committees, which enabled the committees to state their opinion.


Examination of the spent fuel transfer pipe at the Laüe-Langevin Institute, Grenoble (Isère).

The conclusions of the experts

First conclusion: if the facilities authorised in France can legitimately be considered safe, it is still true that some of them do not fully satisfy the requirements defined in the applicable safety requirements reference state. These compliance gaps must be quickly eliminated.
As regards the ability of the facilities to withstand scenarios beyond those imagined during design or re-evaluation, the conclusion of the experts is two-fold. First, the Fukushima accident, as well as the CSAs, have highlighted certain limits of the current safety requirements reference states. *"They do not consider the cumulative impact of the total loss of electrical power supply or the loss of heat sink with the external hazards taken into account in the different safety requirements reference states,"* explains Caroline Lavarenne. *"Furthermore, Fukushima showed that it was possible."*
Also, as the simultaneous occurrence of events was not considered, the equipment necessary for managing such situations is not protected and a total loss of heat sink or electrical power supply simultaneously affecting several facilities on one site is not

Milestones for the Complementary Safety Assessments

11 March 2011 : **nuclear disaster at Fukushima Daiichi.**

End of June to mid-October: inspections of the 79 facilities carried out by ASN inspectors accompanied by IRSN experts.

15 September to beginning of November: preparation of documentation by IRSN.

23 March — French prime minister asks the ASN[1] to carry out a **safety analysis** of nuclear facilities.

5 May — The ASN asks Operators (EDF, ILL, AREVA and CEA) **to carry out CSAs**[2] in their nuclear facilities deemed to be priorities.

1 June — **Submission of a note from the Operators** to the ASN, presenting the methodology used for the evaluation, the organisation put into place to respect the deadlines and structure...

6 July — **Meeting and opinion of the Nuclear Safety Advisory Committees** for the reactors, facilities and laboratories: examination of procedures proposed by the Operators on the basis of IRSN analysis.

19 July — **ASN takes a position:** the Operators methodologies are judged acceptable if certain recommendations are integrated.

15 September — ASN received the Operators CSAs reports with their **conclusions and evaluations** . The ASN commissions IRSN to review the 79 files.

4 November — **IRSN's expert report** returned to the ASN and members of the Nuclear Safety Advisory Committees.

8, 9 et 10 November — **Meeting with the Nuclear Safety Advisory Committees** for opinions on reactors, facilities and laboratories: analysis of the CSA reports of the Operators based on IRSN review.

17 Nov — **Publication of the IRSN report.**

1. French Nuclear Safety Authority. 2. Complementary Safety Assessments.

READ IT ONLINE

Transparency at all levels

The Nuclear Safety Authority and IRSN desired the greatest possible transparency on the complementary safety assessments. Several documents of the assessment process can be consulted online:

On the IRSN website (**www.irsn.fr/en/**):
- The 500 pages assessment report submitted by IRSN on 4 November 2011 following the review of the Operators CSAs reports (in French)
- A summary of this report (in English).

On the ASN website (**www.french-nuclear-safety.fr**):
- The Operators CSAs reports (in French)
- The Conclusions of the Nuclear Safety Advisory Committees, based on the IRSN report (in French)
- The ASN report on the CSAs published in January 2012 (in English).

View from the field

ASN-IRSN inspection of the cooling water pump station at the Cruas plant (Ardèche).

In addition to the complementary safety assessments (CSAs), inspections of the sites covered by the CSAs in 2011 were led by the French Nuclear Safety Authority (ASN). They were performed between June and November of 2011, around topics related to the Fukushima accident: protection against external hazards (earthquakes and flooding in particular), loss of electrical power supply, loss of heat sink and operational management of emergency situations. The goal of these 38 inspections lasting an average of three days, to which the IRSN experts were assigned: to control the compliance of equipment and organisation of the plant operator in terms of existing safety requirements reference states. Before these inspections, IRSN has drawn up a support guide, a sort of common template for the inspections to be carried out. *"Participating in these visits with the ASN provided us with a vision of the field,"* said Karine Herviou, IRSN expert in charge of preparing the CSA documentation. *"For example, it allowed us to observe that the systems for protection against flooding were not always completely deployed."*

