RAPPORT

INSTITUT
DE RADIOPROTECTION
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*Faire avancer la sûreté nucléaire*

# A Human and Organizational Factors Perspective on the Fukushima Nuclear Accident

*March 11 – March 15, 2011*

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Rapport PSN-SRDS/SFOHREX n°2015-01

Pôle sûreté des installations et des systèmes nucléaires
SFOHREX / Laboratoire de recherche en Sciences Humaines et Sociales

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La réponse à l'accident de Fukushima à la lumière des facteurs organisationnels et humains

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**RESUME**

L'étude présentée dans ce rapport aborde la catastrophe nucléaire de Fukushima Dai-ichi sous l'angle des facteurs organisationnels et humains. Elle analyse l'accident à trois niveaux : les opérateurs de première ligne ; la centrale dans son ensemble ; et l'organisation nationale de crise, y compris l'exploitant TEPCO et les acteurs politiques. En regardant chacun de ces niveaux et les relations qui se nouent entre eux, ce rapport décrit la façon dont les structures organisationnelles et les procédures de gestion des accidents ont facilité ou gêné la gestion de crise.

Le rapport présente une chronologie détaillée du déroulement de l'accident en partant des trois réacteurs qui étaient en fonctionnement, avec une ouverture sur la centrale de Fukushima Dai-ni. Ces descriptions servent ensuite de base à une analyse de la gestion des risques et du management de crise, en particulier à la lumière des travaux de Perrow (1999) sur la centralisation-décentralisation des décisions et de Weick (1988, 1993, 1995), notamment sur le « sense-making». Les principales conclusions qui ressortent de cette analyse concernent les questions suivantes :

*1/ Lorsque plus aucune procédure n'est opérationnelle, les opérateurs ont besoin de redonner un sens aux évènements en cours et de définir de nouveaux indicateurs pour pouvoir évaluer la situation.*

*2/ Du fait de la quasi interruption des lignes de communication entre la salle de commande et le local de gestion de crise, l'équipe de conduite a dû gérer l'accident de manière relativement autonome tout en cherchant à retrouver le soutien de l'équipe locale de crise.*

*3/ Dimensionnée pour la gestion d'un accident sur un seul réacteur, la cellule locale de crise a dû prioriser les besoins et son attention s'est portée successivement sur un réacteur à la fois, tout en cherchant à tenir compte de l'impact des actions engagées sur un réacteur sur la gestion des autres réacteurs.*

*4/ Les acteurs éprouvent une réticence – légitime - à assumer le choix de solutions inédites*

*(l'injection d'eau de mer dans un réacteur en utilisant des camions de pompiers) dans un contexte de crise. Une coordination interne et externe est nécessaire pour endosser la responsabilité de la mise en œuvre de ces solutions. A cet égard, une équipe « cross function » apparait très utile pour mettre en place ces nouvelles solutions.*

*5/ Les modalités de mise en œuvre des règles relatives à la radioprotection des travailleurs doivent être aussi claires et précises que possible, notamment celles qui concernent la constitution des équipes chargées de la réalisation d'opérations sur le terrain et celles relatives à l'intervention de personnes d'entreprises sous-traitantes.*

*6/ La décentralisation, alors même qu'elle peut être prévue par les procédures d'urgence peut être difficile à maintenir dans la pratique, en particulier lorsque la crise s'étire dans le temps.*

**ABSTRACT**

This report examines the Fukushima Dai-ichi nuclear accident using a human and organizational factors framework. It analyzes the crisis at three levels: the frontline operators; the plant as a whole; and the political context including the management team of the electric company and national politicians. By looking at each of these levels as well as the relationships between them, this report describes the way the organizational structures and their accident management procedures contribute to or hinder the resolution of the crisis.

The report offers detailed chronologies of the unfolding of the crisis at each of the three active reactors at Fukushima Dai-ichi, at the political level, and at Fukushima Dai-ni. These case descriptions are used as the basis for an analysis drawing on risk and crisis management studies, in particular examining Perrow's (1999) centralization-decentralization conundrum and Weick's (1988, 1993, 1995) work on sense-making, among others. The main findings include:

*1/ The accident disrupts not only the situation, but also in the ways people go about gathering information on the situation People had to make sense of what happened and find new ways to interpret limited information*

*2/ Tue interruption of the communication flow between the ERC and MCR can have dramatic consequences. It is important to maintain the communication between the ERC and MCR in all circumstances.*

*3/ The difficulty of simultaneously supervise crisis room tranches due to its under sizing. A capacity adjustment to the ERC must be made according to the number of reactors involved.*

*4/ Because of the reluctance to make the decision to test a new possibility in a crisis context, internal coordination is necessary to decide on the implementation of new solutions. Cross-functional teams can be very useful in coming up with new solutions.*

*5/ Worker safety policies should be as clear and specific as possible before accidents occur. Where sub-contractors are involved, clear policies on worker safety and degree of commitment are even more important.*

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

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# ACRONYMS

| | |
|---|---|
| AO | Air-operated |
| CWP | Circulating Water Pumps |
| ERC | Emergency Room Control |
| EOPs | Emergency Operating Procedures |
| HPCI | High-Pressure Coolant Injection |
| IC | Isolation Condenser |
| ICANPS | Investigation Committee on the Accident at the Fukushima Nuclear Power Station |
| MCR | Main Control Room |
| MO | Motor-operated |
| MUWC | Make-up Water Condensate |
| METI | Ministry of Economy, Trade, and Industry |
| NAIIC | Nuclear Accident Independent Investigation Commission |
| NERHQ | Nuclear Emergency Response Headquarters |
| NISA | Nuclear and Industrial Safety Agency |
| NSC | Nuclear Safety Commission |
| PCV | Primary Containment Vessel |
| PMO | Prime Minister's Office |
| RCIC | Reactor Core Isolation Cooling |
| RHR | Residual Heat Removal |
| S/C | Suppression Chamber |
| SRV | Safety Relief Valve |
| TEPCO | Tokyo Electric Power Company |

# 1 INTRODUCTION

The accident which was triggered at Fukushima Dai-ichi nuclear power plant on March 11, 2011 in the wake of a massive earthquake and tsunami is the worst nuclear accident since Chernobyl and has had a considerable impact on popular as well as political and scientific approaches to nuclear power in Japan and worldwide. While many studies have attempted to disentangle the technical issues and unfolding of the crisis, this analysis aims to contribute to the relatively small body of literature examining the human and organizational factors involved in the management of the crisis.

A nuclear power plant is an extremely complex system. From the moment the earthquake hit at 14: 46, until the eventual cold shutdown of the reactors, numerous decisions were made by human actors ranging from a single operator in the main control room to the Prime Minister of Japan. Since the crisis quickly deviated from the emergency situations described in the accident management guidelines, these decisions were for the most part uncertain, judgment calls made on the basis of incomplete and sometimes erroneous information.

By examining the functions of people and organizations under these circumstances, this study aims to expand our understanding not only about the specifics of the Fukushima Dai-ichi accident, but also of crisis management more generally, in the nuclear industry and beyond. How do technical operators manage a crisis when they have no technical data to work with? How do organizations mobilize their diverse resources in the chaotic context of a fast-moving emergency? How do relations between the primary responding organization – in this case, the utility operator – and external entities, like national governments and local authorities, change during the unfolding of a crisis?

Unlike many reports, this study does not seek to identify the *causes* of the accident. Rather, it aims to examine the *management* of the crisis after the triggering event. Once the triggering event occurred, the consequences were still not completely determined, and depended on the decisions and actions of the individuals and organizations that confronted it. It is worth noting that the incident could have ended much worse than it did. Had the actors simply walked away, or had their efforts failed to prevent catastrophic conditions in even one of the reactors, all of the reactors as well as the significant quantities of spent fuel on site would have been compromised. The decisions and actions after the tsunami mattered greatly.

If, as Perrow (1999) argues, "*Most high-risk systems have some special characteristics […] that make accidents in them inevitable, even 'normal*" then focusing on specific causes, while useful, does not negate the potential for future accidents. Learning about how humans and organizations interacted with the event can point to complementary lessons on how to mitigate and manage crises when – not if – they do occur.

## 1.1 METHODOLOGY

Due to the focus of this study on crisis management, it focuses specifically on the time period of the crisis: from the moment the earthquake hit at 14:46 March 11, 2011 to the point when the situation reached some type of stability. The end point of a crisis is always going to be somewhat arbitrary, but for the purposes of this study it is more or less noon on the 15th of March, 2011. While the days, weeks, and months following that point undoubtedly had many challenges and difficulties, it is the first four days of intense pressure, uncertainty, and chaos that interest us most here. We focused on the reactors 1, 2 and 3 that were functioning that day. Reactors 4, 5 and 6 were stopped.

Given the significant amount of data available, as well as practical constraints, this study is based on existing documentary sources. Priority has been given to documents based directly on primary sources, in particular: the reports provided by TEPCO; the reports from investigations carried out by the Japanese government, largely based on interviews; and articles or books written by journalists based on interviews with participants in the crisis response. A broader literature review was also carried out of other reports, articles, and studies.

Three main documents have been used:

- The Interim and Final Reports from the Investigation Committee on the Accident at the Fukushima Nuclear Power Stations (ICANPS).
- The report from the Nuclear Accident Independent Investigation Commission (NAIIC).
- Ryusho Kadota's book entitled "The man who looked in the abyss of death: Masao Yoshida and his 500 days at Fukushima Dai-ichi"

| | **Diet's investigation commission [NAIIC]** | **Government investigation committee [ICANPS]** | **The man who looked in the abyss of death** |
|---|---|---|---|
| Primary organization | The National Diet | The Japanese government | Independent Journalist |
| Committee chairman | Kiyoshi Kurokawa, Professor, National Graduate Institute for Policy Studies | Yotaro Hatamura, Professor Emeritus at the University of Tokyo | Journalist Ryusho Kadota (1983 Graduate from the Faculty of Law) has been confirmed as the recipient of the 19th Shichihei Yamamoto Prize |
| Number of interviewees | 1167 people (including plant workers, government officials and evacuees) | 772 people (including plant workers, government officials and evacuees) | Interviews with more than 90 people who were involved in the containment efforts, including their family members. Including are interviews with Yoshida |
| Size and date | Report (640-pages) and Data (650-pages) in July 2012 | Interim report (507-pages) in Dec 2011, Final report (450-pages) and Data (380-pages) in July 2012 | Book (375-pages) in 2012 |

Source: adapted from Ryiuji Kubota presentation, "Key HOF related topics from Investigation Reports and the Situation of Progress in and around the Fukushima site", In the 13th meeting of the CSNI WGHOF, 18-19 September 2012

First, a detailed chronology was traced for each of the three active reactors. This was based on existing reports, mainly the ICANPS interim report, the ICANPS final report and the NAIIC report. We also based on the Yoshida testimony, written by Kadota. This allowed for a clear common understanding of the way the accident unfolded, but also for a way to identify interactions and patterns across the different reactors. We do not focus on the causes of the accident, but on the human and organizational factors of the response and not about what should have been done but on what was done. Through the chronology of the accident, we interrogated the ability of actors to act and coordinate in an emergency and examined how or if their actions may have amplified the disaster.

Second, based on this chronology of the Fukushima Dai-ichi accident, we have conducted an analysis with a focus on human and organizational factors. The method led to develop a multifaceted, qualitative analysis at different levels: micro-level, meso-level and political level. It has the advantage of restoring people's logics of action and revealing the systems' dynamic aspects. In particular, the method should shed some light on how actors react and adapt facing an unexpected and dramatic event.

For the analysis at a micro-level, we examine the cognitive frameworks and biases of individuals and small working groups to try to understand decision-making (Chapter 4.1). How did the internalized perspectives and sense-making processes of the operators affect their understanding and actions during the response? We examine the relationship of the front-line operators with other parts of the organization. We also question how ethical principles influence the decision-making process during drastic choices (Chapter 4.2).

At the meso-level, we focus more on the organizational structure (Chapter 4.3): how decisions are made, how resources are mobilized from different parts of the company, how different teams interact in searching for new solutions. We also examine the same time period at Fukushima Dai-ni nuclear power plant, for the purposes of comparison (Chapter 4.4).

In studying the management of the accident, it becomes clear that political actors were involved. We examine how political actors – politicians and bureaucrats as well as scientists or technical advisors within government – interacted with the utility (Chapter 5). How was decision-making distributed across these actors? Did the various roles of the government – regulator, head of state, and ministry of energy – coordinate or conflict? Did their actions conform to their stated crisis management procedures? Were decisions being made by the people who were supposed to make them? Did communication flow according to plan? On what basis were certain pieces of information given more priority or trust than others? By exploring the interplay between the political actors and the utility, we uncover the dynamic of power relations during the crisis.

## 1.2 CONSTRAINTS

As mentioned above, this study relies entirely on existing documentary sources, primarily in English, Japanese,[1] and French. While there is a very rich literature about the disaster, much of it drawn directly from primary sources, not having the possibility of conducting qualitative interviews or quantitative surveys for the purposes of this study was a distinct limitation. We could not ask actors to clarify discrepancies in the different accounts, for example, of which there are several, nor to add detail where there are gaps.

