RAPPORT

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Six questions to learn from the Fukushima disaster through Human and Organizational Factors

GISQUET Elsa

Rapport PSN-SRDS/SFOHREX n°2015-03

Pôle sûreté des installations et des systèmes nucléaires
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RESUME

Partant de l'ensemble des rapports officiels et des témoignages qui ont été publiées sur l'accident de Fukushima, l'IRSN a élaboré un rapport intitulé : « L'accident de Fukushima à la lumière des facteurs organisationnels et humains ». A partir de ce rapport, 6 questions essentielles ont été identifiées du point de vue des facteurs organisationnels et humains (FOH).

1- Comment faire face à l'accident malgré une défaillance totale du contrôle-commande ?

2- Quelle surmonter l'isolement de l'équipe de conduite ?

3- Comment gérer simultanément plusieurs réacteurs accidentés ?

4- Comment encourager l'innovation dans une situation d'urgence totalement inédite ?

5- Face à des choix tragiques, quels principes éthiques ?

6- Comment l'intervention de la sphère politique peut conduire à une centralisation des décisions dans la gestion de crise ?

Pour chacune de ces questions sont présentés le déroulement des « faits » et les « mécanismes d'action » associés, essentiellement les dynamiques organisationnelles et humaines. Sont également formulées des pistes de réflexion FOH qui restent à explorer.

ABSTRACT

Starting from the official reports and testimonies on the Fukushima accident, IRSN published a report entitled “A Human and Organizational Factors Perspective on the Fukushima Nuclear Accident”. Based on this report, **six essential questions** regarding the human and organizational factors (HOF) have emerged :

1- How to deal with the accident, despite a total failure of the control-command?

2- How Independent can the Control Room be?

3- How Several Units can be Managed Simultaneously?

4- How is Innovation Encouraged in an Extreme Emergency Situation?

5- When Confronted With Tragic Decisions, Which Ethical Principles Should be Applied?

6- Decentralization, even when planned and professed, may be difficult to maintain in practice, particularly as crisis become drawn out.

For each of these questions have been described the “facts” and the “The mechanisms guiding actions” which allowed us to identify the lessons to be learned from emergency response and to highlight themes requiring further exploration by the HOF experts.

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INTRODUCTION

On March 11, 2011, an earthquake in eastern Japan caused the reactors in operation at the Fukushima Daiichi nuclear power plant (NPP) to trip. The emergency generators started and then suddenly failed following the tsunami. The cooling water injection system no longer worked. Suddenly plunged into total darkness, the operators had to manage the accident.

Four years after the accident, however, as more witness accounts become available, IRSN feels useful to return to the human and organizational response to the accident inside the NPP itself. To what extent can the participants act and coordinate their actions when faced with such a dramatic situation? To what degree did their actions contribute to the disaster?

Starting from the official reports and testimonies on the Fukushima accident, IRSN has published a report entitled “Human and Organizational Factors Perspective on the Fukushima Nuclear Accident.” Based on this report, six essential questions regarding the human and organizational factors (HOF) have emerged. These questions can be used to identify the principles and rules of action that the stakeholders applied in response to the accident and, more generally, to learn from this accident in terms of the human and organizational factors involved. First, we will focus on the Main Control Room (MCR), most notably the reactor 1 crew - questions 1 and 2- , then on its relationship with the plant Emergency Response Center (ERC) - questions 3, 4 and 5 - and lastly, on the political sphere - question 6. For each question, we will present the “facts” and the sequence of events and analyze the “mechanisms guiding the action” (the organizational and human dynamics).and identify the lessons to be learned from the accident and to highlight themes requiring further exploration by the HOF experts on crisis management

1 - HOW TO DEAL WITH THE ACCIDENT, DESPITE A TOTAL FAILURE OF THE CONTROL-COMMAND?

1.1 FACTS

At 2:46 pm local time on March 11, 2011, an exceptionally violent earthquake occurred on the east coast of Japan. The three reactors in operation at the Fukushima Daiichi NPP (which has six) immediately shut down and when electrical power was lost, emergency power generators took over. The emergency response organizations started up and the emergency response center (ERC) was established. In the MCR supervising both reactors 1 and 2, confusion and chaos reigned, with sudden post-seismic shocks and alarms tripping unexpectedly. Nevertheless, the emergency procedures were followed as planned.

At 3:37 pm, the MCR lost all electrical power and was suddenly plunged into silence and darkness. Suddenly, however, the tsunami warning sounded. Although everyone took it seriously, nobody—including the meteorological service—imagined the potential height of the tsunami. When the emergency generators suddenly stopped working, neither the operators in their windowless control room nor the workers in the ERC enclosed in an earthquake-resistant building with no external visibility could understand what had happened. No one imagined that the wave had been so high that it had flooded the emergency generators.

The operators use flashlights to read the emergency procedures. These procedures were of no assistance in managing the nuclear reactor, however, as the indicators used to monitor its operation were out of action. It became impossible to check the parameters essential in cooling the reactor: the water level and the vessel and containment pressures.

In order to understand how the operators reacted to this unexpected situation, we will take the example of reactor 1, which was the first to melt downexperience difficulties. In reactor 1, the Isolation Condenser (IC)—the cooling circuit of the emergency system—operates independently without fuel or electricity. There was therefore every reason to think that the IC, which had started up just after the earthquake occurred, was still operating. As there were no indicators, however, it was impossible to be sure. It was necessary to visually check that the water level in the IC tank was dropping, thereby indicating that the heat exchanger was working correctly. This was not a simple operation, however: without indicators in the control room, it required a team to be sent to the spot. A team from the MCR ventured there at around 5:19 p.m. but, on reaching the doors of the reactor building, their dosimeters were already warning of an abnormally high radiation level[1], and the team returned to inform the MCR of the fact.

The two sets of valves delimiting the circuit must be open in order for the IC to operate correctly without electricity. One set is outside the containment, but the other set, within the containment, is neither visible nor manually accessible. In the panic following the earthquake, while operators were opening and closing the IC valves, they no longer seemed sure of their positions when the general power failure occurred.

In fact, the IC has a failsafe mechanism which closes all the valves in event of a loss of power, but the operators were not familiar enough with the IC, which none of them had ever used before, to know about this. Moreover, it is still not clear whether the valves were completely closed when the loss of power occurred, or only partially. For the operators at the time, it was impossible to check the status of the valves inside the vessel, as the indicators no longer worked. When an indicator light

[1]This implied that the core could have already begun to degrade.

unexpectedly came on a few hours on the 11th of March, after the disaster suggesting that the valves were closed, the operators attempted to open them from the MCR.