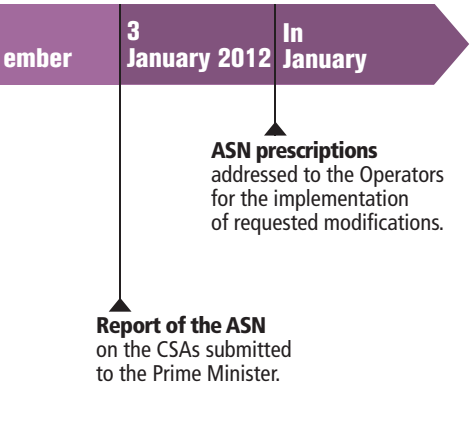
considered. *"Certain equipments, such as pumps or depressurization and filtration devices, are common to two units. There is mobile emergency equipment on the sites, but they are intended for one reactor or one facility only,"* explained Karine Herviou. Final conclusion: the need to reinforce or put into place equipment for the management of extreme situations that is capable of withstanding large earthquakes or floods. They will form the "hardened safety core". Today, each facility must have a minimum of two sets of vital equipment that are extremely robust and available in all circumstances, to prevent a severe accident or to control the consequences. *"If we only prevent, we always risk forgetting something and helplessly watching a release like Fukushima take place,"* said Emmanuel Raimond, project manager for analysis of severe accidents. *"Systems for controlling a possible accident must also be designed."* Karine Herviou summarises this in one expression: *"belt and suspenders"*. The robustness of the means for emergency response must also be enhanced for these situations.

Issues already known

Certain conclusions of the CSAs match longstanding works, for the reactors for example. *"The flood that occurred in 1999 at the nuclear power plant in Blayais had already raised the question of combined climate hazards. Protection against flooding had been reinforced,"* recalls Martial Jorel, reactor safety specialist at IRSN. *"After the accident at Three Mile Island, the French nuclear plants were equipped with sand filters to depressurize the chamber in the event of severe accident, as well as hydrogen recombiners. Following the third wave of ten-year inspections in 2003, a decision was taken to reinforce the bolts in the containment building, and to equip reactors with a system for detecting a vessel break and a system for measuring hydrogen in the containment."* Precious improvements, that would certainly have played a role if they had existed at the Fukushima plant, although most probably still incomplete due to the fact that they cannot necessarily withstand extreme hazards. *"The sand filters cannot withstand earthquakes,"* Martial Jorel noted. An analysis shared by Thierry Charles, his colleague in charge of safety in laboratories and plants. *"Like the reactors, the fuel cycle facilities are subject to periodic safety re-examinations where everything is reviewed from the point of view of the latest data and knowledge. For example, the facility of company FBFC, which produces uranium-based fuel, had benefited from several reinforcements between 2003 and 2008, related to earthquake behaviour in particular: reinforcement of buildings and confinement with implementation of a second leaktight barrier around the UF6[1] cylinders, fire protection, etc…"*

Scheduled for 2012

After the CSAs, the conclusions of the Nuclear Safety Advisory Committees



Hervé Bouilly/IRSN - Source IRSN

and the decisions taken by the ASN in the beginning of 2012, each facility operator will propose a practical, precise and concrete definition of the equipment to be put into place. An implementation schedule, taking into account the particular sensitivity of certain sites, should also be proposed. *"The facility operators have made a number of commitments in their documents that they must implement today,"* recalls Daniel Quéniart.
Caroline Lavarenne adds: *"The CSAs are only the first step of a long process of lessons learned following Fukushima. In France they are going to lead to a reinforcement of the capacity of the facilities to maintain their fundamental safety functions when faced with hazards that are clearly greater than those retained during their design."*
What about the European stress tests? At the end of 2011, France, like each of the member States, submitted a final report on the complementary safety assessments of their facilities to ENSREG (European Nuclear Safety Regulators Group, who coordinates this project for the European Council and prepares European decisions) and the European Commission. This version is slightly different in format, but its content is identical to the French report. "This report will be subject to a peer review during the first half of 2012," Daniel Quéniart specified. All this is within the scope of moving toward a common nuclear safety approach. ■