In addition, although over four years have passed since the Great East Japan Disaster, knowledge of the events at Fukushima Dai-ichi is still evolving. There are still elements of the technical course of the disaster that can only be guessed at or modeled, as researchers wait for more access to data at

[1] Where English translations were available for Japanese sources, those were used, although in some cases they were checked against the original. Where published English translations were not available, the translations cited here are by the author.

the plant. Similarly, as more people become willing to talk about their role, the understanding of the human and organizational factors involved may also develop.

## 1.3 BACKGROUND

A comittee within IRSN was assigned to supervise this survey. The committee members included: Hervé Bonneville, Eric Cogez, Véronique Fauchille, Carine Hebraud, François Jeffroy, Emmanuel Raimond and Daniel Tasset.

We sincerely thank our reviewers for their comments:

- Valerie Barnes (NRC, USA)
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- Ryuji Kubota (NSR, Japon)
- Monica Haage (IAEA, Autriche)
- Brigitte Skarbo (IAEA, Autriche)
- Helen Rycraft (IAEA, Autriche)

The views expressed in this report are those of IRSN and reviews do not constitute an official endorsement from the reviewers.

# 2 GENERAL INFORMATION ON FUKUSHIMA DAI-ICHI NUCLEAR PLANT

## 2.1 TYPES OF REACTOR

Fukushima Dai-ichi was the flagship plant of TEPCO's nuclear production. Established in 1967, the plant is located in the towns of Futaba and Okuma on the coast of Fukushima Prefecture, about 250 kilometers north of Tokyo and around 90 kilometers by road from Fukushima City, the capital of the prefecture. The plant has six nuclear reactors, making it one of the largest in the world; only TEPCO's Kashiwazaki-Kariwa has more, and only one other, Gravelines in France, equals it with six. All of the reactors at Fukushima Dai-ichi were of the boiling water reactor (BWR) type. At the time of the tsunami, units 4, 5, and 6 were off-line, while units 1, 2, and 3 were at rated output.

| Unit | Type | Containment | Start construction | Commercial operation | Electric power | Reactor supplier |
|---|---|---|---|---|---|---|
| Fukushima I – 1 | BWR-3 | Mark I | July 25, 1967 | March 26, 1971 | 460 MW | General Electric |
| Fukushima I – 2 | BWR-4 | Mark I | June 9, 1969 | July 18, 1974 | 784 MW | General Electric |
| Fukushima I – 3 | BWR-4 | Mark I | December 28, 1970 | March 27, 1976 | 784 MW | Toshiba |
| Fukushima I – 4 | BWR-4 | Mark I | February 12, 1973 | October 12, 1978 | 784 MW | Hitachi |
| Fukushima I – 5 | BWR-4 | Mark I | May 22, 1972 | April 18, 1978 | 784 MW | Toshiba |
| Fukushima I – 6 | BWR-5 | Mark II | October 26, 1973 | October 24, 1979 | 1,100 MW | General Electric |

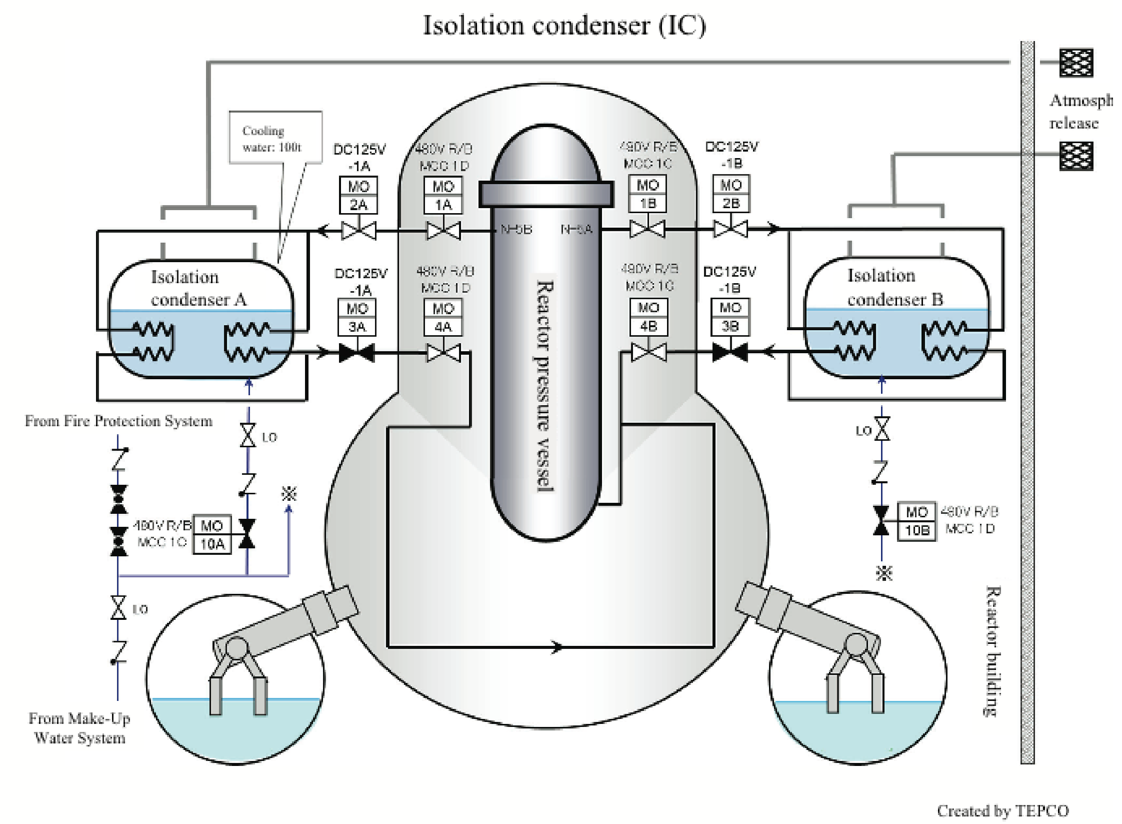
Source: ICANPS report data

Since the reactors at Fukushima Dai-ichi were built consecutively, there were some differences among them, indicating improvements in the technology over time. The most salient for our purposes are the differences in emergency cooling systems, particularly between unit 1 and the other two units functioning at the time of the disaster.

### *2.1.1 RESIDUAL HEAT REMOVAL*

Reactor 1 had a number of different emergency cooling options, including high-pressure coolant injection (HPCI), core spray, and reactor shut-down cooling; however, most of these systems were directly damaged by the tsunami or knocked out of commission by the station black-out. The last-resort emergency cooling system for reactor 1 was an Isolation Condenser (IC). The attractive element of the IC in this emergency was that it did not require electricity to run: as described in the ICANPS report, "*The IC cools the reactor core without using a pump as it condenses steam inside the reactor pressure vessel into water using a condenser tank for emergency use, and feeds that water back into the reactor. In this case, the atmosphere serves as the ultimate heat sink*" (ICANPS, p. 16). The IC performed the residual heat removal function by letting the steam rise into heat exchange tanks, and could, in theory, run indefinitely, as long as the tank was supplied with water.

Reactor 1 had two separate IC circuits, to provide additional redundancy. Each circuit functioned, as mentioned above, through the inherent properties of condensation (cooling) and steam production (heating). If the system was functioning (with electricity), it would be activated and turned off cyclically by operators in order to avoid cooling the rector too quickly[2] via two pairs of valves: intake and outtake valves within the containment; and intake and outtake outside the containment (in the below diagram, these valves are labeled MO-1A, MO-2A, MO-3A, and MO-4A for IC system A, and correspondingly for IC system B). If any of these valves were closed, the system would not function. Moreover, the system had a built-in failsafe designed to close all the valves in case of power loss. Finally, the valves inside the containment were inaccessible and could not be activated manually.

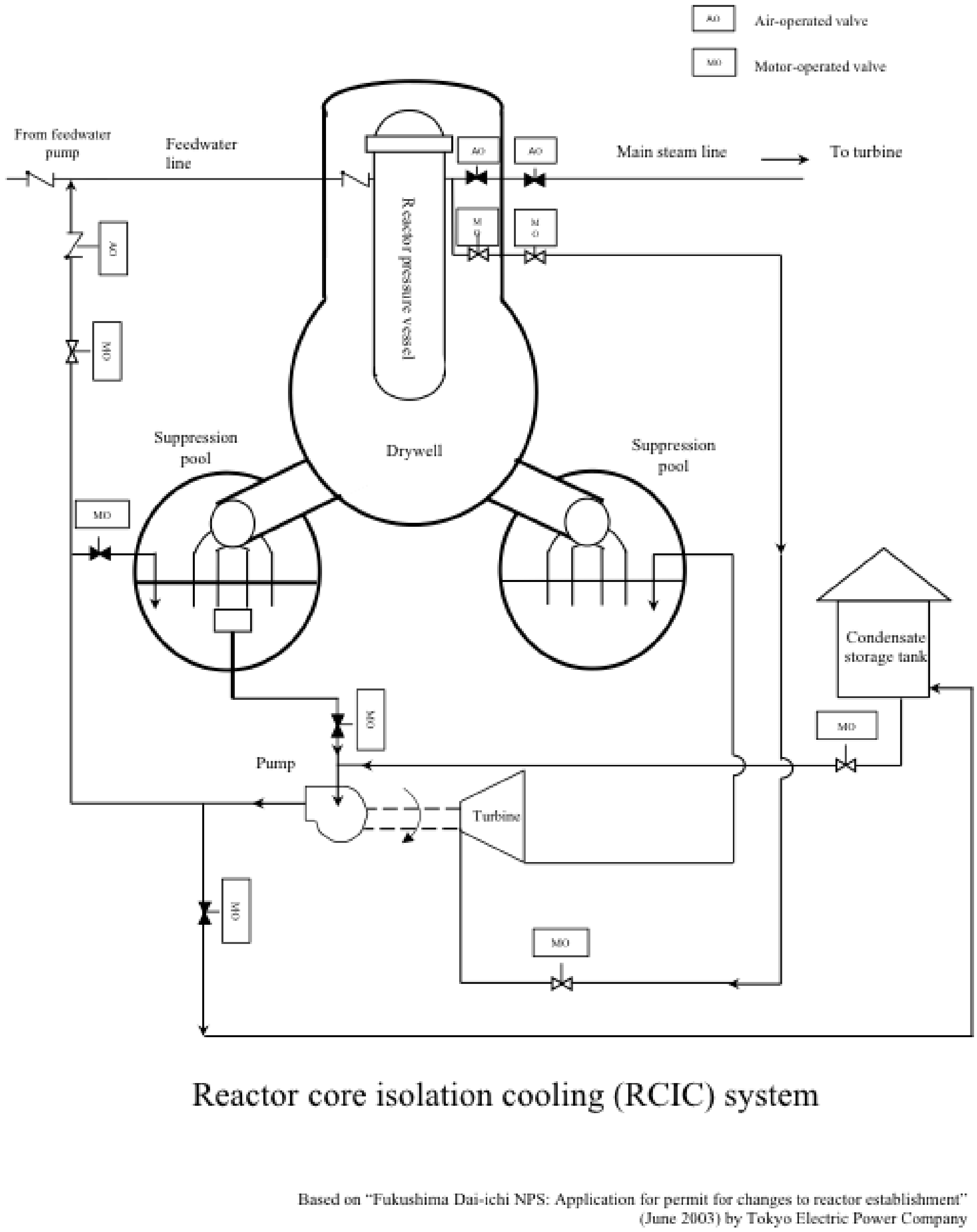



Source: ICANPS Attachment IV-4

Reactors 2 and 3 (as well as the four reactors at Fukushima Dai-ni) had the same HPCI and core spray systems as reactor 1. Instead of the IC, however, they had a reactor core isolation cooling (RCIC) system, which "runs on a turbine-driven pump system, operated using a portion of steam generated in the reactor pressure vessel, to compensate for the loss of coolant due to evaporation using the supply of water from the condensate storage tank or from the S/C" (ICANPS, p. 17). It is a rapid-start system designed to supply make-up water to the reactor until pressure and temperature levels had been reduced to allow the residual heat removal (RHR) systems to be used, since the

[2] The cooling rate was specified at 55 degrees Celsius per hour or less (ICANPS, pp. 99-100).

RCIC itself did not provide residual heat removal. The RCIC could run off of battery power, although the length of time was not completely clear.




Source: ICANPS Attachment II-18

In unit 2 the HPCI was damaged, but for unit 3 it was still functioning. The system injects significant amounts of water (up to approximately 19,000 liters per minute)[3] quickly, such as in the case of a leak. Like the RCIC, the HPCI transferred heat from the reactor to the containment building, but did not perform the residual (or decay) heat removal function of cooling the containment (and thereby lowering the pressure). In units 2 and 3, it was the residual heat removal (RHR) systems that needed to perform this, but they were disabled by the tsunami.