The operators in the MCR then had no way to check whether this operation had had any effect upon the IC. They therefore decided to leave the MCR through an emergency door to see whether any steam was escaping from the IC venting pipes. Their visibility was limited, however, as they did not know the wind direction, although they did notice a slight jet of vapor rising at the top of the building.[2] When they checked again, the operators could no longer see any vapor.[3]

If a jet of vapor was no longer escaping from the IC pipes, this could have been because the valves inside the tank were closed. The operators envisaged a second possibility at the time, however: the lack of vapor could also be because the IC tank no longer contained any water. If the tank was empty, then running the IC could cause permanent damage to the pipes. They therefore decided to close the valve shortly after opening it. A few hours later in the evening of the 11th of March, when power started to fade from the indicator light, they once again attempted to open the valve from the MCR; once again, they did not know whether this was successful, or whether it was rendered most because the interior valves were closed.

Meanwhile, the MCR tried to restore power to the indicators by setting up an emergency electricity supply using batteries taken from cars and buses in the parking lot. At the end of the afternoon on March 11, the indicators temporarily showed that the water level was 253 cm at the active part of the fuel (90 cm wide range). At 9:16 pm, the water level was only 20 cm above the fuel. Strangely, the water level then rose to reach 55 cm above the fuel at 10:00 pm. When the team then connected the batteries to other indicators, however, it was very clear that the containment pressure was dangerously high. The fact that the pressure was very high suggested that the water level indicator was malfunctioning and provided a warning that reactor 1 was in a highly dangerous condition. As a result, everyone concentrated on this reactor. Investigations subsequently revealed that the water level indicator in this tank was giving false readings because of the extreme conditions to which it was being subjected.

1.2 THE MECHANISMS GUIDING ACTIONS

- When all indicators and procedures became ineffective due to the loss of electricity, new means of gathering and interpreting the information had to be found.
- When most of the centralized controls are out of order and the actions must be performed manually in a dangerous environment (aftershocks, contaminated environment, etc.), it is necessary to have a very good knowledge of the installations to anticipate the course of action.
- It was difficult to establish a relationship between problems and solutions for the following reasons:

  1/ The lack of previous experience—it was difficult to operate by analogy, as no one had ever experienced a similar situation.

  2/ The lack of empirical knowledge founded on practical knowledge—“good sense”, such as looking out for vapor jets and visually checking the water level in the vessel—and expert knowledge, such as changing the position of the valves based on a knowledge of NPP operation.

2 They may have been confused by the vapor, which they believed was leaving the IC but may have come from reactor 4 instead.
3 Interim ICANPS, p. 125.

- Empirical knowledge was limited due to the division of tasks between humans and machines. The operators were faced with an "on-screen world"[4] in which "we do not see what we do"[5]. They were not directly involved in the production process but acted instead upon control and display systems that centralize information from groups of machines (alarm messages, measurement readings, etc.). There was a literal division of labor between humans and the automatic systems that they set up. This division of labor led the operators to act upon technical intermediaries rather than acting directly upon work objects.

- Empirical knowledge is also limited because of the important requirements and procedures that constantly guide the action of the operators, but reduce the parallel ability of operators to act without procedures.

- When the work object itself failed, the operators firstly had difficulty in realizing the fact because they thought of it as operating independently (as a result, no one imagined that the indicators might be malfunctioning). Secondly, the operators experienced difficulties in acting directly upon it (by developing other means of measurement, for example).

Exploring the Themes Further

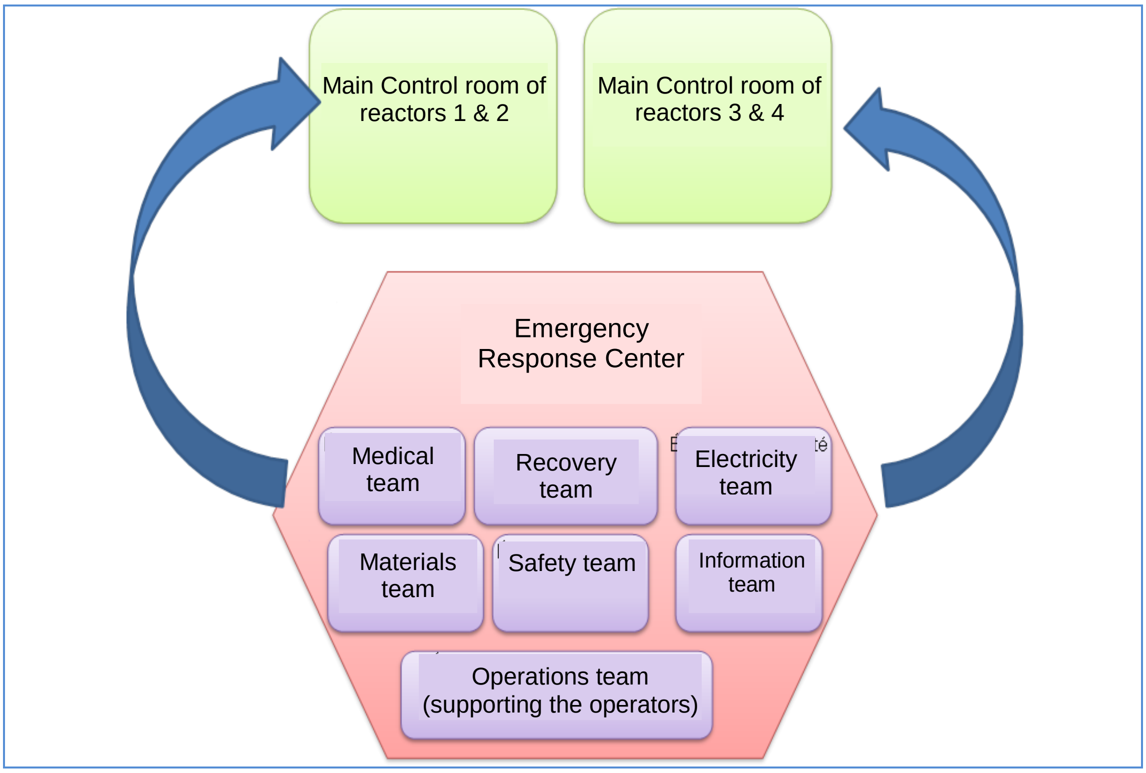
- ❑ What empirical knowledge enables us to respond to and tackle an unexpected situation?
- ❑ How can we encourage the development and dissemination of this empirical knowledge?
- ❑ To what extent can it coexist with "technological" knowledge in a highly proceduralized environment?