1. Uranium hexafluoride.

Helping local information committees in critical analysis

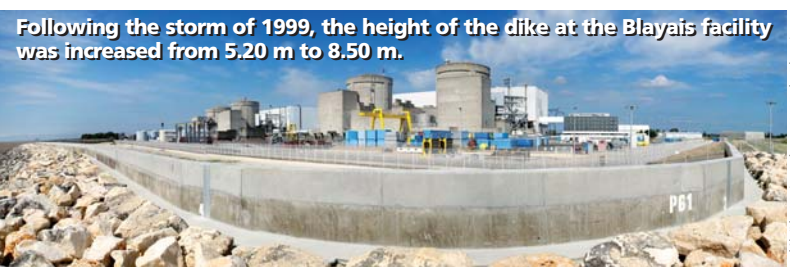
The local information committees, which are the embodiment of the public's right of review and right to information, have requested to monitor the preparation of the complementary safety assessments (CSAs). They have asked IRSN to support them in this task. *" On the 14th of September 2011, we brought together 80 people in Paris, especially the members of the local information committees and associations, to scrutinize the CSAs with them and to give them basic and methodical elements,"* explained Ludivine Gilli, in charge of the openness to society at IRSN. Four experts came to explain seismic and flood hazard, loss of heat sink, loss of electrical power supply and management of accident situations. Although all the subjects got a reaction, the loss of heat sink and power supply generated a lot of questions, as did seismic hazards.
One month later, the submission of the Institute's summary report led to another meeting between the IRSN and the local information committees, where they discussed the conclusions offered on the 24th of November. *" All these meetings lead definitely to an increase in know-how and technical skills of these commissions and offer the Institute an outside view of its efforts. They help to identify emerging technical questions, contributing to IRSN considerations both in research and expertise."*

Learning lessons from events related to nuclear safety

Three Mile Island (United States). In 1979, the Three Mile Island accident showed that a core meltdown was possible. Procedures for managing the final situations, the total loss of heat sink or electrical power supply in particular, were added. Emergency response was developed. A new approach was defined ("state-oriented" operating procedures), based on the real state of the facility rather than on supposed scenarios. *"This accident was the starting point for a research programme that now provides for the anticipation and establishment of measures,"* adds Emmanuel Raimond, project manager for analysis of severe accidents at IRSN. *"Today, the French PWR's are equipped with hydrogen recombiners that limit the possibility of explosion like Fukushima, and containment building venting and filtration systems, making it possible to lower pressure while limiting releases of radioactive particles. With the use of such filters, in combination with containment buildings of even a bigger size, caesium releases would have been 10,000 to 100,000 times lower at Fukushima."*

Chernobyl (Ukraine). In 1986, in addition to the decommissioning of RBMK reactors (except in Russia), the main lessons learned were related to the management of nuclear risk in Europe, the necessity of transparency and large-scale management of contaminated areas.

Blayais (Gironde). During the storm of 1999, a combination of high tides, depression and swells generated waves flooding the facility site and rendered several safeguard systems inoperable. This led to a re-inforcement in site protection against flooding. A list of strategic equipments has been defined, which, using dikes or leaktight walls, should remain out of the water. This is the beginning of an approach leading toward the re-inforcement of facility defence in-depth against environmental hazards.



Following the storm of 1999, the height of the dike at the Blayais facility was increased from 5.20 m to 8.50 m.
Adélaïde Maisonabe - CNPE du Blayais

Stress test

Close-up of the Gravelines nuclear power plant

Preparing a complementary safety assessment report means days of work. Testimonials from a unique summer in the North of France.

Gravelines (North), summer 2011. While tourists are visiting the city redesigned by Vauban and trying their luck at water sports, time is not spent on leisure for the workers at the nuclear power plant, the largest site in Europe with 6 900-MWe reactors. As for the 18 other EDF sites, all are mobilised for the preparation of the complementary safety assessments (CSA) report. More than 300 engineers from the EDF group are participating. *"Since the end of March, EDF has created a project team at central department level, bringing together engineering and production, and associating other EDF areas, such as R&D,"* recounts Philippe Renoux, head of production.