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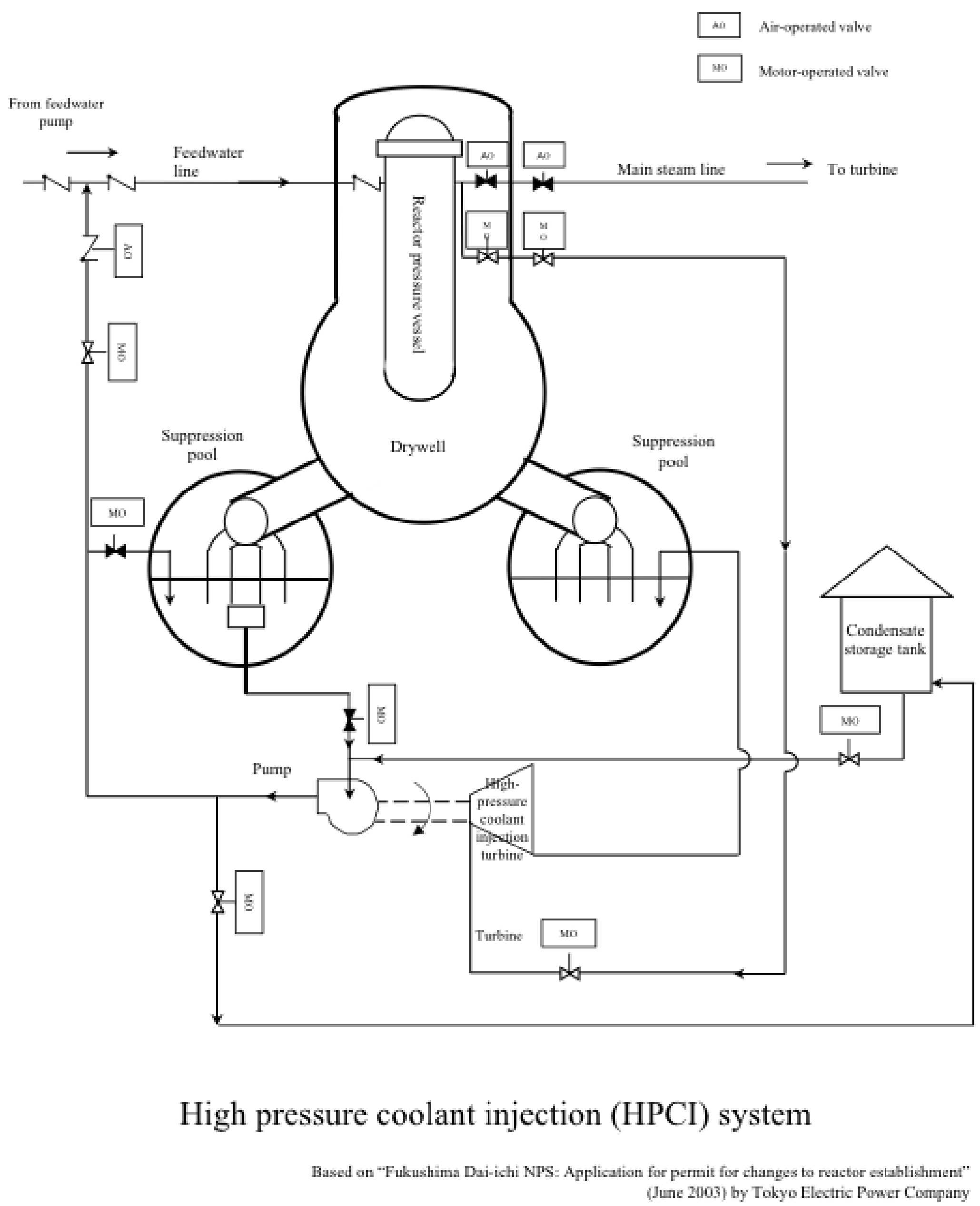
3 Wikipedia(http://en.wikipedia.org/wiki/Boiling_water_reactor_safety_systems_Isolation_Condenser_.28IC.29)



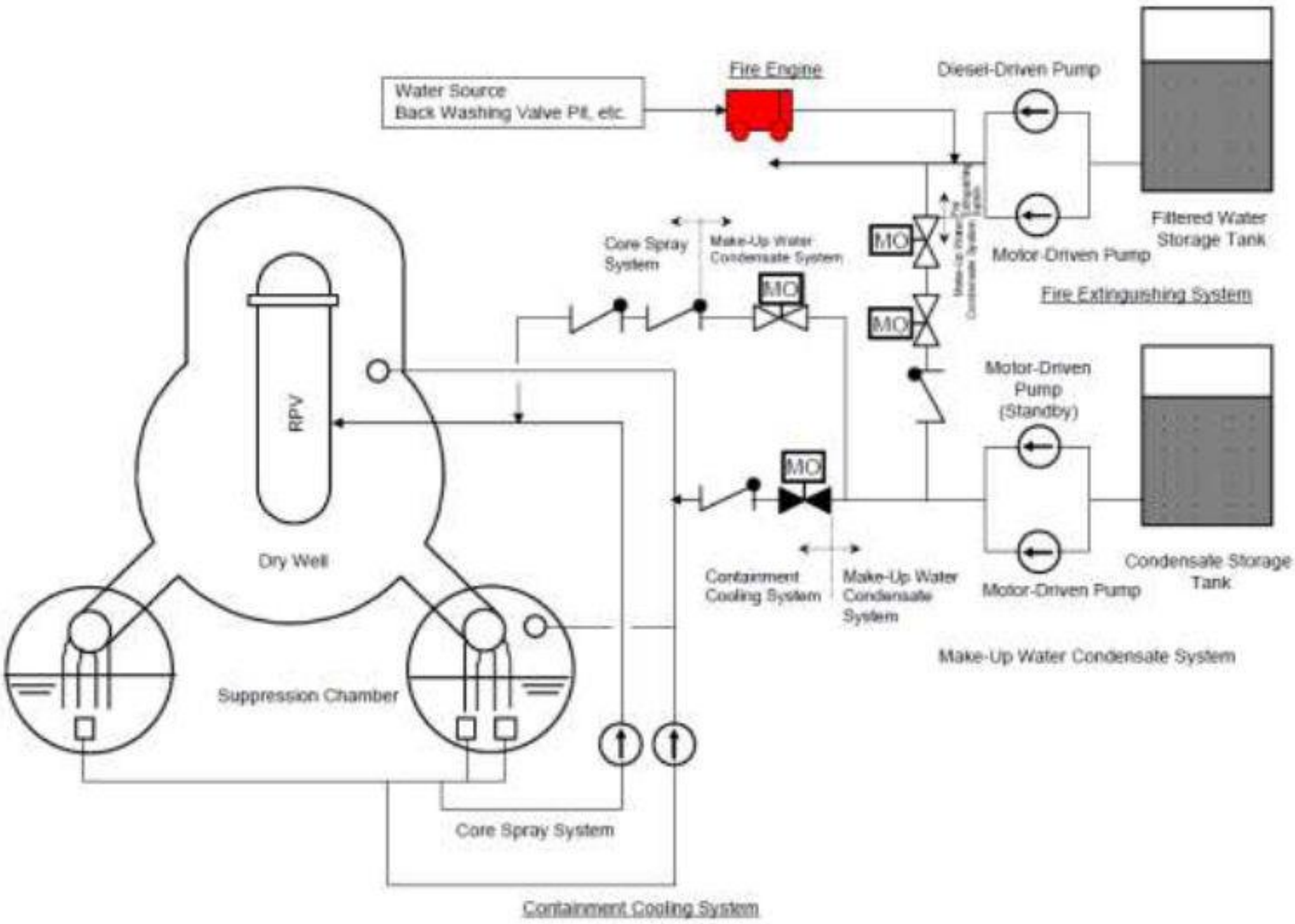

Source: ICANPS Attachment II-19

The reactors at Fukushima Dai-ni were able to use core sprays and, eventually, the residual heat removal systems, as well as their RCICs.

When core cooling failed or slowed and the temperature rose in the reactor, so did the pressure. The first step in managing the reactor pressure (absent core cooling ability) was to depressurize the reactor by using the main safety relief valve (SRV) to transfer some of the pressurized steam to the suppression chamber (S/C, or wet well) where it would be cooled and condensed in the suppression pool.

However, when the suppression chamber became too hot and pressurized, or when the containment pressure rose because of leaks from the core, it becomes necessary to vent the containment, releasing radioactive materials into the environment. This can be done through the suppression chamber, which is preferred since the water and other filters reduce some of the radioactivity, or more directly from the containment.

Reactivity (or re-criticality) was mitigated by adding boric acid, which absorbs neutrons, to the water used for core cooling. The risk of hydrogen gas created by the interaction of zirconium and steam under extremely high temperatures was mitigated by filling the reactor with inert gas to prevent an explosion. However, there was no plan for dealing with hydrogen that escaped the containment into the reactor building.




## *2.1.2 VENTING VALVES*

Each unit had two vent lines, known as reinforced lines, which were installed between 1999 and 2001 in case of severe accidents. One line was connected to the torus, the other to the drywell in the containment. If venting proves necessary, the line to the torus is given priority because the water in the torus acts as a filter, trapping a high percentage of the fission products present in the containment in the form of aerosols.

Each line was equipped with a rupture disk and 3 valves: one motor-operated valve, and two air-operated valves. The rupture disk breaks when the pressure exceeds approximately 5.3 bar. The two air-operated valves on the torus line, known as the large and small vent valves, were mounted in parallel, which means either one, or the other can be opened. Normally, all the valves were activated from the control room. But if electrical power was lost, an operator must go to the valve to open it. The motor-operated valve was equipped with a wheel handle and can be opened manually. The small air-operated vent valve could also be opened manually with a wheel handle, but access to the handle was difficult. The large vent valve was even more difficult to open: a generator or a battery is required to energize the solenoid valve that opens the compressed air vessel; another solution also exists - a portable compressor can be used to directly inject compressed air. As we will see later on, the operators would encounter major difficulties with these air-operated valves – both when attempting to open them, and when attempting to keep them open.

## 2.2 PLANT OPERATION ORGANIZATION

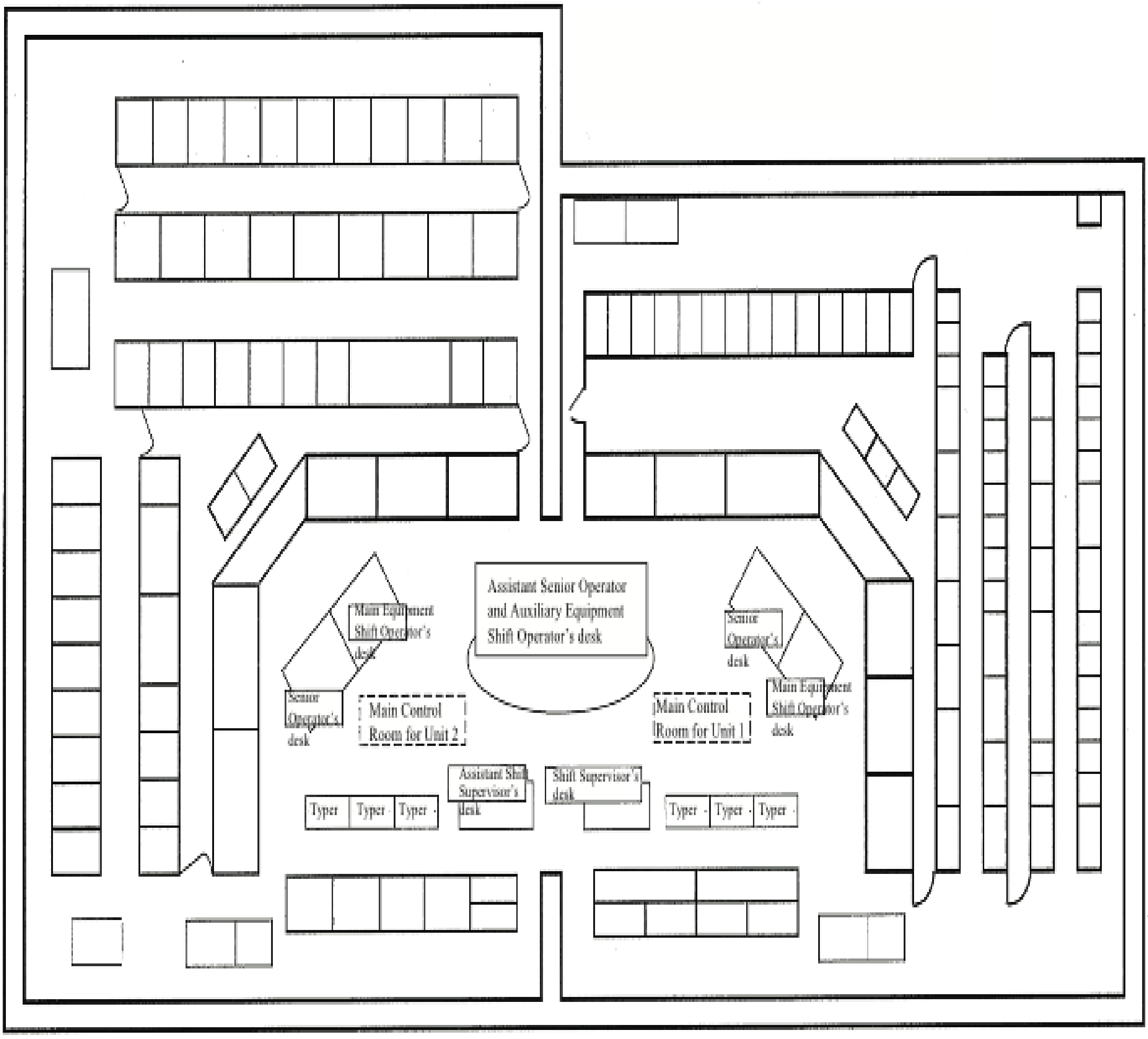
There was a main control room for adjacent units; one for Units 1 and 2, one for Units 3 and 4, and one for Units 5 and 6. Until the earthquake, five teams had been working in shifts at each main control room. Each shift team had 11 members comprising of one shift supervisor, one assistant shift supervisor, two senior operators, one assistant senior operator, two main equipment shift operators, and four auxiliary equipment shift operators[4]. Immediately after the earthquake, the shift teams (meaning all members including the section chief and the other members shall apply hereinafter) working at the main control rooms played a leading role in controlling the reactors. Some members of other teams, who were off duty at the time of the earthquake, went to their control rooms in charge to help the members on duty while other members stayed in the Emergency Response Office of the Seismic Isolation Building until it was time to relieve those on duty.