[4] Olson, D.R., 1998. "L'univers de l'écrit. Comment la culture écrite donne forme à la pensée", French translation. Retz, Paris (Cambridge, 1994).

[5] Bidet, 2008.

2 - HOW INDEPENDENT CAN THE MCR BE?

2.1 FACTS



Interim ICANPS, pp. 96-97

The main control room supervises both reactors 1 and 2. The shift team and his deputy and the assistant operators were the same for both units whereas the senior operators were specific to each unit. The shift team rapidly understood that they could not apply the planned emergency procedures. One of the major decisions taken by the shift supervisor on March 11 was then to define safety rules. As a result, the operators were then obliged to move in pairs as a minimum after obtaining the permission of the shift team, and not be absent for more than two hours. After this time, an intervention team would be sent to find them.

Soon after all electrical power was lost, the operators decided to construct a pipeline between a fire protection system pump and reactor 1 in order to inject water directly into the vessel. This line which is provided for in the Severe Accident Operating Guidelines[6], was found to be excessively difficult to set up without electricity. Rather than configuring the line from the MCR (by opening and closing the valves as necessary by pressing the control buttons), the operators were obliged to physically go to the reactor buildings to adjust the valves. They did this by first studying the reactor plans and drawing up a list of tasks to perform. At the sole instigation of the shift team, without any suggestions from the management, a small team dressed in protective clothing set out at 6:30 pm on March 11 and managed to configure the lineup linking the fire protection system pump to the reactor at around 8:50 pm.

At 1:48 am on March 12, however, the fire protection system pump suddenly stopped and no one was able to restart it (the diesel engine had stopped). The shift team had no further recourse at its level.

[6] Interim ICANPS, p. 144

The only possible solution was now to use the fire trucks as an external pump for sending water directly into the vessel. From this point onwards, the new emergency solution envisaged was no longer in the hands of the MCR, but shifted to the ERC supervising the construction of this pipeline. The fire engine pumps were used to drive the water into the reactor, instead of the fire protection system pump.

In the meantime, it seemed certain that it would be necessary to vent, i.e. temporarily release gases from the containment housing into the environment, to reduce the pressure inside the containment and so maintain its structural integrity. Some of the thirty-odd operators in the MCR and began to study the procedure for venting the containment without electrical power. Although they had been able to act on their own initiative up to this point, they were obliged to await the authorization of the ERC before they could perform this operation, because it could affect the populations around the plant and the ERC was trying to confirm evacuations. As the core meltdown process had probably already begun, radioactive releases into the environment were inevitable. The surrounding population had to be evacuated as rapidly as possible, but this took time because of the few means of communication available.

At 9:02 am on March 12, the ERC received confirmation that the population had been evacuated. Three pairs of operators were chosen to perform the venting operation, which required the successive opening of two containment venting valves. After the first team had put on the necessary protective equipment, it entered the reactor building, guided only by flashlights, and succeeded in opening the first valve manually. When the second team, which followed it, was about to enter the torus containment in order to open the second valve, however, the two workers realized that the environment was highly radioactive. They were likely to be exposed to a radiation level exceeding 100 mSv (the maximum legal dose at that time). The team then decided to abandon the operation and return to the MCR.

As it was not possible to open the valve manually, the ERC examined the possibility of opening an equivalent valve remotely in a parallel pipe by means of compressed air. No one had anticipated the need for an air compressor in order to open the valve remotely.

At approximately 12:30 pm on March 12, the air compressor requested a few hours earlier reached the plant and at 2:00 pm, it was installed and started. The reduction in containment pressure and the presence of white smoke escaping from the building suggested that the venting operation had been successful. However, at 3:36 pm an enormous explosion shook reactor 1 and the MCR was filled with dust. As a result, the operators rushed to put on their protective equipment in case of radioactive element releases. Field operations to inject water using the fire engines were also stopped in the aftermath of the explosion. Once they had been allowed to return to the field, the field teams had to repair the lines damaged by the explosion in order to restart injecting water into the reactor.

2.2 THE MECHANISMS GUIDING ACTIONS

- The planned procedures were no longer possible following the total loss of electrical power. The shift team was obliged to work independently or even in isolation due to the communications problems and the many emergencies that the ERC had to manage.
- The operators succeeded in adapting to uncertainty largely unaided. They set up operational procedures as well as procedures for managing the teams in the field. They were also able to develop action sequences independently, without the support of their management.
- Whenever the actions were not directly within the MCR, however, the shift team experienced three types of difficulties:

  1/ Interdependence with other stakeholders: for example, evacuation of the surrounding populations and working with firefighters.

  2/ The problem of anticipating events for unexpected action sequences. For example, no one had anticipated that an air compressor would be needed to open the venting valve remotely, and sourcing one delayed the venting significantly.

  3/ The complexity of the system, meaning that an action could affect another action sequence.

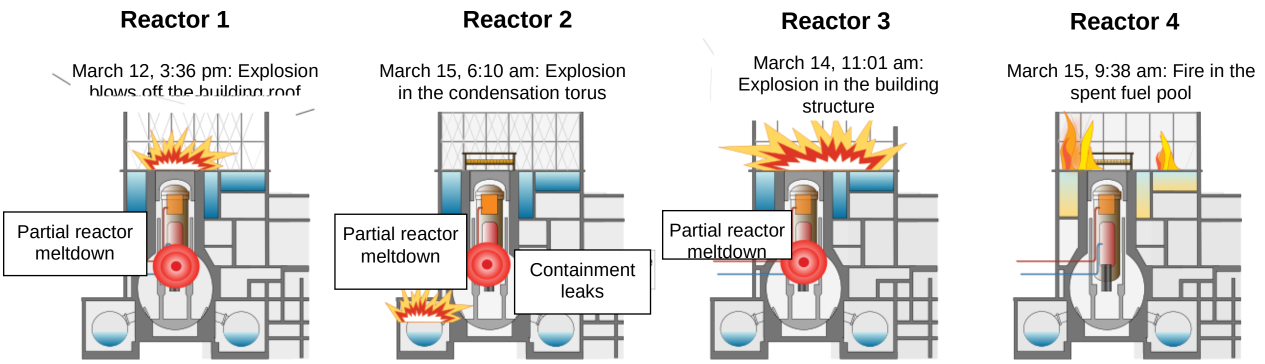
Exploring the Themes Further

- ❑ It is essential to examine how to preserve permanent communication links between the control room and the ERC, as vertical coordination is necessary.
- ❑ How should areas of expertise be redefined “directly” when this vertical coordination is no longer possible because of the interruption of the communication flow.