Centralised preparation

The main part of the preparation of the CSA reports is thus centralised. *"A national engineering team has been put into place, with as many managers as there are subjects: earthquakes, floods, loss of heat sink..."* said Laurent Payen, project leader resonsable for the engineering part of the stress test. Only the sections on the particularities of the plant were prepared by the field manager. This division of work was proposed in June by EDF, assessed for a month by IRSN and validated by the French Nuclear Safety Authority (ASN). *"There are 58 reactors, but there are only four different types of them according to power output.*[1] *Whereas the general layout drawings of the facilities are part of EDF engineering and production services, the detailed drawings are the responsibility of the facilities. IRSN field teams check the compliance of the facilities"*, summarized Pascal Quentin, in charge of the assessments of the French pressurised water reactor (PWRs).

Heat sink is one of the subjects addressed in the facility complementary safety assessments.

"We have inspected compliance point by point," confirms Denis Barras, who led the operation in Gravelines. The task quickly proved time-consuming. *"For example, as the site is located along the sea, it is more exposed to flood hazard. It had to be confirmed that in the event of a rising in waters, the equipment necessary for resupplying the facility with water would not be under water, which requires inspection of the walls and the leaktightness of openings (passageways, cables, pipes)... Just the inspection of the fire valves was assigned to two people for four days for the inspections, preparation and photographs of the reports and the inspection of the editor's work by a second person."* Occasional inspections were organised with the national teams to check that the emergency equipment satisfied earthquake requirements.

For Denis Barras, the CSA file represented more than 1,500 hours of work. *"It took up all of my days from June to September and the same for five engineers from my team. ASN inspections also had to be managed, while managing the day-to-day, and in particular the analysis of the third ten-yearly outage..."*

Simultaneous visits

Following Fukushima, the site had to manage consecutive ASN inspections. *"That's six days of inspection between the end of June and mid-October. Each covering one of the retained subjects: earthquake, flood, heat sink, electrical supply, emergency situations and service providers,"* enumerated François Godin, who checks the Gravelines site for the ASN. *"Also participating were members of the local information committee, members of the National Committee for Transparency and Informa-*


The Gravelines nuclear power plant is the largest site in Europe, with 6,900-MWe reactors.

Laurent Mayeux/EDF

tion on Security and inspectors from the Belgian nuclear safety authority within the framework of long-standing exchanges. IRSN was present at the six inspections at Gravelines, with one or two experts. These experts were either specialists in one of the areas addressed or managers of the Gravelines site at the Institute."

One ASN pilot inspector was preparing the visit with an ASN copilot and experts from the Institute. *"IRSN specialists participated in the preparation of visits. They contributed to the development of a common guide for all inspections, which is then applied by taking into account the specifics of each site"*, explains Karine Herviou, one of the IRSN experts preparing the CSA documentation. *"This support represented more than ten days of work."*

On the field and in the meeting room, everything was carefully screened. *"We were asked to implement the equipment to be used in case of an accident,"* recounts Denis Barras. *"We therefore, with the inspectors present, tripped the alarms linked to the seismic sensors."*

What next?

What are the conclusions drawn from these inspections? *"We confirm that the level of safety is good at all facilities,"* answers Philippe Renoux. *"But we are constantly working to improve it,"* he added. Concerning Gravelines, several points were addressed in a follow-up letter requiring a reply from the Operator within two months. *"We demanded certain urgent repairs, mainly of the filters in the reactor cooling system, of which the supports were corroded by seawater and of which certain anchors were missing,"* noted François Godin. *"We asked the Operator to review the diesel motor fuel quality test procedure, as well as backup power supply, which seems insufficient to use. For flooding, the everyday checking that the hatches and doors are closed seemed not to comply with the applicable procedures."* Laurent Payen added: *"Gravelines being surrounded by a dense industrial base, we are working on a convention with these companies to limit the storage of dangerous products in the vicinity of the power plant, and the implementation of an alert protocol in the event of a problem..."*

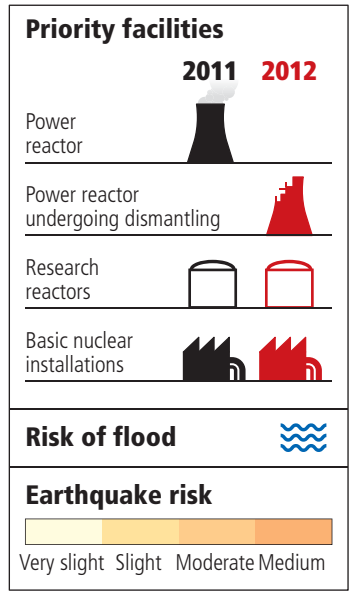
In parallel, the CSA report was presented to the local information committee of Gravelines, on the 11th of October. Members were able to pose their questions to EDF. Based on the responses obtained and the information received during the technical meetings simultaneously organised by IRSN, the local information committee reformulated the questions. They were then sent to the ASN for inclusion in the final report in December.