## 2.3 ORGANIZATIONAL ARRANGEMENTS IN EMERGENCY AT FUKUSHIMA DAI-CHI

After the declaration of the State of Nuclear Emergency, an emergency response center (ERC) must be set up at the Fukushima Dai-ichi NPS. The ERC is located in an anti-seismic building and includes specialized teams: recovery team, operations team, information team, medical team, engineering team, etc.

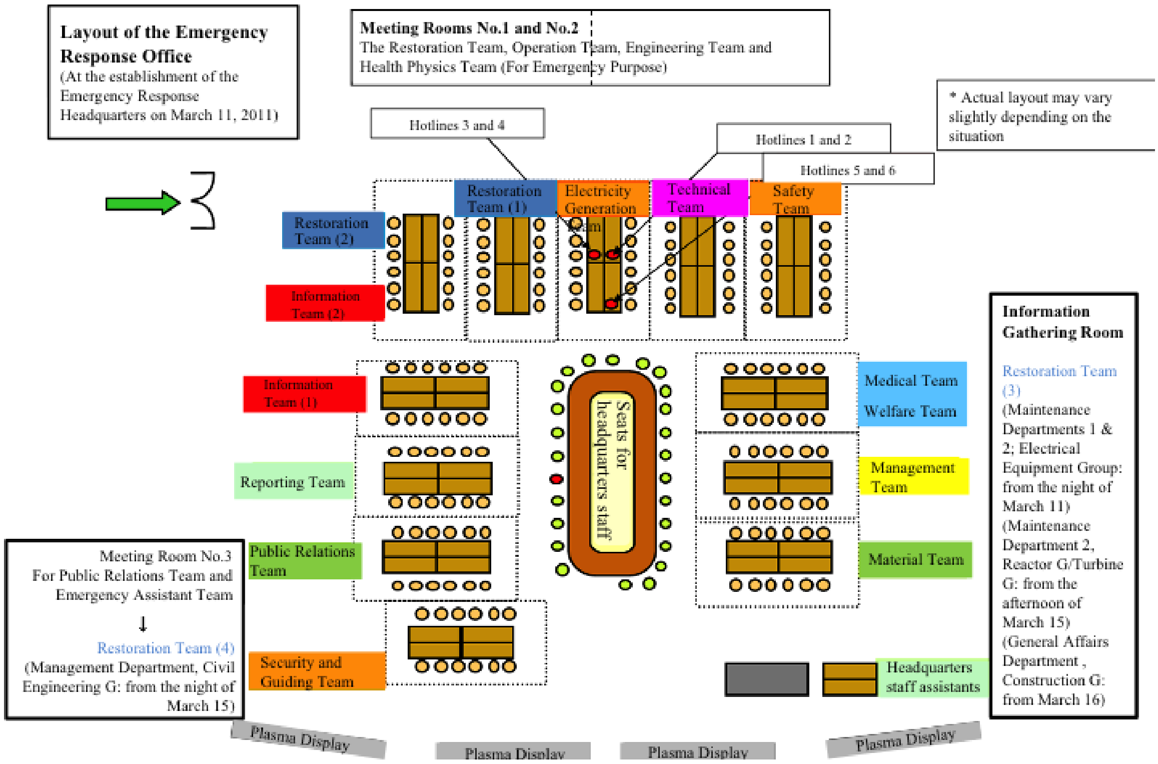
[4] See Attachment IV-2, ICANPS interim

## Layout of the main control room for Units 1 and 2




Source: ICANPS, Attachment IV-3

**Layout of the Emergency Response Office**




Source: ICANPS, Attachment IV-1

The ERC was directed by the plant's manager, Site Superintendent Masao Yoshida. He was seated at the main table with the Unit Superintendents, Deputy Directors, Reactor Chief Engineers and the Section Chiefs for the function teams. Staff members of the function teams were stationed in booths behind their respective leaders. When a function team obtained information that needed to be shared with all those at the response center, they reported it to their section chief, who then announced it via microphone.

When a decision was made at the head table, the leader of the relevant team communicated it to his team members and gave them directions to perform the necessary work.

In addition to the Station Response Center, two other emergency response centers were assembled in Tokyo: one at TEPCO Headquarters, the other at the Prime Minister's Office.

These centers were also in communication with an "off-site" center located 5 km from the nuclear power station, which served both Fukushima Dai-ichi, and Fukushima Daini.

The emergency response center at the Prime Minister's Office gathered information and made decisions concerning population protection, such as evacuation measures and protection from exposure. To assess the situation, the Japanese government was assisted by officials from the country's Nuclear and Industrial Safety Agency (the NISA), and from the Nuclear Safety Commission (the NSC).The off-site center had many tasks, one of which was to measure radioactivity in the environment

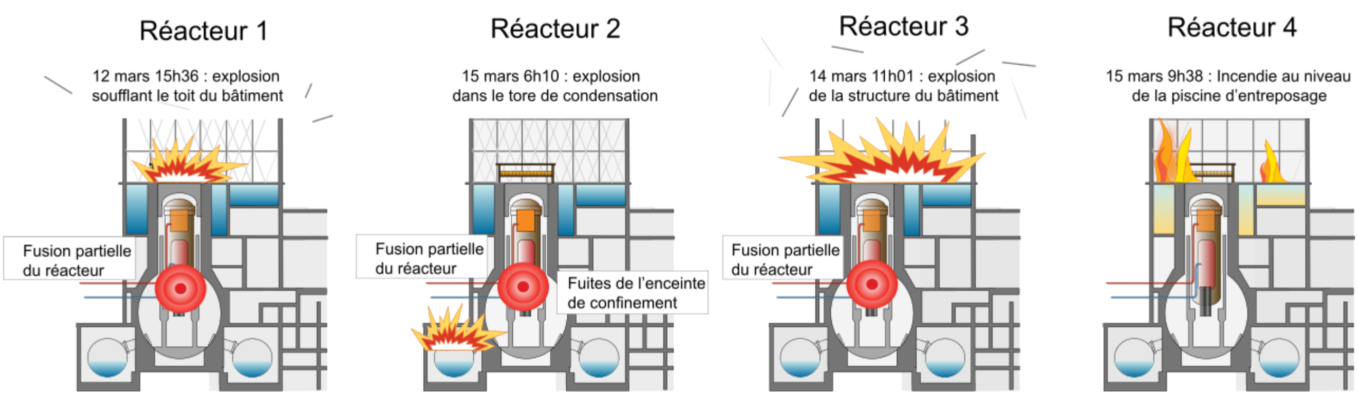
# 3 THE CHRONOLOGY OF FUKUSHIMA DAI-ICHI ACCIDENT

## 3.1 OVERVIEW OF THE ACCIDENT

On Friday, March 11th, 2011 at 2:46 p.m. local time, Japan was struck by an earthquake measuring 9 on the Richter scale. It was the fourth largest earthquake on record since the 18th century, and the largest ever recorded in Japan. When the initial shocks were detected, an emergency shutdown was performed on all the nuclear reactors in operation at the four power plants along the country's Eastern coast. The largest shocks arrived thirty seconds later. The buildings shook for nearly a full minute. In the control rooms at the Fukushima Dai-ichi Nuclear Power Plant, 180 kilometers from the epicenter, the shift teams made sure that Units 1, 2 and 3 were properly shut down with all their control rods inserted.

Less than one hour after the earthquake, beginning at 3:27 p.m., a series of tsunami waves struck the Fukushima Dai-ichi nuclear power plant. The first wave was 4 m high, and was stopped by the breakwater, which was designed to withstand a tide level of +5.7 meters. Just eight minutes later, a wave 14 meters high struck the plant, submerging the platforms of Units 1 to 4, located 10 meters above sea level. The doors of the turbine buildings were not sealed, and water flooded into the basements. The electricity panels were swept away by the tsunami. The seawater pumps for the water-cooled emergency diesel generators, and many of the diesel generators themselves, were completely submerged, as were the batteries. The reactors had been completely cut off from all sources of electrical power and cooling. The only exception was the air-cooled emergency generator for Unit 6, which remained operational. It would alternate between Units 5 and 6 to cool the cores and fuel storage pools. At 3:42 p.m., via the TEPCO headquarters, the Superintendent notified the Japanese nuclear safety authority, the NISA, that a nuclear crisis had occurred at the Fukushima Dai-ichi power plant. The NISA immediately informed the Prime Minister's Office.

The control room for reactors 1 and 2 was in the dark, the alarms stopped functioning and all the indicator lights on the control panels were extinguished. The operators had no information about the status of the valves, the water levels, or the containment pressure. No means of communication, except for fixed-line telephones and no emergency procedures to assist the operators, as these procedures did not cover the current crisis. In the emergency response centers, the reactor parameters were no longer displayed on the big screens. It was under these conditions that the various response teams had to manage the accident.




Reactor cooling was lost for 14 hours (reactor 1), 6.5 hours (reactor 3), and 7 hours (Reactor 2). A great deal of time passed before alternative water injections systems could be connected to the three reactors - often more than 12 hours. Venting was also greatly delayed. It now seems likely that no venting was ever performed on Unit 2, which resulted in containment leaks.

## 3.2 REACTOR 1 AND REACTOR 2 CHRONOLOGY

- *14:46 ON MARCH 11, 2011: THE EARTHQUAKE*

The earthquake that occurred was clearly a serious event, with shaking strong enough that it was difficult to stand and an immediate impact on the operations of the plant. The reactors automatically scrammed due to the seismic motion, grid power was knocked out because of damage to a switchyard breaker[5], and external electricity was lost.

However, although the violent shaking and the sounding of automatic earthquake and fire alarms probably sent adrenaline flowing through the operators, nothing had deviated from the plans and procedures set in place for emergencies. The emergency diesel generators started up automatically, providing power for lighting, instruments, and controls. According to the EOPs, the team of operators in the main control rooms controlled the cooling of the reactors using the available emergency systems.

| Reactor 1 | Reactor 2 |
|---|---|
| The reactor scrams functioned as they were supposed to, and a few minutes later the emergency isolation condenser (IC) cooling system for unit 1 also started automatically. Although they had never used it before, the shift operators were able to manage it cyclically according to emergency operating procedures (EOPs), which required monitoring water levels carefully in order to repeatedly turn off the IC and let it restart automatically as necessary and manage the speed of cooling. | At 14:50 the feed water pump of reactor 2 shut off, and the operators started the RCIC. Since the reactor water level was still fairly high, the system turned off automatically a minute later. To reduce the heat in the suppression chamber, a normal effect of the momentary loss of cooling function, the operators turned on the residual heat removal system (RHR) between 15:00 and 15:07.<br>At 15:02, carefully monitoring the reactor water level, the operators activated the RCIC again.<br>At 15:25 they started the suppression chamber spray.<br>At 15:28 the water again reached the required level, and the RCIC stopped automatically. At 15:39 the operators started it again.<br>This initial response to the shock was proceeding without problems. |

The staff not in the MCR or engaged in other essential duties, following the EOPs they had practiced a week before in a simulation, evacuated to a parking lot, after which those assigned to emergency teams, led by the site superintendent of the plant, Masao Yoshida, gathered in the emergency response center (ERC) in an earthquake-resistant building. The ERC was connected by

[5] ICANPS, p. 98

teleconference to the utility's Tokyo headquarters emergency response center, as well as to an "off-site center" designed to compile information and provide support to residents' evacuation.

During the period after the earthquake, managers, administrators, and off-duty operators in the ERC, as well as the shift team of operators in the MCR, and their counterparts at the TEPCO headquarters in Tokyo, all believed that the accident was manageable, and that by following the procedures they would be able to bring the reactors to cold shutdown. All the indicators were that the emergency procedures were functioning as expected.

- *15:27 ON MARCH 11, 2011: THE TSUNAMI*

The first wave of the tsunami arrived at 15:27, the flooding started at 15:35.

In the MCR, the lights went dark, and the indicators on the control panel faded one after another.[6] The only light in the room came from emergency lights on the unit 1 side of the MCR, the unit 2 side was completely dark.

Fifty-one minutes after the initial earthquake, it was unclear to the operators why the emergency diesel generators had failed. Although a tsunami warning had been issued by the meteorological agency and transmitted throughout the plant over the public address system, the initial alert was for a tsunami of about three meters, later revised upward to six. At ten meters above sea level, it didn't occur to the operators that the tsunami might have reached the buildings, let alone with enough force and depth to cause these problems.

Buried in the windowless MCR, the operators had no sense of the catastrophe going on outside, where the wave was carrying in trucks and cars, ripping free fuel tanks, and crushing cars. They were left with no indicators and, with only minimal illumination functioning, even their most immediate perceptions were hampered.

All the indicators were out. It was impossible to determine whether the cooling injection functioned or not.

The MCR reported the loss of electricity to the ERC.

Similarly, it was a shock for the ERC when the call came in from the shift teams in the MCRs to inform them that electrical power had been lost. Again, it was at first not clear to the emergency team what had happened. The ERC had no windows, and the staff working within it was unaware of the devastation and debris just outside. The site superintendent tasked the electricity team chief with finding out why the power was out.