3 - HOW CAN SEVERAL UNITS BE MANAGED SIMULTANEOUSLY?

3.1 FACTS

General Sequence of Events



Source: Wikipedia

Although the condition of reactor 1 was the primary concern up to this point, the two other reactors were also affected by the accident. Following the tsunami, the situation also became very worrying for reactor 2, which, like reactor 1, was deprived of all electrical power; reactor 3 was partially powered, however, allowing some control to be maintained.

In the MCR controlling reactors 1 and 2, the operators tried to check the operational status of the emergency systems. The temporary recovery of indicators finally provided information on the situation and clearly showed that the condition of reactor 1 was the most dangerous and venting it was the highest priority. The emergency system of reactor 2 seemed to operate normally (until the March 14).

As all indicators and emergency systems were still working in unit 3 even after the tsunami had passed, the attention of the ERC mainly turned to reactors 1 and 2. Nevertheless, on March 12 at 11:36 am, the reactor core isolation cooling system (RCIC)[7] of reactor 3 suddenly stopped working. A second emergency system, the high-pressure coolant injection system (HPCI)[8], then started up automatically. However, given the unusual circumstances the operators were managing the HPCI in an unusual way to attempt to save power. When they lost the water level indicator for the reactor, they became very concerned about the operation of the HPCI and whether they were controlling it correctly. The shift team, in consultation with the ERC, decided to create an injection line from the fire protection system pump and then reduce the pressure in the vessel in order to be able to inject water in that way.

At 15:36 on the 12th of March there was an explosion in the unit 1 reactor building. Even though the emergency systems – the RCIC for unit 2 and the HPCI for unit 3 – continued to work for the moment, the superintendent of the plant, Yoshida, realized during the difficulties with unit 1 that many normally simple tasks, such as the preparation of a venting line, would take far longer than expected under these circumstance. At 17:30, he therefore gave the order to prepare venting lines for both reactors.

[7] The RCIC is not an emergency core cooling system proper, but it is included because it fulfills an important-to-safety function which can help to cool the reactor when all electrical power is lost.

8 The HPCI is the first line of defense in the emergency core cooling system. HPCI is designed to inject substantial quantities of water into the reactor while it is at high pressure so as to prevent the activation of the automatic depressurization, core spray, and low-pressure coolant injection systems.

At 2:45 am on March 13, the operators in the MCR stopped the HPCI and then tried unsuccessfully to reduce the reactor vessel pressure. It was impossible to inject water using the fire protection system pump under these conditions, because its use required the pressure to be less than 10 bar within the reactor vessel. Moreover, neither the HPCI nor the RCIC could be restarted. In fact, considerable electrical power was required in order to open the depressurization valve and insufficient batteries were available. The additional batteries sent by the neighboring Fukushima Daini NPP were not powerful enough. As a result, the recovery team took batteries from employee vehicles parked in the parking lot. During this time, the radiation level in the MCR rose drastically.

At 9:08 am on March 13, once batteries had been reconnected it was finally possible to open the depressurization valves, thereby allowing fresh water to be injected into the vessel by means of the fire trucks shortly afterwards. Nevertheless, the radiation level continued to rise. At around 12:00 pm, as the fresh water had been exhausted, it was decided to inject seawater into the vessel (we will return to this decision when in question 6). As access to the sea was difficult, seawater trapped in pockets of the plant after the tsunami had receded was used.

Benefiting from the lessons learned from the difficulties in venting the containment of reactor building 1, the operators anticipated this step. They connected the venting valve to the air compressor and electrical power from car batteries found in the parking lots. They also constructed lines for injecting water directly into the vessel in the event of an emergency. However, these line configuration operations were slowed because the firefighters were completely occupied by reactor 3.

On March 14 at 1:00 am, the seawater reserves began to fall low and it was necessary to configure a line to the sea as rapidly as possible. Initially, the line was constructed from the sea to the pit where the seawater had collected after the tsunami, to utilize the line that had already been configured from that pit to the reactors. At 11:01 am, the reactor building of unit 3 finally exploded, however, injuring 11 people. All of the workers were immediately evacuated to the earthquake-resistant building. At 1:00 pm, the damage assessment team noted that most of the fire trucks had been damaged and the hoses were unusable. It was then decided to construct an injection line directly from the sea to the reactor using the fire trucks. Seawater injection began at 4:30 pm.

In the unit 2, when the operators return, after the explosion, it appeared that the emergency cooling system of reactor 2 was no longer operating at all. Water had to be injected directly into the vessel as rapidly as possible. To do this, however, it was necessary to reduce the pressure in the vessel. Normally, the reactor can be depressurized using the wetwell or suppression chamber. In this case, however, it was more complicated. Two days earlier operators had switched the emergency RCIC system source to the suppression pool, gradually increasing the pressure and heat in the suppression chamber. Discussions ensued between the plant director Mr. Yoshida, TEPCO managers, and the experts advising the Japanese Prime Minister as to the best means of lowering the pressure in the reactor. While the Prime Minister's advisor recommended immediately depressurizing to the suppression chamber, Yoshida worried that the heat and pressure in the wetwell would prevent significant depressurization, and that therefore a venting line to the outside should be constructed first.

Once again, however, venting the containment turned out to be an extremely difficult process. At 4:00 pm on the same day, despite the use of compressed air by the recovery team, the venting valve could still not be opened. As a result, TEPCO ultimately asked for the pressure inside the reactor vessel to be reduced without delay. Despite the use of ten batteries connected in series, it was still very difficult to open the vessel pressure relief valve fully. At 6:20 pm, while the water level was now below the core, the pressure was still too high to allow the injection of water. By 7:54 pm, however, the pressure had decreased sufficiently to allow the injection of water to begin, although continuous water injection was not possible since the pressure remained too unstable. Core meltdown was had almost certainly already occurred. Mr. Yoshida, in consultation with the national crisis management committee, considered evacuating the personnel. At 1:00 am on March 15, however, the pressure eventually stabilized, allowing water to be injected continuously at last.