The Gravelines report and those of the other priority sites contribute to the national analysis performed by IRSN in September and October. The IRSN analysis mainly served as a base for the conclusions presented at the beginning of November by the ASN's Nuclear Safety Advisory Committees. Based on their conclusions, on the record of inspections and on the comments from the local information committees, in the end of December, the ASN prepared a French report for submission to the Prime Minister. A second report having a different format but identical content was drawn up for Europe. It was a tight schedule, but it was respected. ■

1. Specifically: 34 PWR reactors of 900 MWe, 20 of 1,300 MWe, 4 of 1,450 MWe and 1 EPR reactor under construction, of 1,600 MWe.

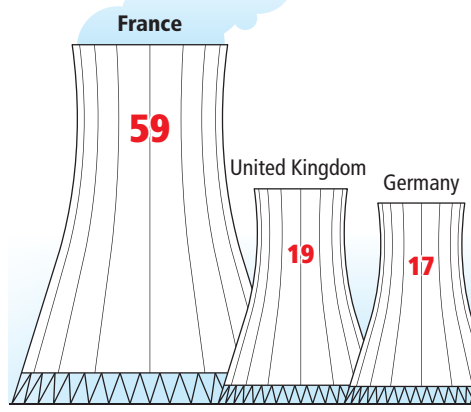
Close-up of facili

The Operators of the power reactors reactors, and fuel cycle facilities (enri assembly manufacturing and repro submitted their complementary safety assessment report on the 15th of Se 2011. **In all, 79 facilities are con priorities in France.** The Operators 24 other facilities will need to submit report on the 15th of September at the latest.



The European fleet of Nuclear Power Plants

The fleet includes **144 operational power plants** in Europe and 6 under construction, in 14 member States. France is ranked first, with 59 reactors, including one under construction in Flamanville (Manche).



Source Nuclear Power Reactors in the World IAEA (31/12/2009)

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Radiological impact on the Japanese population

Initial evaluation map

28 days after the Fukushima accident, the IRSN became the first institute to publish a map showing the radiological impact on the Japanese population living in the Fukushima area.

Toma Mark-M Way

A Japanese resident measures the level of radioactivity in produce from his orchard.

70,000 Japanese people, living as far as 80 km from the nuclear power plant, are likely to receive doses exceeding 10 millisieverts (mSv) during the first year following the accident. This was the result of an evaluation carried out by IRSN experts in April 2011. These figures raised the alarm, four weeks after the accident. *"Based on aerial measurements obtained by the USA and the IRSN's simulation of radioactive releases, we have drawn up a map of the doses that the Japanese population would be likely to receive in the year following the accident through external exposure to the radiation emitted by the contamination deposited on the ground,"* said François Queinnec, then the coordinator of the unit dedicated to radiological consequences at the emergency response centre. The experts looked in particular at a 20 x 70 km strip of contamination located north-west of Fukushima, beyond the evacuation zone. *"Between 20 and 35 km on this north-west line, the doses reached 100 to 500 mSv per year."*

Reacting quickly to provide protection

The IRSN experts then cross-referenced this map with the population distribution data for the area. *"Our calculations suggested that 2,200 inhabitants could receive an annual external dose exceeding 100 mSv, 3,100 could receive doses between 50 and 100 mSv, 21,100 could receive doses from 16 to 50 mSv, 43,000 could receive doses from 10 to 16 mSv, and 292,000 could receive doses from 5 to 10 mSv,"* adds François Queinnec.