- *15:42 ON MARCH 11, 2011: THE LOSS OF ELECTRICAL POWER*

Despite this confusion, according to the ICANPS, "Site Superintendent Yoshida understood that a situation that far exceeded any expected major accident had actually taken place"[7].

At 15:42, Yoshida informed his headquarters and, as obligated by law, the relevant governmental authorities, of the loss of power. He then requested TEPCO headquarters to send any available electricity-generating trucks from other plants. Several vehicles took to the road by 16:50; no one realized how long it would take them to reach Fukushima Dai-ichi on the tsunami-ravaged roads.

[6] Kadota, p. 50
[7] ICANPS p. 113

The ERC was also confounded by the loss of reactor indicators, which were normally transmitted automatically to the ERC and to the headquarters. Yoshida asked the Recovery team to figure out some way of getting the indicators back online.

The normal shift supervisor for the team on duty in the MCR for reactors 1 and 2 during the disaster, named Hirano, was out for a routine medical examination, and he was replaced by the leader for a different team, Izawa. The first important decision Izawa took was to organize interventions outside the MCR. Rather than either continue with the status quo working procedures, or allow unregulated, individual determination of what constituted safe practices as the situation developed, Izawa set in place new measures, specifically changing the rules for going to the “field” (conducting any work outside of the MCR). Missions to the field would now require permission from the shift supervisor, would need to be conducted by at least two people, and would have a strict time limit of two hours, whether or not the objective had been achieved. Rescue missions would be sent after anyone who was away from the MCR for longer than two hours.

These changes reflected the changed context. Communications were almost completely down; although there was still a landline available for communication between the MCR and the emergency response center (ERC) in the seismic-resistant building. Cell communications and the PA system were both inoperable, leaving no way to communicate with operators in the field. Aftershocks were continuing, and there was no way to tell which of these earthquakes, many of them large, would cause another tsunami. In addition, there was no way to know the condition of the reactors, either the two they managed or the other ones on site. Under these circumstances, being out of communication for even two hours could easily be fatal; delays in reporting back to the MCR on field conditions could also have dire consequences. Of course, these new restrictions also had implications for the work that could be done and the way it was conducted.

With this groundwork of safety procedures established, the operators proceeded to attempt to assess and understand the situation they were facing. Under normal circumstances, their understanding of the status of the reactor was completely mediated by the indicators and dials on their control panels: the water level within the reactor, the pressure within the reactor, and the pressure in the primary containment vessel (PCV). Managing the interplay between these related factors was the key to navigating a safe shutdown. After the loss of power, however, the operators for units 1 and 2 had access to none of these indicators. Because of their limited experience with emergency shutdowns, they had no way of understanding the situation of the reactor or knowing what, if any, effect their actions had on it.

- *15:42 ON MARCH 11, 2011: IS THE EMERGENCY COOLING FUNCTION WORKING?*

However, if the control room indicators were both the easiest and the most familiar way to understand what was going on in the reactors, there were other options. Although there was no way to directly observe the water or pressure levels inside the nuclear reactor, by physically going to the reactor building the operators would have access to other gauges that might tell them more about the situation. The shift supervisor sent several different missions to the field simultaneously to assess the situation and try to diagnose key elements of the crisis: what was working; what could be fixed; and what was useless.

| **Reactor 1** | **Reactor 2** |
|---|---|

For the moment the biggest question was whether the emergency cooling function was working. The confusion was augmented by the operators' lack of familiarity with the IC, which none of them had actually used before. A closed vapor condensation loop, the IC could, at least in theory, run without electricity. It did have some requirements, however. Most obviously, it needed water in its tank; this would therefore eventually need to be refilled. Furthermore, it was controlled by two sets of two valves to open and close intake and outtake, one set on the inside of the containment and one set on the outside. These valves were normally moved by electricity, rendering them inoperable during the blackout. The exterior valves could be observed and, at least in theory, opened or closed manually. The two interior valves, however, could not be accessed or operated manually; nor could they even be operated using direct current, since they had been designed with alternate current motors considered more resistant to the extreme conditions within the containment, meaning even if a battery could be connected, they would not function. Furthermore, the safe position of these valves is closed, but nobody knows it.

If the IC was running – if both sets of valves were at least partially open, there was enough water, and the automatic circuit was functioning correctly – the operators had a margin of time before meltdown. If not, then the margin was much shorter. The fall in the water level in unit 1 suggested that it was not working; but then again, it might have been working partially, and preventing a faster evaporation of the water. The mantra for the operators, repeated over and over in their reminiscences of this timeframe,[8] was to inject water into the reactor, somehow and as quickly as possible.

At 16:42, the reactor water level wide-range indicator for unit 1 illuminated. It showed the water at 90 centimeters below normal: low, but still above the critical level that would leave the fuel uncovered. The relief was short-lived, however; the gauge showed the water level dropping, and barely 15 minutes later, at 16:56, the light flickered out again, with the last recorded level at 150 centimeters below normal. The

There was another emergency coolant option: the high-pressure coolant injection (HPCI) system would, normally be activated after the initial usage of the RCIC, if the water level dropped too low. But the HPCI indicators were not lit, and with the loss of direct current electricity, the team believed it was impossible to start the HPCI. A little later they learned that the power source of the HPCI, located in the basement of the service building of unit 2, was flooded. The cooling system for the suppression chamber (S/C), the residual heat removal (RHR) system, was also knocked out by the tsunami.

At 16:25 Izawa told the ERC, who then reported to the authorities, that it was impossible to confirm the level of water in the reactor, or the status of the emergency cooling system.

[8] Kadota, p. 73

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|---|---|
| operators were again left in the dark about the state of reactor 1, although with at least a sense of its ominous trajectory. | |

- *16:55 ON MARCH 11, 2011: ALTERNATIVE MEANS FOR EMERGENCY COOLING (1)*

| Reactor 1 | Reactor 2 |
|---|---|
| The operators find out another solution for cooling the reactor: it was possible to re-route water systems intended for fire control within the reactor building to inject their water directly into the core, powered by a diesel-driven fire pump (D/DFP) located in the basement of the turbine building. Since the extent of the damage was still far from clear, the shift supervisor sent a team to the turbine building at 16:55 to find out if the pump was still functioning, but they returned almost immediately because of a tsunami alert; the turbine building was accessed from the MCR via an underground tunnel, which would be a death trap in a tidal wave.<br><br>Another mission set out at 17:19. A young operator had been stationed on the roof to observe the ocean and send runners after the field team if the waters receded; the public address system no longer worked and there would be no other means of communication to alert them. The team found the floor and walls of the tunnel damp and sandy, with a large dead fish stranded there; evidence of the tsunami.[9] In the pump room of unit 1, however, they found that the pump was dry on its concrete stand, its battery was undamaged, and it was still operational.<br><br>Since the line was not yet configured to redirect the water to the core, they placed it in standby so as to save fuel and returned to the MCR by 18:00. | Trying to come up with alternatives to carry out the urgent task of getting water into the reactor, the team thought of the diesel-driven fire pump (D/DFP) for both reactors 1 and 2. However, when operators from the MCR went to the pump room, they found that the area around it was flooded, and therefore thought that the pump itself was inoperable. In any case it was inaccessible for the moment.<br><br>With little faith that the RCIC was running, the staff in the ERC believed that the situation of reactor 2 was extremely urgent. There as well, workers and team leaders were trying to come up with cooling alternatives. The D/DFP, which figured in the EOPs for accident management, was the obvious one. But Superintendent Yoshida was concerned that there might be problems. Based on his experience of an accident at the Kashiwazaki-Kariwa plant, also caused by an earthquake, he thought that the outdoor, underground piping might have been broken by the tremor.[10] He therefore asked the restoration team to consider other alternatives, such as the possibility of using a fire engine, which could be connected directly to an outlet in the reactor building, as the pump for the water. The team began to investigate the possibilities, studying the blueprints for the piping. However, the question of the fire engines was particularly difficult for them to approach, as it was not considered in the accident management manuals and did not fall clearly under the purview of any of the specific teams – operations, engineering, restoration, etc. |

[9] Kadota, p. 74.

[10] ICANPS, interim, p. 145. In the interview with Yoshida in Kadota's book, he does not specifically cite the accident at Kashiwazaki-Kariwa, but says that the idea came during the process of thinking about all possible means of injecting water, with the experience of many years of work in nuclear power plants (p. 99).

During this same time period the staff in the ERC was also trying to figure out what was going on and what they should be doing about it.

At 17:12 Site Superintendent Yoshida ordered the operations and recovery teams to start exploring options for alternative water injection, both those that "were defined as AM measures, and other methods that would be available if the power sources were restored" (ICANPS Interim, p. 145). Another possibility not defined in the accident measures was the idea of using fire engines as a pumping mechanism for injecting water, which the superintendent considered an important option since "based on his memory of indoor pipes soundness in the buildings at the Kashiwazaki-Kariwa NPS after the Chuetsu-oki Earthquake," he "thought it likely that the outdoor pipes laid from the filtered water tank to the T/B might have been damaged due to the strong earthquake," but "assumed that the indoor pipes would not be damaged in the earthquake" (ICANPS Interim, p. 145).

The MCR and its staff were shared among reactors 1 and 2. For the moment, it was not clear which was in worse shape. In the ERC, most people still believed that it was more likely that the IC of unit 1 was functioning than the RCIC of unit 2, but in the MCR there were serious doubts about the IC.

| Reactor 1 | Reactor 2 |
|---|---|
| At the same time a third team had set out for the unit 1 reactor building in order to check on the level of water in the IC condenser tank via a gauge on the fourth floor of the reactor building. This would help them confirm whether or not the IC was functioning, estimate to what degree it was replenishing the water in the reactor, and determine whether they needed to worry about refilling the water in the tank. However, this team never made it to their objective. Arriving at the double door entrance to the reactor building at around 17:50, they found that their radiation meters were already vibrating and showing levels more than the maximum measure of 300 cpm. Although this was probably not a dangerous level, it was unexpected and likely to rise further within the reactor building, and the operators were not wearing protective equipment. The team returned to the MCR to report this new data point.<br><br>While the information about the radiation, combined with the brief glimpse of dropping water levels, suggested to the operators that the IC was not working or, at best, not working at full capacity, it was still not certain, and to the operators the IC still may have seemed like their best hope for stabilizing the situation, at least temporarily. This hope was further fanned when, at 18:18, some of the indicators on the IC control panel came back to life, possibly as their batteries dried. The newly illuminated indicators showed that the two valves on the outside of the containment (MO-2A and MO-3A) were closed. The indicators for the valves on the inside of the containment were still blank. As mentioned above, the operators were unable to move those valves, but it was still unclear what state they were in: open, closed, or somewhere in between? In the case that they were open or at least partially open, the IC still required the opening of the exterior valves to work.<br><br>Given this situation, the operators used the control panel switches to | |

| | |
|---|---|
| try to open the outer valves. This done, they tried to determine whether or not the IC was functioning by looking out the back door of the MCR to check for steam from the IC exhaust vents. Although steam was briefly visible, it soon faded out, leaving the shift team to conclude that the IC was not functioning properly. This raised another concern: if there was little steam because there was little water left in the IC condenser tank, running the system under those conditions could lead to pipe ruptures or other serious problems. (This could also, however, be read as somewhat reassuring; lack of water in the condenser tank suggested that the IC had been functioning and that at least some of that water had cycled through the core, slowing overheating and water evaporation).<br><br>The shift team decided therefore to close the exterior return valve at 18:25, effectively turning off the IC (they left the exterior supply valve open, as per normal operating procedure). | |

While getting water into reactors was the top priority, Yoshida was very aware that restoring electrical power to the plant would make it much easier to achieve. The electricity team, having determined that restoring grid electricity was, in the short term, impossible, and still waiting for the electrical vehicles to provide a large-scale alternative, searched for batteries as a temporary solution. They were able to scrounge some 6- and 12-volt batteries from cars and buses, and attempted to connect them in series to power some of the indicators in the control room, but it was a slow and time-consuming process.

- *18:25 ON MARCH 11, 2011: ALTERNATIVE MEANS FOR EMERGENCY COOLING (2)*

| Reactor 1 | Reactor 2 |
|---|---|
| The apparent non-functioning of the IC, which became all but certain with the maneuvering of the controls to close the outer valves, left the shift team with no option but to proceed with the alternative means of water injection. The D/DFP for unit 1 was working. However, they still had to configure the line for the water to be injected into the core. Normally this would be a simple matter of flicking switches on the control panel. Without electricity, however, it would be necessary to open and close valves by hand, in the reactor building. The first problem was to understand which valves were necessary and where they were located. The operators themselves studied blueprints and made a checklist of the valves; without direct experience of having performed this unusual task manually, they accessed codified knowledge and applied it to their situation. The second problem | At 18:25 on the 11$^{th}$ of March, the shift team in the MCR realized that, given the situation, they would almost certainly need to vent the reactor. If the cooling couldn't be restored quickly, the pressure in the core would rise, risking a loss of containment which would release catastrophic amounts of radiation in the environment, and leave the core exposed. Even worse, this would render all but impossible any intervention in the surrounding reactors, starting a chain reaction that would lead to a massive combined meltdown. Venting would release the pressure before this happened. However, it would also release radioactive materials, though in much smaller quantities and in a somewhat controlled way. Venting through the suppression pool would filter much of the radiation out, though not all, and the operators would theoretically be able to stop |

was who would go.