3.2 THE MECHANISMS GUIDING ACTIONS

- The undersized ECR was obliged to prioritize needs and its attention was focused successively on one reactor at a time.
- The ERC began to reason by analogy: what happened in reactor 1 served as a frame of reference for the others. In particular, the venting difficulties that appeared for the reactor were used to anticipate the venting action sequences for the other reactors.
- Nevertheless, the management of each reactor in turn created certain difficulties because it was not easy to prioritize actions between the reactors.

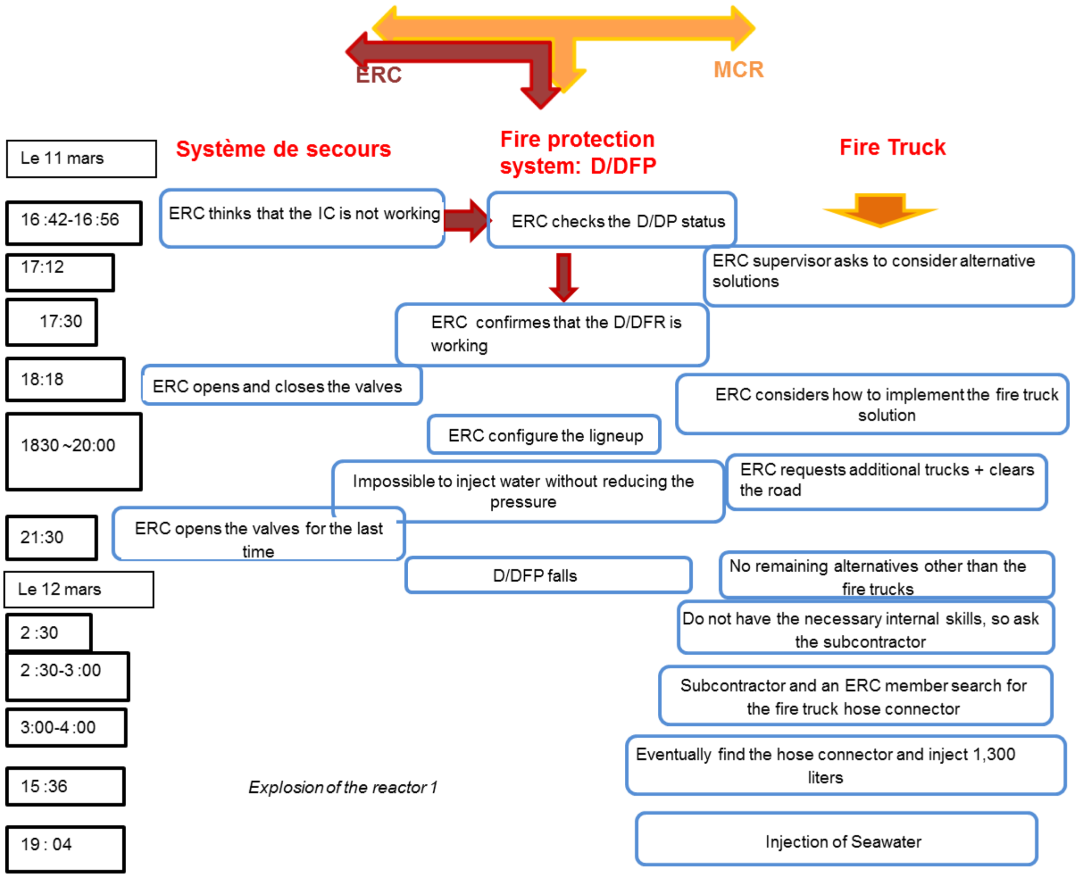
Exploring the Themes Further

- The emergency response team is obliged to face two conflicting issues simultaneously:
  - Maintain its ability to provide the advice and strategic steering specific to a nuclear reactor.
  - Be able to track all units simultaneously in order to manage a complex system.
- It seems important to examine the procedures and tools used to coordinate the different bodies comprising the emergency response team.
- In particular, it could be useful to think about the possibility of adjusting the size of the emergency response team to cater for the number of units involved.

4 - HOW IS INNOVATION ENCOURAGED IN AN EXTREME EMERGENCY SITUATION?

4.1 FACTS

The idea of using the fire trucks to inject water directly into the reactors in order to cool them occurred to Mr. Yoshida, the Fukushima Daiichi NPP director, only hours after the tsunami. This solution was only implemented later, however. In fact, three cooling solutions were envisaged in turn: the emergency systems (IC, RCIC and HPCI), an emergency coolant system (produced by linking three existing coolant systems together) powered by the fire protection system pump and, lastly, the use of the use of this emergency coolant system powered by the fire trucks instead.



When the emergency cooling system of reactor 1 started, it was not possible to check that it was operating correctly following the tsunami. Faced with this concern, the MCR rapidly considered alternative solutions and decided to use the fire protection system pump to inject water directly into the reactor. At 5:30 pm, the MCR operators set to work.

Mr. Yoshida had doubts regarding this solution, however. Having lived through the Kashiwazaki-Kariwa NPP incident following the Chuetsu-oki earthquake, he knew that the external water lines and equipment could have been damaged whereas the internal piping was better protected. In parallel with the work of the shift team, Mr. Yoshida therefore ordered the ERC, at 5:12 pm on March 11 , to consider alternative solutions to those provided by the procedures, including notably, the use of fire trucks.

Originally, three fire trucks were available on the site but only one was directly usable after the tsunami (one had been destroyed and the other could not move to the desired location because of debris). The ERC requested that additional trucks be sent. However, the earthquake and tsunami had caused considerable damage. The roads were damaged and blocked by large debris such as oil tanks and boats. These debris delayed the arrival of external fire trucks (and other equipment), and also created significant obstacles to movement within the plant once they arrived. One team within the ERC, the recovery team, therefore had to unblock the roads on the site to enable the fire trucks to reach the reactors.

Meanwhile, the line between the fire protection system and the vessel was completed, but the emergency diesel pump ran out of fuel in the early hours of March 12, before it could even begin to inject water. Even after the pump had been refueled, it could not be restarted.