"Twenty-eight days after the disaster, IRSN was the first institute in the world to publish a map showing that the dosimetric impact on the non-evacuated population could be significant. Ten days later, an American estimate [1] confirmed the French results. This was swiftly followed by a Japanese evaluation [2] that obtained results that were 2 to 2.5 times higher, but broadly consistent with the French and American results." Since then, gradual evacuation measures have been applied, which will reduce the calculated potential impact. ■

1. *Conducted by the American Department of Energy.*
2. *Conducted by the Japanese Ministry of Education, Culture, Sport, Science, and Technology.*

Symbiose software

Monitoring environmental releases

What happens to the radionuclides emitted by a nuclear facility? Symbiose, a tool used to model the transfer of radionuclides into the environment, provides quantified answers to support the field investigations. *"It simulates what happens to radionuclides in the medium that constitute a continental environment: agricultural land, rivers, inhabited areas, etc.,"* summarises Marc-André Gonze, Project Manager and Engineer at the IRSN environmental modeling laboratory. *"This applies to normal or accidental operating conditions, or during the dismantling of facilities."*

In the first few days following the accident, this laboratory collected and processed data characterising the Fukushima region to feed the models: land use, agricultural production, food rations, contamination of drinking water, etc. *"Starting from an estimate of the source term and the atmospheric deposits, our simulations have allowed an initial evaluation of the changes over a four-month period of the expected contamination levels in soil and agricultural produce in a radius of 80 km. Although the activity levels predicted by Symbiosis had been overestimated, the decay kinetics turned out to be fairly realistic."* In late April, the maps of radioactive caesium deposits published jointly by the USA[1] and Japan [2] made it possible to *"refine our predictions and gain a more realistic picture of the levels of caesium contamination and their spatial variability."*

The IRSN's current aim is to analyse all the information it receives concerning the state of contamination of the media and to embark on the qualification and consolidation of the constituent models of Symbiose. ■

To find out more: www.irsn.fr, menus: Research > Scientific tools > Computer code > Symbiose code

1. American Department of Energy. 2. Japanese Ministry of Education, Culture, Sport, Science, and Technology.

Téléray network

Working towards improved environmental monitoring

More radiation monitors, more modern equipment: modernising of the Téléray network was underway since 2007. Fukushima has given it fresh impetus.

The renovation of the Téléray environmental radioactivity monitoring network began in 2007. *"We plan to renovate everything,"* explains Guillaume Manificat, head of monitoring networks at the Institute: *"the probes, signal transmission, data supervision, in other words the management of alarms and repairs, and their siting, whether this involves the 160 existing probes or any additional ones."* The radioactivity in the air is thus monitored in real time all over France in order to detect any irregularities or accidents. There was also a plan to provide finer monitoring by covering the territory with at least one beacon per department, and as many as 16 beacons around power plants, at a radius of 10 to 20 km and 20 to 30 km.

A perfect partnership

The ideal candidate: the roof of gendarme stations, which have a mast and a transmission network to which the probes can be connected. *"Discussions were already underway, and Fukushima accelerated them, because beacons had to be installed before the contaminated air masses arrived over the Antilles. It was a perfect partnership: a meeting on Tuesday morning, the go-ahead given at 3 PM, and seven operational probes overseas by the following Monday!"* An agreement is currently being drawn up for the installation of 260 probes on gendarme stations. These sites will supplement the 160 existing ones, which will be given new beacons. Even so, with the deposits from Fukushima extending well beyond the 30 km zone, further reinforcement of the network is already being envisaged: *"Fukushima has confirmed our decision to add probes from 10 to 30 km from power plants, but it raises the question of whether we might need another circle of beacons at 50 km."* This would mean 200 more beacons. ■

A new-generation Téléray beacon installed on the roof of Navy headquarters in Paris.

Arnaud Bouissou/MEDDTL/IRSN

Three questions for... Didier Champion

Noak/Le bar Floréal/IRSN

Head of the collective work conducted at IRSN concerning crisis management in the event of a nuclear accident or incident in or affecting France.

What were the main lessons in crisis management that Fukushima taught us?

Before Fukushima, the studies concerned scenarios on a moderate scale and the releases over the course of one day. Fukushima showed us a more complex dimension, with releases over several days and deposits starting on 16th March affecting the food chain and the habitat. There was a concertina effect between the managing of the emergency, with its evacuation measures, the question of whether or not to distribute stable iodine, etc., and the start of post-accident management across more extensive territories. The accident had an unprecedented impact on the marine environment, highlighting the gaps in our crisis expertise. Providing calculations concerning the dispersion of the pollution in the sea is not sufficient to enable the right decisions to be made. We need to be able to predict what we are likely to observe, when and where, so that we can take preventive action. We need to know which marine species will be the worst affected, and whether swimming can be allowed.