This mission was completely an initiative of the shift team, neither suggested nor ordered from higher up in the hierarchy.[11] They were aware that it would be dangerous; the normal shift supervisor, who despite having the day off for a medical procedure had joined the working team at the plant after the earthquake, said “After all, reactor 1, and well, maybe reactor 2 also, in the situation where we didn’t know if the water was going to the core or not, there could be a meltdown at any time, to work in that context, yes, directly, I was scared” (Kadota, p. 77). However, they also understood themselves that it was necessary; a deputy shift leader recalled that “anyway, if we didn’t do this at an early stage it would be bad, I think that’s what Otomo [another senior operator] said. Then, I brought the blueprints. Looking at them, I also came to that conclusion” (Kadota, p. 77).

Given the danger, the shift supervisor on duty, Izawa, was reluctant to send others and offered to go himself, but he was quickly dissuaded by his colleagues, who insisted on the need for consistent leadership in the MCR. There was also a reluctance to let younger operators take the risk of radiation exposure.

At 18:30 five operators, all of them senior, of whom two had not originally been assigned to control room duty that day, left for the reactor building to configure a line linking the D/DFP to the core of reactor 1. This required manually adjusting valves in the reactor building. They found the reactor building strangely quiet and dark without electricity. Some of the valves were large and difficult to turn, and the men were very aware of the invisible danger of radiation.[12] They were hampered by the heat and by their masks and protective gear.[13] Nevertheless, they persisted and were able to configure the line and and restart the venting. It had never been done in Japan. However, it now seemed inevitable.

To prepare, Izawa found in the EOPs for AM the checklist and the location of the valves necessary for containment venting but he had to figure out how to do it without electricity[15].

In the ERC, the operations team was also trying to confirm the venting procedures. They were joined by the restoration team in the effort to figure out which valves necessary for venting could be opened manually. To search for the necessary diagrams, they went into an administration building which had been declared off-limits due to potential structural damage from the earthquake. They also tried to contact a sub-contractor familiar with the valves, but they could not reach them until the morning of the 12th.[16] Without access to these experts, they used the blueprints. The preferred method of venting passed through the suppression chamber, where some of the radioactive materials could be filtered. But given the high pressure in the core this risked damaging the pipes, leaving a direct venting from the containment the only viable option.

In terms of what was possible, however, the D/DFP of unit 1 still worked, while that of unit 2 was flooded, so the operators decided to do what they could to move forward with the water injection.

At 20:00 part of the shift team began to configure a line linking the D/DFP to the core of reactor 2; while the D/DFP was not working, it was possible they would find another source of pressurized water to push through the line. The work took until the end of the day.

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[11] Kadota, p. 77; ICANPS Interim, p. 151
[12] Kadota, pp. 78-80
[13] Kadota, pp. 79-82
[15] ICAMPS interim p.165
[16] ICANPS, interim, p. 165

return to the MCR after 20:00.

At 20:50, the D/DFP was activated.

However, although the line had been completed and the pump activated, water was not flowing into the core: the reactor pressure was too high. The team in the reactor building had confirmed at 20:07 that the reactor pressure was at 6.900 MPa, far too high for the D/DFP, which had a discharge pressure of 0.69 MPa. Normally, the reactor pressure could be lowered by opening the safety relief valve (SRV) to transfer steam from the vessel into the suppression chamber (S/C).

However, this valve could not be opened remotely from the MCR due to the lack of electricity. It would have been possible to connect batteries totaling 120 volts to activate the SRV, although not easy; teams from the ERC were already struggling to scrounge batteries and figure out how to connect them to various indicators and controls. However, there is no evidence that the shift team clearly requested assistance in procuring and arranging these batteries or finding other means to open the SRV.[14]

- *20:30 ON MARCH 11, 2011: ALTERNATIVE MEANS FOR EMERGENCY COOLING (3)*

The electricity team from the ERC was trying to restore indicators and controls any way they could. With a growing awareness of the delays facing the electricity-generating vehicles – the headquarters in Tokyo had even explored the possibility of bringing them in by helicopter, only to learn they were too heavy, even for military aircraft – a request had already gone out for batteries, but those too were slow to arrive.

In the meantime, the team salvaged batteries from cars and buses in the parking lots and tried to connect them, but it was not an easy task. They had to sort through thousands of pages of electrical blueprints to try to understand which connections went with which indicators, and at the same time connect many smaller batteries in a row, since they didn't have the correct voltage.

By this time, in the ERC they were actively considering solutions beyond the standard ones, in particular the idea of using fire engines to pump in water. These could be connected to the line configured for the D/DFP.

The ERC sent out a request for as many fire engines as possible to be sent to the plant. While waiting, the restoration team began to clear roads to allow fire trucks to reach the reactors. Since a

[14] See ICANPS Interim, pp. 134-136

great deal of debris, often very large, was scattered around the plant, this was no easy task. Some blockages were also caused by the lack of electricity; the team had to break a gate which couldn't be opened manually. This work continued through the night.

At 20:49 a small generator was able to restore temporary lighting in the MCR. Connecting power to control panel indicators was more challenging, and the workers sorted through more than 10,000 pages of diagrams to try to identify the right connections.

The electricity team meanwhile had found two 12-volt and four 6-volt batteries, allowing them to charge, with difficulty, some of the indicators.

Another part of the recovery team, working towards larger-scale electricity recovery, was clearing roads within the plant in order to allow the electrical vehicles, when they finally arrived, to reach their destinations. This was a significant task, given the size of some of the debris thrown there by the tsunami, such as a truck and a fuel tank.

To connect the electricity vehicles, they would have to use the power centers (P/C) used to transform current arriving from outside into three different voltages: 6,900, 480, and 100. Without these power centers functioning, a safe connection to grid electricity would be difficult if not impossible.

At 20:56, the restoration team confirmed extensive damages to the P/Cs, including the total destruction of all the metal clad transformers for high-voltage electricity (6,900 volts) and also all the 480 volt centers of unit 1. However, the 480 volt P/Cs of unit 2 were working and the connection work focused there.

At 21:28 some electrical vehicles finally arrived at the plant, but they had the wrong connectors and could not be used.

During these hours, more and more off-duty operators had arrived in the main control room; by 21:00, which was the moment when, in normal times, the shift would have changed, there were around 30 people in the MCR for reactors 1 and 2. Izawa remained in command in MCR.

At 20:50 Fukushima Prefecture issued an evacuation order for the two kilometers surrounding the plant. Legally, they had no authority to do this, making it more of a recommendation than an order, but worried by the situation and by the lack of further information either from the plant or from the central government, they decided not to wait.

A half hour later, at 21:23, the Prime Minister gave an evacuation order for a three-kilometer radius, and a shelter-in-place order out to ten kilometers.

- *21:00 ON MARCH 11, 2011: ALTERNATIVE MEANS FOR EMERGENCY COOLING (4)*

By this time, in the ERC they were actively considering solutions beyond the standard ones, in particular the idea of using fire engines to pump in water. These could be connected to the line configured for the D/DFP. The ERC sent out a request for as many fire engines as possible to be sent to the plant. While waiting, the restoration team began to clear roads to allow fire trucks to reach the reactors. Since a great deal of debris, often very large, was scattered around the plant, this was no easy task. Some blockages were also caused by the lack of electricity; the team had to break a gate which couldn't be opened manually. This work continued through the night.

| Reactor 1 | Reactor 2 |
|---|---|
| At 21:15 the radiation levels in the reactor building 1 had risen to the point where Yoshida prohibited entry (although as we will see, this prohibition could be waived for urgent work). However, it was still not clear, to Yoshida or to the other observers in the ERC and at the Tokyo headquarters, which of the reactors was in a more desperate state. Within TEPCO and even among the experts advising the Prime Minister, there was still a degree of confidence or at least hope in the IC, which could run without electricity, as opposed to the RCIC of unit 2, which seemed less likely to be operable and in any case could not remove the decay heat. Much of the focus therefore remained on unit 2.<br><br>At 21:19, they were able to light up the indicator for the level of water in the reactor, which indicated 200 millimeters above the top of active fuel – low, but reassuring in that it was still above the fuel, meaning that meltdown had not yet occurred and that the evaporation was slower than calculated. Could it be that the IC was working, at least partially, after all?<br><br>In order to save the charge, the batteries were then disconnected.<br><br>In fact, this indicator was almost certainly malfunctioning, probably due to the meltdown which was already occurring. But for the operators desperate for some information about the state of the reactor and the workers in the ERC desperate for hopeful news, it was easy to believe. Moreover, the malfunction of the indicator was not immediately evident; understanding it required specialized knowledge of how these indicators would work under the extreme conditions of an accident. | The concerns about the status of reactor 2 continued to grow. There was no indication whether or not the RCIC was functioning, nor of the level of the water.<br><br>Around 21:02 Yoshida told the authorities that it was likely that the water would reach the level of the fuel.<br><br>At 21:13 ERC staff estimated that, given the level of water before the accident, the time since any cooling function could be confirmed, and the theoretical temperature, the water would reach the top of fuel at 21:40, and they report this estimate to the authorities. |

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|---|---|
| Around 21:30 the operators in the MCR noticed that the lights indicating the state of the IC valve were fading. Still uncertain whether the IC was functioning, the operators had at least confirmed that lack of water in the tank shouldn't be a problem yet, and they wanted to keep their options open. If the controls lost electrical charge while the valve was closed, it might have been impossible to open it again. The operators therefore activated the control to open the valve. | |
| At 22:00, the restoration team reconnected the small generator with the indicator of the level of water for reactor 1. This now indicated 550 millimeters over the level of the fuel, even more than the previous time. The team connected the battery with other indicators. | At 22:00 the indicator of water level in the MCR, connected to batteries, showed a level of 340 millimeters above the top of the fuel. With this new data, the estimated time of reaching top of fuel was greatly extended, and the new calculations were reported to the authorities. The information also suggests that the RCIC may have been working well, and continuing to cool the reactor.<br><br>At 23:25 the restoration team, working on the recovery of the indicators in the MCR, managed to measure the pressure of the drywell (D/W) of unit 2, which they found to be at 0.141 MPa abs, well within design specification. |
| At 23:50 they found that the pressure within the drywell (containment) was at 0.6 MPa (absolute), already higher than the maximum operating pressure according to the specifications, which was 0.528 MPa (absolute).[17] Something was wrong: if the water was still above the fuel, why was the pressure rising? It was at this point that the focus really started to shift from reactor 2 to reactor 1.<br><br>The high levels of radiation (288 mSv/h close to the entrance of the reactor building) suggested that the fuel could already be melting; the high pressure raised concerns about the integrity of the core and the containment. It was absolutely imperative to vent the reactor core before the pressure led to an explosion, damaging the | |

[17] ICANPS, p. 168

containment building and releasing radioactive material into the atmosphere. The venting was not a procedure to be taken lightly because it also necessitated a release, and this was the first time it would be done in Japan. However, at least the release with venting would be controlled. In any case, there was no longer any choice.

- *00:06 ON MARCH 12, 2011: PREPARING VENTING (1)*

At 00:06 on the 12th of March, Yoshida ordered the teams to accelerate the preparations for the venting of unit 1, but also ordered that they prepare for the eventual venting of unit 2, believing that sooner or later unit 2 would reach the same situation as unit 1.

Rather than the simple pushing of buttons from the MCR, the operators would have to physically go to the reactor building, where radiation levels were already dangerously high, and manually open two valves: the MO valve in the reactor building, which had to be opened to 25%, and the one of the AO valves in the torus room, which despite being air-operated did have a wheel allowing it to be opened by hand.

In the MCR, the shift chief received the order to decide which of the operators should take on this mission. Everyone was aware of the dangers of going into the reactor building. Izawa started by excluding the young operators. Once again, he offered himself, but once again the other senior operators refused to let him go. Three teams of two senior operators each were eventually chosen by a discussion among the operators.[18] The first team would open the MO valve, the second the AO valve, but because of the absence of communications they would work successively instead of simultaneously. The third team would be a back-up in case one of the others did not return on time.

However, there was one important step that had to be completed before the order to vent could be given. As the core was damaged, the steam that would be released would contain radioactive materials. The operation would increase radiation around the plant beyond legal limits, so the surrounding towns – where many of the operators lived with their families – would need to be evacuated. With blocked and damaged roads, limited communications and no electricity, the evacuation was not easy to complete, especially since no practices had been carried out ahead of time. Even four hours after the initial orders were given, the evacuations were still not complete.

The process of evacuation was complicated by the lack of clarity over the decisions of evacuation orders and venting. The evacuation was clearly a question for the government, while decisions within the plant were the province of the utility that ran it. However, since the venting and the evacuation were interconnected, the coordination of these decisions was challenging.

Around 1:30, TEPCO informed the authorities of their intention of venting of the two reactors and received their approval, even though that wasn't strictly necessary. On the other hand, frustrated by the delay in the venting, the politicians in Tokyo began to demand that it proceed faster.