The fire truck solution, which might appear extravagant and difficult to implement, became the only viable solution. However, no one at TEPCO was able to operate the fire trucks on site. Only the Nanmei subcontracting company was able to do so, and the Nanmei CEO raised concerns about collaboration on the effort, given the danger the situation posed to his workers. Although he finally agreed, when the Nanmei team set out it was difficult to identify the precise location of the external hose connector on the reactor building facade for connecting the to the fire truck, particularly with the debris and damages caused by the tsunami. With the help of recovery team members, the Nanmei team studied the plant plans and finally located a TEPCO employee who had first-hand knowledge of the port location.[9] It was only at 4:00 am, with the help of head flashlights, that they managed to find the hose connector hidden under a pile of debris and could begin the water injection process.

[9] TEPCO report, June 20, 2012, pp. 179-180.

4.2 THE MECHANISMS GUIDING ACTIONS

- The first phase of the work was characterized by the stakeholders attempting to use the emergency systems while distracted by many doubts from the outset.
- Their persistence in restoring those lost capabilities can be explained by the fact that this solution satisfied everyone involved: the shift team, which possessed the technical expertise, as well as the ERC, as it was easier to follow existing procedures than to create new ones with uncertain results.
- The solution to turn to an extremely innovative solution using fire trucks was made by the director of the plant, on the basis of his experience of a past crisis.
- The decision to turn to a innovative solution was taken when it appears that the emergency systems will not work. The solutions are implemented sequentially. Thus, the solution of fire trucks is considered from 5:12 p.m., but preparation is not anticipated and the difficulties encountered in the implementation of it will extend the effective implementation time (around 4:00 on March 12).
- It was possible to resort to an innovative solution because of centralized coordination that did the following:
    - proposed an innovative solution drawing on analogies with previous experiences;
    - took responsibility for the decision;
    - assigned stakeholder functions and roles that were not predefined, such as operating the fire trucks;
    - negotiated possible requirements with the subcontractor in a highly risky situation.
- Its implementation was facilitated, even if it was not unproblematic, by the recovery team, which:
    - can take responsibility for poorly defined emergencies whose handling requires several fields of expertise;
    - can adopt a “DIY” approach in making creative use of the available resources.

Exploring the Themes Further

- Centralized coordination is fundamental to the implementation of innovative solutions.

- The role of this coordination, not only in choosing the solutions but also in fixing (and enforcing) the limits outside which the envisaged operation must be abandoned, should be examined.

- The operating experience feedback from past crises contributes to the development of innovative solutions.

- It is important to study the role of a recovery team that:
  - is not assigned specific functions and whose skills are likely to be deployed in response to unexpected situations,
  - and at the same time demonstrates its solid skills, including the ability to draw on an "empirical approach" founded on a "practical knowledge" as well as an "expert knowledge" (see question 1).

5 - WHEN CONFRONTED WITH TRAGIC DECISIONS, WHAT ETHICAL PRINCIPLES SHOULD BE APPLIED?

5.1 FACTS

Choosing the Operators Who Will Risk Radiation Exposure

Faced with the severity of the accident, the operators, managers and politicians were confronted with tragic choices. Institutional decisions were taken that could affect the course of a life[10].

Two successive situations confronted the stakeholders with tragic choices. The first was the selection the operators who would be asked to act in the field. After electrical power was lost, the operators could no longer simply configure the new water lines using the controls in the MCR. They were obliged take direct, manual action in the field even though the radiation level was continually rising. Several members of the shift team admitted they were afraid: “After all, the situation prevented us from knowing the water level of reactor 1 and perhaps reactor 2, and core meltdown could have occurred at any time. Given the context in which we were working, yes, I was definitely afraid”[11].

The shift supervisor, not wanting to send operators into the field, volunteered to go himself. He was rapidly dissuaded by his colleagues, however, who emphasized the need for consistent leadership [12] in the reigning chaos. Concerns were also expressed regarding the exposure of the younger workers to the risk of radiation.[13] As a result, five operators, two of whom were actually not on duty that day

duty) and two deputy shift supervisors were selected for the three teams.

The second situation that resulted in a tragic choice concerned the venting of the reactor. The emergency response team asked the crew foreman to choose who would be responsible for performing this operation[14]. The crew foreman firstly ruled out the youngest operators and then stated that if no one volunteered, he would participate in doing so himself. At that time, several operators volunteered and emphasized the importance of the crew foreman remaining in the control room[15]. The selection process became a little more complex when the risk involved in completing the task increased. Mr. Kadota then stated that the names of the seniors and of the most experienced operators were written down on a whiteboard in order of age. Pairs of workers were then selected to perform certain tasks, based on their knowledge of the work point in some cases, or so that less senior workers performed more physically difficult tasks in other cases. The selection of two pairs was required. It was also necessary to choose another pair to come to their aid if a problem occurred in the field[16]. Four crew foremen (in addition to the one on duty) and two deputy crew foremen were chosen to train the three teams.

Risk Negotiations

The conflict between worker safety and the need to perform urgent tasks is a recurring theme in crisis management. In the case of Fukushima these two issues were not entirely opposed. If workers failed to bring the reactors under control, they would be the first to suffer the consequences, followed by the surrounding population, much of which consisted of their families and loved ones.

Rather than deciding between two issues, there was constant negotiation between the risk facing the operators and the expected benefits of the action to be taken.

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10 We are basion our support on the book Jon, E., & Nicolas, H. (1992). Éthique des choix médicaux. Arles, Actes Sud.

11Kadota, p. 77.

12 Kadota, p. 77.

13 Kadota, p. 79.

14 Kadota, p. 122.

15 Kadota, pp. 124-125.

16 Kadota, p. 127.

The International Commission on Radiological Protection (ICRP) has stated that in extreme radiological emergency situations, there is no exposure limit when the operators (who must all be volunteers) participate in life-saving emergency operations. The exposure level must be less than 500 mSv in the case of rescue operations in an already radioactive environment, however. In accordance with these recommendations, the exposure limits in emergency situations in Japan were fixed at 100 mSv.