What about protecting the population?

Fukushima will also lead us to review the emergency protection doctrine. The current rules are fairly rigid: distribution of stable iodine and sheltering within 10 km, evacuation within 5 km. Experience shows, however, that although this 10 km radius is still the priority action zone, we must be prepared to go beyond that, both in space and in time, because the releases can be long-lasting. Supplementary elements must be added to the doctrine with this in mind, and more flexibility must be allowed in the protection strategy.

Will Fukushima also have an impact on the Institute?

The IRSN has acted as an expert for many bodies in addition to the Nuclear Safety Authority, of which it is the technical support arm. When a nuclear crisis arises, national government authorities, as well as local authorities under the responsibility of Prefects, call upon the Institute. This means that we must review our position in the national crisis organisation. Internally, we must change our mobilisation rules and stop applying an all-or-nothing system: we need to allow for intermediate levels of mobilisation of our crisis organisation, with the possibility of mobilising teams without necessarily activating the emergency response centre. Finally, experience has also shown that IRSN must be recognised as an actor that contributes in full measure to informing the public in real time.

Areas of scientific research

The Fukushima crisis highlights

Scientists did not wait for the Japanese disaster to occur before working on nuclear accident a large number of tools were used to manage the crisis. But certain lines of research were

"This is not a revolution," insists Bernard Chaumont, who helps to coordinate research at the Institute. He has been given responsibility for a working group dedicated to post-Fukushima R & D. *"The crisis did not give rise to new topics or reveal any lines of research we hadn't already thought of."* But the initial feedback from Fukushima reinforces certain safety and radiation protection needs.

Prevention and damage limitation in facilities

The first issue identified by IRSN concerns the facilities themselves. The aim is to better prevent accidents and, to do this, to better characterise natural events (earthquake, flood, etc.). When these are given greater consideration, particularly in probabilistic safety analysis, the weak points of facilities can be identified. This will require collaboration with other research bodies, and certain underlying problems will need to be answered: *"We will need to work out, for example, how to allow for rare events, such as an earthquake that exceeds all the predictions,"* says Véronique Rouyer, Head of Programmes at IRSN. *"Should they be considered sufficiently rare, and therefore so unlikely that they should not be given priority, or should we take the opposite approach by allocating a research budget to them in view of their potential consequences?"*

Fukushima also showed that prevention is not enough; it is preferable to control severe accidents in the event that they occur. *"The phenomenology of accidents like these is well known now,"* adds Bernard Chaumont. *"The relevance of much previous research has been shown. For example, during the Japanese crisis, the release of fission products was estimated, in particular thanks to the work carried out for the Phébus programme [1]. How far did the decay of the reactor core progress? What about breaches in the vessels?"*

The second strengthened line of research: protection of persons and the environment, because the accident confirmed the realistic nature of accident scenarios leading to significant releases. *"The crisis has changed the priority of certain lines of research,"* Bernard Chaumont confirms. *"Certain topics have become more urgent, such as studies on the health effects of low doses, and the effects of contamination on the environment–particularly the marine environment."*

IRSN

Astec software simulation of a core meltdown accident in a pressurized water reactor.

Radiation protection around facilities

The scope of the work is turning out to be very broad: to gain a better understanding of the effects of ionizing radiation on the scale of a cell, a living organism, or a population; to be able to map contamination zones quickly so that populations can be better protected from radioactive fallout; to improve the individual dosimetry methods for personnel working on an accident site; and to strengthen the platform for the evaluation of the dispersion of radionuclides in the food chain. *"We have*

Operational tools for a fast response

Grégory Caplin, an engineer specialising in criticality research and analysis at IRSN, received questions from the Institute's emergency response centre concerning the risk of a criticality accident in Fukushima at the time of the crisis.