[18] Kadota, pp. 122-127

| Reactor 1 | Reactor 2 |
|---|---|
| At 1:48 on the 12th of March, the D/DFP which had been turned on once the line was configured stopped suddenly. The cause was eventually confirmed as a lack of fuel.[19]<br><br>At 2:03 the operators informed the ERC, where the managers concluded that the only remaining option to inject water into the core was the fire engines.<br><br>The operators meanwhile replaced the fuel for the D/DFP, a process which started at 2:10 and, with the difficulties of sourcing and transporting the fuel, was not complete until 2:56, but their efforts to restart the D/DFP were fruitless. | Meanwhile, between 1 and 2 am, members of the shift team went to the RCIC room to confirm whether or not RCIC was functioning. By this point the radiation levels in reactor building 1 were already very high, making it dangerous to enter the building and raising levels even for unit 2. The operators used air tanks, rubber boots, and flashlights. They found the room flooded to the top of their boots. They did not go into the room, although they did hear a metallic noise within. Without any means of communication they returned to the MCR to report what they had found, without confirming the functioning of the RCIC.<br><br>At 2:10, members of the shift team wearing the same equipment returned to the RCIC room. The level of water in the room was even higher, but they went in to confirm the functioning of the system. They found encouraging signs – the pipes were vibrating, and they heard a metallic sound – but they still could not confirm whether or not the RCIC was running. |

- *02:03 ON MARCH 12, 2011: RESTORING COOLING INJECTION*

| Reactor 1 | Reactor 2 |
|---|---|
| There were three fire engines at the plant, of which only one was still functioning. However, no one on the TEPCO staff, including the team of on-site firefighters, was qualified to operate it. The plant fire engines were the responsibility of a sub-contractor, Nanmei Kosan (hereafter “Nanmei”), which was hired for accident prevention. Nanmei had eleven staff at the plant, nine of whom ran the fire engines in three shifts.[20]<br><br>Once the Nanmei staff, who were also in the earthquake resistant building, had been tasked with running the fire engine, they still had to find the connection port that would let the fire engines pump water into the line previously configured by the operators, and thereby into the core. Members of the restoration team and the firefighters, using | To try to settle the question of RCIC running in another way, the operators checked the reactor pressure and compared it with the pressure of the RCIC discharge on the instruments in the reactor building (since the indicators in the MCR still did not work). They found that the discharge pressure for the pump was at 6.0 MPa and the reactor pressure was at 5.6 MPa, indicating that the RCIC was working. |

[19] TEPCO report 20 June 2012, p. 179
[20] ICANPS interim, p. 146

blueprints and working from the ERC, confirmed the location of the connection point, near the turbine building on the side facing the ocean.[21]

Around 2:10, a team composed of Nanmei staff and a member of the operation team of the ERC took the fire truck to connect it to the port. They found the area covered with tsunami debris, including vehicles pushed against the building by the force of the wave, which had also pushed open the door at the entrance of the building.[22] Using the headlights of the fire engine they looked for the connection port, but could not find it.

At 2:45 on the 12th of March, the operators observed that the pressure in the reactor had gone down significantly and reached 0.8 MPa (gage, around 0.901 MPa absolute), approaching the pressure level in the containment building. This, along with the fact that the pressure was falling despite the SRV not having been opened, suggested that there were leaks caused by the meltdown. The pressure was still too high for the now defunct D/DFP, but the fire engines had much higher pressure and it seemed possible to inject water in that way without opening the SRV.[23] However, first the fire engine had to be connected to the correct port, which still had not been located.

The Nanmei staff and the member of the operations team on the fire engine, unable to find the port, decided to return to the earthquake-resistant building. There, they consulted the blueprints, and also found someone who had been involved in the installation of firefighting equipment and therefore was physically familiar with the location of the port.

At around 3:00, they returned to the area with this person.

Meanwhile, in preparation for the venting, the ERC was calculating the amount of time the operators would be able to stay in the highly radioactive environment of the unit 1 reactor building without passing the legal limit.

At 2:24 they fixed the maximum exposure time at 17 minutes. In the dimly lit MCR, the operators chosen for the mission were visualizing their task, mentally rehearsing so as to be able to complete it in the limited time available.[24]

During the night, a heated discussion took place between Yoshida and the Tokyo headquarters of TEPCO on the question of iodine pills. The headquarters, based on the advices of the NSC, suggested

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

[22] ICANPS, interim, p. 154

[23] ICANPS, interim, pp. 220-221

[24] Kadota, pp. 170-171

that only staff under 40 should take the pills, but the directive wasn't clear enough for Yoshida, who preferred that everyone follow the same procedure regardless of age. They finally came to an agreement by which the pills were required for staff under 40 and optional for those over, but the argument represented one of the first fractures between the headquarters and the field.[25]

At 2:55 the shift leader reported this to the ERC, and Yoshida decided definitively that the venting of unit 1 had priority over unit 2.

At 3:06 the Prime Minister, the Director General of NISA, and a managing director of TEPCO held a press conference on the venting, which they thought was imminent. Meanwhile in the ERC the engineering team was calculating the amount of radiation expected to be released during the venting; this estimation was communicated to the authorities at 3:45.

| **Reactor 1** | **Reactor 2** |
|---|---|
| At last the team on the fire engine found the port they were looking for, hidden in the tsunami debris.<br><br>Around 4:00 they were able to connect the fire engine's hose with the port and inject the 1,300 liters of fresh water from the tank of the truck. When they had emptied the tank, they drove to one of the fire engines damaged in the tsunami and transferred the 1000 liters in its tank to that of the truck they were using.<br><br>However, at 4:20 they became aware of increasingly high radiation levels, and the Nanmei workers went back to the earthquake-resistant building without injecting the 1000 liters of water. The head of Nanmei did not want to let his team work under these conditions, which were not covered under the contract he had with TEPCO. However, given the urgency of the situation, TEPCO negotiated with Nanmei, requesting their help, and eventually a compromise was reached: the fire engine would be manned by TEPCO staff with just one Nanmei employee helping them.[26] | Around 4:00, it was confirmed that the level of water in the unit 2 condensation tank was falling. This was the source for the RCIC as well as for other possible means of injecting water (which could be used if the electricity was restored). The shift team therefore decided to change the source for the RCIC from the condensation tank to the water of the suppression chamber (S/C) to avoid decreasing the level of the condensation tank further and also to limit the water volume increase in the S/C.<br><br>From 4:20 to 5:00, members of the shift team with protective equipment worked in the RCIC room in the basement of reactor building 2 to manually maneuver three valves, changing the water source to the S/C. The room was still flooded up to the level of their boots.<br><br>This change also meant that the temperature and pressure of the suppression chamber would gradually rise as the water cycled through the RCIC got hotter. However, the operators did not check on the temperature and pressure of the S/C until 4:30 on the 14th of March.[27] |

At 4:45 the ERC delivered protective equipment to the MCR, where the levels of radiation were already high.

At 5:00, when the source of the RCIC had been changed, the radiation levels in the MCR were so high that the operators tried to minimize their exposure by crouching low and staying on the unit 2

[25] Kadota pp. 96-99
[26] ICANPS, interim, p. 155
[27] ICANPS, interim, pp. 224-225

side of the room where the levels were slightly lower. Five minutes later a worker returning from the field to the earthquake-resistant building was found to be contaminated, and the ERC ordered an increase in protective equipment and screening.

| Reactor 1 | Reactor 2 |
|---|---|
| Around 5:00, the fire engine team returned to the field to continue the injection. They used cisterns, planned for firefighting, as a source of water. Initially the team drove the fire engine back and forth between the cistern and the pipe they had set up at the connection port, but this took time, especially with the debris cluttering the road. The team therefore decided to configure a line allowing permanent injection from the cistern directly into the reactor line. They parked the truck near the cistern, and connected hoses to the port.[28]<br><br>Around 5:46 this line was finished and the fire truck pumps were started for continuous injection. To avoid too much exposure to the radiation, the Nanmei staff took turns monitoring the situation with the TEPCO firefighters.<br><br>The restoration team continued its efforts to reconnect electricity for critical equipment with the electricity-generating vehicles. At least 40 TEPCO and sub-contractor staff worked all morning to establish the connection for the high-voltage cables, while another ten staff worked on the low-voltage cables. | |

At 5:44 the Prime Minister extended the evacuation order to a 10-kilometers radius.

Between 6 and 7 am, 13 soldiers and two fire engines from the Self-Defense Forces arrived at the plant. The soldiers did not know what they would be tasked with when they arrived at the plant. They first waited for someone to give them their orders (which was delayed by the visit of the Prime Minister); finally they were told to help with the injection of water into reactor 1.[29] They were given protective equipment and joined the TEPCO fire engine at the site. They started out bringing water from cisterns farther away and putting it into the cistern in use as the source for the injection. Unfortunately, the cistern only had one hose connection point, meaning that every time they wanted to refill it with water, they had to temporarily stop pumping water into the reactor. [30]

- *07:00 ON MARCH 12, 2011: VISIT OF THE PRIME MINISTER*

A little before dawn Yoshida was warned of the imminent visit of the Prime Minister. This visit raised some difficult logistical problems. First of all it was necessary to find a site for the helicopter to land, and then to find a way to transport the Prime Minister from that site to the earthquake-resistant building with a minimum of contamination. The plant had a limited amount of protective equipment, since some was lost in the tsunami and the remaining number is falling quickly due to

[28] ICANPS, interim, pp. 155-156 and attachment IV-14
[29] Kadota, pp. 161-166
[30] ICANPS, interim, p. 156

the fact that each set of equipment can only be used once. Yoshida wanted to prioritize field workers for the remaining equipment, and requested that the Tokyo headquarters manage the Prime Minister's visit and provide additional equipment. However, the headquarters resisted these demands, saying that the visit is the responsibility of the plant.[31]

However, Yoshida did get some help with the visit. Several important officials from both TEPCO and the government had already arrived at the Off-site Center, an office five kilometers away from the plant designated to support emergency operations. A TEPCO vice-president, Muto, and a deputy minister of METI, Ikeda, were the most important. However, the Off-site Center initially had no electricity and almost no communications, rendering it almost completely useless in terms of supporting crisis management. When the officials there learned of the Prime Minister's impending visit to the plant, they went there to meet him. Muto, who knew Yoshida from their years working at TEPCO, tried to see him first for an update but was unable to meet him before making his way to the helicopter landing site.

At 7:11 on the 12th of March the Prime Minister arrived with the head of the Nuclear Safety Committee, Madarame. Already irate, the Prime Minister without preamble or greetings demanded of Muto why the venting hadn't happened yet. In the conference room in the earthquake-resistant building Yoshida managed to calm the Prime Minister by explaining the difficult conditions in the field. He assured him that the venting will start at 9:00, and the Prime Minister departs at 8:04.

- *09:00 ON MARCH 12, 2011: VENTING OF REACTOR 1*

During the hours that followed, while the efforts to vent unit 1 became more and more desperate, unit 2 was not the focus of attention.

At 8:27, the ERC was informed that the evacuation of the surrounding populations is not yet complete.

At 9:02 on the 12th of March the ERC received confirmation that the evacuation was complete.

| Reactor 1 | Reactor 2 |
|---|---|
| Yoshida requested the operators in the MCR to vent the reactor manually.<br><br>At 9:04 the first of three teams left the MCR heading for the reactor building to begin the mission. At 9:15 they opened the MO valve 25% as planned, and 9:24 the first team returned to the MCR and the second set out in turn. But at 9:30 the second team returned without having completed the mission: the radiation levels were too high for them to even reach the room where the valve was.<br><br>Informed of this by the MCR, the ERC realized that it wouldn't be possible to open the AO valve, and therefore implement the venting, manually. They decided instead to attempt to open the | |

[31] Kadota, pp. 136-139

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| large suppression chamber (S/C) valve, which worked by compressed air. They therefore needed to find both an air compressor and a small generator to power it. Since TEPCO did not have the compressor on site, the team looked for one among the sub-contractors, and eventually found both the compressor and the adapter to connect it to the valve control.<br><br>While waiting, the ERC tried to open the valve without the compressor, hoping that there might be air remaining in the system, working the controls at 10:17, 10:23, and 10:24.<br><br>At 10:40 an elevated level of radiation was registered by the main gate of the plant, suggesting that possibly the venting worked, but at 11:15 the levels had dropped again, and the ERC concluded that venting has not taken place and that pressure continued to rise within the containment. | |

- *11:00 ON MARCH 12, 2011: USING SEAWATER FOR COOLING (1)*

| Reactor 1 | Reactor 2 |
|---|---|
| The water injection via the fire engines continued, but around noon Yoshida was informed that there was not much fresh water remaining on site. The other option was seawater; this was not ideal. It would result in decommissioning the reactor (something which already seemed likely if not definite); in the medium term the salt could eventually concentrate in the core as the water evaporated but the salt did not; and in the long term it would cause corrosion. There was also a concern that the salt water could cause recriticality; adding salt water to a reactor in this state had never been tried before. However, with fresh water running out and an urgent need to inject water into the core to cool it, salt water seemed to be the only possibility left. However although the plant was beside the ocean, it was not necessarily easy to access it. The plant was situated 10 meters above sea level; if this distance was not enough to protect it from the tsunami, it was too much for the hoses of the fire engines.<br><br>Yoshida ordered the injection team to find a solution, which they identified in a backwash pit behind reactor 3 which contains water left by the tsunami, and Yoshida approved this source.<br><br>Around 12:30, the air compressor and adaptor were transported in a four-ton truck to the site of connection for the large valve. By 14:00 it was put into operation and the team tried to open the valve. At 14:30 the pressure in the containment building was at 0.75 Mpa (absolute). At 14:59 it was measured at 0.58 Mpa (absolute), and a white steam was visible escaping from the building. Based on these observations, the team concluded that | |

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|---|---|
| the venting has been successful.<br><br>At 14:53, there was no more fresh water available in the cisterns of the plant, and at 14:54 Yoshida gave the order to switch to seawater. The injection team began configuring a line to link the backwash pit of seawater with the fire engines injecting water into reactor 1.<br><br>By 15:18 Yoshida was able to inform the authorities that venting had succeeded and the injection of seawater was imminent. | |

At the Prime Minister's office, where politicians and experts were gathered to support the emergency response headquarters, frustration was growing with the pace of a response that they see as slow, particularly due to perceived lack of communication from TEPCO. At 15:04 the METI minister informed TEPCO that if the interruptions continued, he would give an order to continue the water injection. This order was unlikely to have much practical effect, since the team at the plant was already doing everything it could to continue the injections.