Nevertheless, the TEPCO ERC noted that the radiation levels continued to rise and realized that it would soon be impossible for the operators to continue their work if they complied with the current exposure limits. The TEPCO executive management then requested the advice of the regulatory authorities (NSC and NISA). In response, the Prime Minister's Office decided to increase the limit to 250 mSv on March 14 (and then 500 mSv on March 17)[17]. In the view of Mr. Yoshida, "although the governmental authorization allows the exposure time to be extended, it does not give the bodies of the workers a higher resistance to radiation."[18]

In addition, it was difficult to estimate the exposure level of the workers. Some dosimeters were damaged by the tsunami, while others were only designed to operate up to a maximum of 100 mSv and were not available in sufficient numbers in any case (especially when reinforcements joined the MCR).

The workers tried to limit their exposure to radiation while continuing to work. In the MCR, they developed various strategies such as wearing protective equipment, keeping as close as possible to ground and taking refuge in the least contaminated parts of the MCR. In the field, the workers responsible for constructing the water lines or restoring electrical power tried to limit their risk by reducing their exposure time by taking turns with other workers, or by taking refuge in the areas least at risk from time to time.

When the radiation level continued to rise after reactors 1 and 3 exploded and the TEPCO workers had no means whatsoever of preventing the core meltdown of reactor 2, Mr. Yoshida considered the possibility of temporarily evacuating the NPP.[19] The ERC chose 600 people who were allowed to leave and the 50 (including Mr. Yoshida) who were to remain at the plant. Ultimately, the evacuation was only temporary as the situation of reactor 2 improved slightly.

Subcontractors

These tragic decisions became even more complex when they involved subcontractors. Early on March 12, some employees of the Nanmei subcontracting company were mobilized, as they alone were able to drive the fire trucks. According to the ICANPS report, although the task was extremely dangerous due to the high radiation level, the head of the local Nanmei office agreed to take the risk because of the urgency of the situation.[20] Members of the operations team within the TEPCO ERC came in support to assist them in the field operations.

When the radiation subsequently rose to high levels, which was not provided for in the contract, the head of the local Nanmei office began to show signs of hesitating to continue to participate in the seawater injection process.[21] At that time, TEPCO had very few options available. They could not renegotiate the contract or train TEPCO personnel within the short timeframe of the crisis. They finally managed to reach a compromise, although the negotiations delayed the extremely urgent injection of water into reactor 1: one member of the Nanmei personnel would accompany the TEPCO firefighters in order to operate the vehicle.

5.2 THE MECHANISMS GUIDING ACTIONS

> In the extremely urgent situation facing them, the Fukushima workers were confronted with two levels of tragic decisions whose consequences could potentially affect the rest of their lives. The first level consisted in choosing the workers who would be responsible for performing dangerous but necessary tasks. The second level consisted in defining acceptable conditions under which the task concerned was to be performed.

[17] Interim report, p. 341.

[18] Kubota, chapter 3.

[19] There is still controversy regarding this point.

20 Interim ICANPS, p. 154.

21 Interim ICANPS, p. 155.

- As the first level of decisions consisted in choosing the people who would be exposed to considerable radiological risks, several ethical principles were applied:
    - The "common good" was a fundamental principle in this situation. Individuals agreed to cooperate even though they put their lives at risk.
    - Status-related principles: based on biophysical and more generally, social characteristics, age is a central criterion in this case. The cancers that develop after exposure to low-dose ionizing radiation have a latency period that can be as long as several decades. As a result, elderly workers are less likely to develop cancer. However, Mr. Yoshida himself said in his testimony that age does not only refer to biological characteristics. The social dimension also seemed to have been taken into consideration, although this has not really been explained.
    - The need for efficiency: the procedure was the result of a compromise between local efficiency and overall efficiency. Overall efficiency consisted in choosing the worker with the best chance of success in the shortest possible time. Local efficiency consisted in ensuring that the operational teams continued to operate properly by maintaining the integrity of the existing leadership. The chosen compromise therefore consisted in choosing experienced personnel who were not leaders.
    - In this case, the time principle was particularly complicated to apply. Various people were chosen to perform the necessary tasks. However, the performing of these tasks was spread over time as necessary. The more time passed, the more the task concerned became dangerous due to the rising radioactivity levels. As a result, the passage of time was a regulatory principle that was difficult to control.
    - The egalitarian principle was rejected. An egalitarian procedure would have consisted in assigning the task by giving an equal chance to all participants, by means of a lottery for example. The fact that this potential regulatory procedure was rejected is in itself an implicit decision that should be examined.
- The first level of decisions was taken by the shift supervisor in consultation with other the operators in the MCR. The shift supervisors were used to managing their crew and allocating tasks on a daily basis. They continued to perform this role almost spontaneously in emergencies. The decision was no longer routine, however, and was independently endorsed by the shift team.
- The second level of decisions was mainly made by the ERC, TEPCO executive management and the experts of the political authorities. They wished to adjust the exposure limits in order to adapt to the new context. The compromise was based on the exposure limit below which the risk was assumed to be acceptable.

Exploring the Themes Further

- The ethical dilemmas that can face workers, including subcontractors and external stakeholders, are rarely anticipated and can greatly influence group dynamics in such cases.
- Their emergence demands study to decide which ethical principles should be prioritized in situations that put the workers at considerable risk.
- Should the legitimate stakeholders in emergency situations also be studied to decide which should shoulder the first or second levels of such decisions?

6 - INTERVENTION OF THE POLITICAL SPHERE; OR WHY IS DECISION-MAKING CENTRALIZED IN CRISIS MANAGEMENT?

6.1 FACTS

Investigations looking into crisis management quickly identified shortcomings in crisis management capabilities[22]. The Prime Minister's excessive interference in decisions beyond his expertise has been called into question[23]. This centralized decision-making process can be attributed to four organizational factors:

The ad hoc crisis management structure widened the gap between groups

The initial crisis management structure at the national level was changed very quickly after the start of the accident. The crisis plan featured a cooperative way of working, bringing together a number of experts and politicians within the NEHRQ (Nuclear Headquarters).

However, just a few hours after TEPCO declared a state of nuclear emergency, the Prime Minister and a small group of his most trusted advisors isolated themselves in his office, away from the chaos of the NEHRQ.

As a result, the crisis management structure diverged almost immediately from the organizational methods laid out in the emergency plan, as if crisis management poorly coincided with organizational standards.[24] The Prime Minister organized his scope of action, changing and creating procedures according to what he thought was best for the situation. Lanzara[25] argues that ephemeral organizations have the ability to adapt to their environment so that necessary actions can be established and closely supported. However at the same time, the Prime Minister and his advisors disregarded established procedures and broke lines of communication.