"Measurements and observations were reaching us from the contaminated area in Japan. We had to establish whether or not such an accident had occurred. We had a development version of Vesta, a software that simulates the state of the irradiated fuel. It is flexible enough to model a boiling water reactor. We were also helped by a thesis project in progress concerning inverse calculation algorithms for our Prométhée software. We normally examine a given situation and look for its consequences, but in this case, we had to take the consequences of the accident as the starting point. Thanks to this work, we were able to assert that there was no evidence to confirm a criticality accident at Fukushima. I see this not just as a combination of circumstances, but as the result of forward-looking research using high-performance and operational instruments. Our responses were fast thanks to our computing resources and our habit of conducting research almost like an expert analysis."

DR

Grégory Caplin, criticality research and analysis specialist engineer at IRSN.

the avenues to be explored

prevention. On the contrary, bolstered by these events.

found some discrepancies between the territorial contamination predictions made by IRSN and the in-situ measurements, suggesting that these predictive models need to be improved," acknowledges Véronique Rouyer. She then adds: *"Fukushima has confirmed the need to open ourselves up more to the social sciences at different levels: this could be at the level of a facility, to better understand the role of human factors, for example in terms of decision-making before or after the accident, or, outside the boundaries of the power plant, work concerning the resilience of society."* ■

1. The Phébus PF severe accident programme is to help reduce the uncertainty concerning the estimation of radioactive products in the event of a core meltdown accident in a pressurized water reactor, and to increase the IRSN's analysis and crisis management expertise in this field.

Anticipating release in the event of uncovery in spent fuel pools

"Before it can be transported, spent fuel must be cooled for several years in pools," reminds Philippe March, head of an experimental laboratory focused on fuel cladding at IRSN. *"Although the vulnerability of irradiated fuel in reactor pools was demonstrated by Fukushima, the issue has long been a subject of research at IRSN. The Mozart programme, which determined the oxidation rates of cladding in air and the runaway limits of this reaction, has made it possible to estimate the time available before cladding ruptures and releases of radioactive substances. Nonetheless, Fukushima means that we will have to specify the runaway conditions in order to determine these time margins more accurately and adapt the response measures where necessary. Over the coming years we are going to work on the strength of fuel cladding in an atmosphere that is closer to real conditions and evaluate whether this cladding retains its confinement properties after being uncovered then covered again with water."*

When asked what other tool was useful during the crisis, Olivia Coindreau, a researcher in charge of modelling at IRSN, replied: *"ASTEC [Accident Source Term Evaluation Code], which is used to determine the amount of radionuclides released into the environment during a severe accident."* A special pool version of ASTEC, containing forthcoming results of experimental investigations on the behaviour of cladding, is expected to be developed. *"Had the pools emptied during the crisis, the current reactor version of ASTEC could have been used to quickly calculate the time periods prior to significant releases. Fortunately, that scenario apparently did not occur. Still, it sent a strong message that work on the issue of accidents involving irradiated fuel in pools must be continued."*

Emergency launch of research projects

Pierre-Yves Bard is a seismologist in charge of the Flash Japan call for projects, launched on 17th June by the French National Research Agency (ANR) and the JST[1]. "This procedure, known as Flash, responds to exceptional events to collect data as soon as possible and learn as much from it as we can." It is the second one of its kind; it was first triggered following the earthquake in Haiti. There was barely a month between the call for projects and the submission of proposals to the ANR. The nine chosen projects were launched in September. This pace was not too fast for an IRSN project led by Christelle Adam-Guillermin, a radioecology and ecotoxicology biologist. This project, known as Free Bird, studies the effects of ionising radiation on birds (barn swallows, tree sparrows and greenfinch in China) exposed in the area affected by the accident at Fukushima. "These species were chosen because of their different lifestyles and the characteristics of their plumage.

Experiments in the radioecology and ecotoxicology laboratory.

Noak/Le bar Floréal/IRSN

The more colourful birds could be more sensitive to radiation if the anti-oxidant carotenoids that pigment their feathers are used to counteract the oxidative stress due to radiation. The aim is to evaluate the impact on living organisms of chronic exposure to ionising radiation. Based on laboratory studies, we were able to estimate an acceptable dose rate below which no harmful effects on fauna and flora are anticipated. For birds, this value may be exceeded by one or two orders of magnitude in the zone within a 100 km radius of the Fukushima site. In particular, the Free Bird project will test the robustness of this radiation protection criterion."

1. Japan Science and Technology Agency.

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