When he demanded a direct line of communication between TEPCO and his office, TEPCO had not yet put appropriate procedures in place, since the plan was for direct communication with NISA, not with the Prime Minister's Office. A lot of information was therefore lost or poorly relayed because TEPCO did not know what information needed to be passed on nor who should receive it. In addition, although both the NEHRQ and the Prime Minister's office continued to receive some information from TEPCO, they were not necessarily obtaining the same level of information, leading to discrepancies in assessing the situation and cooperation problems. In the end, this ad hoc crisis organizational structure distanced the local level from the highest levels of government, which is typical of a bureaucratic system.

22 NAIIC- chapter 3

23 Perrow, Charles. Normal accidents: Living with high risk technologies. Princeton University Press, 2011.

24 Clarke, Lee. Mission improbable: Using fantasy documents to tame disaster. University of Chicago Press, 1999.

25 Lanzara, Giovan Francesco. Ephemeral Organizations In Extreme Environments: Emergence, Strategy, Extinction [I]. *Journal of Management Studies*, 1983, vol. 20, no 1, p. 71-95.

Lack of trust leading to heavy-handed control

Political authorities placed limited trust in TEPCO's management of the accident, as it may have been more concerned with preserving its reactors than protecting people[26]. The Prime Minister thinks that it does not have enough information on the management of the accident, especially since it is ultimately in charge of the evacuation perimeter population[27]. This distrust likely played a role in the actions taken by the government.

The Prime Minister did not just want regular updates on the situation. He wanted to understand the stakes and ensure that all the emergency measures were being properly implemented. When he felt that he was not receiving enough information from TEPCO, especially to understand how long containment venting would take, the Prime Minister decided to go to the site himself[28] to understand what was going on, at the risk of creating a distraction and delaying emergency operations[29.]

This lack of trust reached a climax a few hours later. After successful venting, the reactor building containment suddenly exploded on the afternoon of 12 March. TEPCO executives with the Prime Minister found out from television reports rather than through official communication channels[30]. Meanwhile, the Prime Minister received reports of the explosion from police and not from TEPCO[31]. Until then, experts had been adamant that there was little, or even no chance of an explosion occurring. The unexpected event changed the management dynamics around the accident. Rather than encouraging decentralization so that flexible and creative solutions could be implemented, the Prime Minister tightened his control of the Fukushima Daiichi Nuclear Plant.

A question of power and responsibility

At the same time, as management of the accident progressed, decision-making became highly centralized. After successfully injecting freshwater from various storage areas into the reactor vessel, TEPCO realized that sea water would need to be injected. Most experts also backed this opinion, to the point that the Minister of Energy and Industry, responsible for nuclear plant activity supervision, became impatient with delays and ordered TEPCO to inject sea water into the vessel.

However no one in the Prime Minister's office heard about the order. Advisors then scrambled to convince the Prime Minister of the need to inject sea water. He remained skeptical, especially when no one was able to provide any definite answers concerning the risks. When a TEPCO representative charged with facilitating communication between the Prime Minister's office and the Fukushima Daiichi plant realized that sea water injection had already begun, he immediately requested that injection be stopped. Fearing that it would be dangerous to stop injecting sea water, Mr. Yoshida spoke with TEPCO head office, which confirmed that "as long as the Prime Minister's office had not made a decision, it would be difficult to continue injecting sea water". This approach demonstrates the strong desire to maintain the appearance of centralized decision-making. It was not just about

26 NAIIC, Chapter 3 p.53

[27] Entretien de Naoto Kan réalisé par le rédacteur en chef du site Reporterre Hervé Kempf pour le film « Libres ! » (http://www.sciencesetavenir.fr/nature-environnement/20150225.OBS3366/naoto-kan-comment-fukushima-m-a-rendu-definitivement-anti-nucleaire.html).

[28] ICANPS Final p 220.

[29] NAIIC, p. 53

[30] ICANPS interim p 76.

[31] NAIIC Report, Chapter 3, p 40.

obeying orders from higher up. It also enabled TEPCO to avoid taking sole responsibility for the decision to inject sea water given all the uncertainty[32]. In situations where extreme threats are involved, power and authority tend to be concentrated in the hands of political leaders or high-level officials[33]. To some degree, political authorities are sucked into taking on the role and responsibility of decision-maker. The desire to give the appearance of centralization is so strong that it can paralyze the chain of players involved in taking action.

Parallel power relationships

Extremely strong centralized decision-making often leads to the development of parallel power relationships to adapt to needs in the field[34]. In this case, Mr. Yoshida was faced with the dilemma of having to bend to an appearance of centralized decision-making while being absolutely convinced that sea water injection should continue. He therefore asserted that injection had stopped even though it was not the case. When the Prime Minister eventually gave his approval, TEPCO reported that it had restarted injection even though it had never stopped.

Not all players are able to adhere to the stringent requirement for centralized decision-making. There is high tension between the need to present centralized decisions with consensus support and the need to make decentralized decisions in urgent situations to effectively meet the needs of those concerned. This situation causes the players that are closest to the accident to develop parallel power relationships and decision-making processes.

6.2 THE MECHANISMS GUIDING ACTIONS

- The coherence and dynamics of the centralized response to the Fukushima accident were based on 4 main characteristics: a large gap between groups of protagonists, a lack of trust that led to a need for control, highly centralized decision-making, and consequently, parallel power relationships.
- When put together, these characteristics increase centralized decision-making and the pitfalls that come with it.
- The successive presence of these fundamental traits is the functional response to communication issues and organizational problems in a crisis situation.

32 NAIIC, Chapter 3, p. 30

11 Paul ‘t Hart, Uriel Rosenthal and Alexander Kouzmin. “Crisis Decision Making: The Centralization Thesis Revisited.” Administration & Society 1993 25: 12

34 Crozier, M. (1963). The Bureaucratic Phenomenon (Chicago, 1964).

Exploring the themes further

- The existence (or otherwise) of a climate of trust between the licensee and government authorities is decisive in crisis management.
- If an ad hoc crisis management team is created, it must not break lines of communication and create a source of distrust
- Crisis management is the extension of a pre-existing operational framework. Complicated relationships will remain in crisis. Relationships between operators and regulators, and between technical and political stakeholders therefore need to be taken into consideration.
- This is why preparedness for crisis management is important. Shared procedures and reference guides will contribute to building trust.