At 15:30 the high-voltage cables were finally connected from the electricity vehicles to one of the plant power centers, and the workers began to test the electrical connections. This seemed to promise an exit path from the crisis: with high voltage power, everything – venting, cooling – would be easier, and there would be indicators to drive the work.

- *15:36 ON MARCH 12, 2011: EXPLOSION IN REACTOR 1 BUILDING*

Just as the lines were prepared, there was a huge explosion at 15:36. In the MCR, panels fell from the ceiling, filling the room with dust. The operators rushed to put on their protective equipment, in case the explosion had dispersed radioactive material. The shift leader Izawa called the ERC, but they didn't know the cause of the explosion, asking in turn if it was one of the generators in the MCR. Shortly after the ERC called back to inform the MCR that the fifth floor of the reactor building was apparently gone. The explosion also damaged the earthquake-resistant building, knocking out air filters that had an important functioning in reducing contamination. [32] Yoshida ordered the evacuation of the workers in the field, a few of whom were injured.

Once they were allowed back to the field, the workers checked on the damages caused by the explosion. The line connecting the fire engines to the seawater ditch was damaged, and had to be restored. The fire engines, fortunately, were still functioning. The air compressor, however, was not. The debris from the explosion, much of it radioactive, severely hampered the work in the field. Despite the hazards in the field, it was imperative that the work continue.

- *17:20 ON MARCH 12, 2011: USING SEAWATER FOR COOLING (2)*

| **Reactor 1** | **Reactor 2** |
|---|---|
| At 17:20 Yoshida authorized work in the field and ordered the staff to restart the operations to inject seawater into the reactor. | At 17:30, Yoshida ordered the preparation of vent lines for the primary containment vessels (PCV) of units 2 and 3. The shift team, which had just lost |

[32] Kadota, pp. 210-213

For the politicians, this was none too soon; at 17:55 the METI minister verbally ordered TEPCO to fill the reactor with seawater. Although this order was communicated to TEPCO headquarters and to the plant, since they were already making every effort to do so it did not change much in the field.

Shortly afterwards in a meeting about the situation the Prime Minister showed himself to be concerned about the question of injecting salt water into the reactor. There was a great deal of uncertainty about the effects, since it had never been done before. Unable to answer all of the Prime Minister's questions, the TEPCO liaison to his office, Takekuro, promised to get the responses before the operation started.

At 19:04, the line was repaired and the injection of seawater began.

At 19:15 the authorities were notified, but the information did not reach the Prime Minister or those in the meeting with him. After it finished, Takekuro called the plant to get the answers to the Prime Minister's questions, only to be told that the injection had already started. Takekuro demanded it be halted immediately until approval could be obtained from the Prime Minister. Reluctant to stop the injection, Yoshida spoke with the Tokyo headquarters, but they agreed with Takekuro that the Prime Minister's approval should be clear.

Unsure if he would be able to restart the injection once it was stopped, and knowing that in any case every liter of water was important in controlling the accident, Yoshida told the operators to continue the injection even though he was going to give an order for them to stop it that would be audible via teleconference in the Tokyo headquarters.

At 19:27 on the 12th of March, the TEPCO headquarters informed the authorities that the two of its members to a medical evacuation after they passed the legal radiation limit attempting to vent unit 1, was also very conscious of the risks of venting too late, and decided to manually open the venting valves of the PCV of unit 2 while the radiation remained relatively low. This action left a rupture disk, which would break automatically when the pressure reached a certain level, the only barrier to venting, and would avoid the need of going to the reactor building to open the valves later, when the radiation might be higher.

But at 19:10 the operation team of the ERC told them to close it again, fearing that hydrogen, the presumed cause of the explosion in unit 1, could leak through the pipes and cause an explosion in unit 2 as well.[33]

[33] ICANPS, interim, p. 233

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| seawater injection had been stopped pending the approval of the Prime Minister. However, the Prime Minister did not receive this information; instead, Takekuro was able to speak with him and then transmitted his approval of seawater injection to the headquarters.<br><br>At 20:20 Yoshida gave the order to “restart” the injection which had never been stopped.<br><br>At 20:45 boric acid was added to the salt water being injected to prevent recriticality. | At 20:05 they found that the D system P/C of unit 4 was available, and decided to try to connect a 480-volt cable there. This required once again clearing roads and cutting through bent steel doors to lay the cable. Around 40 TEPCO workers were involved in laying cables and preparing connections, and the work continued through the following days.<br><br>At 22:00 another part of the restoration team attempted to reconnect the low-voltage cable for the instruments in the MCR for reactors 1 and 2, but water on the ground led to repeated shorts. |

- *08:10 ON MARCH 13, 2011: THE PREPARATIONS FOR VENTING REACTOR 2*

| **Reactor 1** | **Reactor 2** |
|---|---|
| | At 8:10 on the 13th of March, following the order of the ERC, members of the shift team went, with all their protective equipment, to the reactor building of unit 2 to open the vent valve for the PCV to 25%, as they had the previous night only to be told to close it again.<br><br>At 10:15, Yoshida gave the order to complete the PCV vent line except for the rupture disk, and the shift operators went to the reactor building to open the vent valve of the S/C, using air left in a compressed air cylinder. At the same time, the restoration team connected a small generator to complete the opening of the valve. Around 11 the line was complete except for the rupture disk. However, the pressure did not raise high enough to break the rupture disk. |
| | Just after noon, Yoshida ordered preparations for injecting seawater in to the unit 2 reactor to be able to begin the injection quickly if the RCIC stopped working. Fresh water was for the moment reserved for unit 3, and so there was no option but seawater. However, the team of firefighters and Nanmei staff, who worked on the water injection lines, were busy with preparations to change the source for unit 3 injection from fresh water (which had run out) to seawater, and therefore they were not able to complete the line for unit 2 until late in the afternoon that day.<br><br>To avoid difficulties injecting the water due to the high pressure in the reactor, as they had faced for units 1 and 3, the restoration team decided to connect the SRV to a power source, to facilitate its opening in case of |

necessity. During the morning they found ten 12-volt batteries from cars and took them to the MCR, where by 13:10, they had connected them to the SRV.

At 15:18, Yoshida reported to the authorities the calculated radiation release in case of venting unit 2.

Again based on the experiences with the other units, the ERC decided to install a portable air compressor, in addition to air cylinders, to keep the S/C valve open. The ERC requested this compressor from other TEPCO's plants at 18:10 and at 22:10; around 1:50 on the 14th of March on arrived from Fukushima Dai-ni, and the restoration team connected it. Its capacity was lower than needed, like the one installed at unit 3, but there was no way to find a larger one.

- *01:10 ON MARCH 14, 2011: THE DIFFICULTY OF VENTING REACTOR 2*

Around 1:10 on the 14th, the water in the backwash pit used as the source of seawater for the injections seemed to fall too low to access. The workers looked for other sources of water before realizing that they could still manage to access the water in other backwash pit for the moment. So at 3:20 injection was resumed for unit 3, considered the most urgent at the moment.

Around 4:30 on the 14th, the pressure in the reactor building was finally measured. The gauge showed a dramatic rise in the pressure These conditions led Yoshida to worry that unit 3 was at the point of exploding as unit 1 had done a day and a half previously. Between 6:30 and 6:45, with the approval of the TEPCO officials in Tokyo and at the off-site center, Yoshida evacuated the workers in the field to the earthquake-resistant building. The explosion did not happen, the pressure in the reactor building stabilized, though remaining high, and it was urgent to connect the line for seawater injection, so at 7:30 Yoshida canceled the evacuation order and the workers returned to the field.

Around 9:00 on the 14th the workers completed a line from the sea to the backwash pit they were using as a source for water injection, making it possible to refill the pit.

Around 10:00 seven water trucks from the self-defense forces (SDF) arrived at the plant with 35 tons of water. They were assessed and two went towards the backwash pit.

At 11:01 on the 14th there was an explosion in the unit 3 reactor building, injuring some TEPCO and Nanmei staff, and all workers were evacuated for a while to the earthquake-resistant building, to confirm safety of workers and field conditions. Four SDF soldiers, busy working to refill the backwash pit with the water they had trucked in, were also injured, and all seven water trucks left the plant, without unloading the water.

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|---|---|
| | At 12:00, the core water level of unit 2 showed a decrease. Yoshida ordered his teams to find an alternative means of injecting water to all the reactors but especially for reactor 2.<br><br>At 12:50 it was confirmed that the solenoid valve of the large S/C valve had been moved by the explosion, requiring the reconfiguration of the venting line. |

- *13:20 ON MARCH 14, 2011: THE EMERGENCY COOLING FUNCTION STOPS SUDDENLY*

| Reactor 1 | Reactor 2 |
|---|---|
| | Around 13:25 on the 14th, Yoshida came to believe that the RCIC had stopped. He ordered, again, that his teams find alternative means of injecting water. The firefighter team, with the Nanmei staff, finding that the explosion had damaged the line they had constructed from the backwash pit, began to construct a line from the sea to reactors 2 and 3. This line was completed around 14:43, but frequent aftershocks caused repeated evacuations slowing the work, and the fire engines could not begin to pump until around 16:30. During one of these pauses caused by an aftershock, at 15:28, Yoshida had informed the authorities that the water level of unit 2 was estimated to reach the top of the fuel at 16:30.<br><br>To inject the water, it was necessary first to depressurize the reactor. But Yoshida was concerned about the procedure due to the high temperature and pressure in the S/C, which had been receiving the circulating water from the RCIC for two days. He believed that opening the SRV without a complete PCV line as an escape route for the pressure in the S/C risked damaging the S/C. He therefore ordered that the PCV line be completed before the depressurization. The headquarters agreed with this assessment, but the head of the NSC Madarame thought that depressurization and the injection of water should be prioritized to protect the fuel.[34]<br><br>Around 16:00 on the 14th, the restoration team tried to open the large S/C valve with a portable air compressor, but it did not open right away, because the air pressure was too low. When this was reported to the ERC, it triggered another discussion about the question of priorities between depressurization and the construction of the PCV line. Finally, the TEPCO president, Shimizu, decided that they could not wait any longer to depressurize. Yoshida accepted this decision and gave the order. The injection line was connected at 16:30, and at 16:34 the restoration team connected 10 batteries in series to the control panel in the MCR to open the SRV. However, the SRV did not open right away. They continued to try to open it, but it was difficult to keep it in place, and the suppression chamber conditions – hot and high pressure – meant that the steam that was released there barely condensed. The depressurization was very slow. |

[34] For a simplified explanation of this technical question, see ICANPS Attachment IV-28.

| | |
|---|---|
| | At 17:17 the water in the reactor reached the top of the fuel, and at 18:22 it was 3,700 millimeters below the top of the fuel, exposing the fuel rods completely. [35]At 18:50 the indicator of water level passed off the scale. The pressure did not get down to a level which would allow water injection until 19:03. Then at 19:20 the firefighters realized that the two engines which should be pumping the water in had run out of gas.<br><br>They were restarted at 19:54 and 19:57, leaving at least 37 minutes when the injection was not happening. After this experience, the injection team set up a schedule of relays for checking the fuel regularly.<br><br>Around 21:00 on the 14th, the S/C vent valve (the AO valve) was opened, completing the venting line (except for the rupture disk). At 21:20 it was confirmed that the level of water in the reactor was rising, and by 21:34 the authorities could be informed that at 21:30 the water was 3000 mm below the top of fuel.<br><br>During the following hours, Unit 2 reactor pressure seemed higher than the discharge pressure of the fire pump and therefore, it was highly likely that water had not been injected into the reactor. This situation, where the fuel had already been exposed and the continuous injection of water was impossible, raised the possibility of a meltdown, at least for Yoshida.[36] Considering this possibility in consultation with TEPCO headquarters, Yoshida discreetly prepared for an evacuation. According to TEPCO, the preparations were already underway at the off-site center, where TEPCO vice-president Muto had ordered the preparation of an evacuation manual at 19:45. TEPCO claims that this evacuation was always meant to be limited to nonessential personnel, leaving an emergency team, including Yoshida, to continue their efforts to bring the reactors under control. This assertion is borne out by the manual.[37] |

- *1:00 ON MARCH 15, 2011: THE CONTAINMENT LEAKS OF REACTOR 2*

| Reactor 1 | Reactor 2 |
|---|---|
| | However, the pressure in reactor 2 remained stable from 1:00 March 15th, facilitating the continuous injection of water, and the evacuation order was not given at that point.<br><br>In the morning on the 15th of March, the ERC was once again shocked by an explosion. The cause was not immediately evident to the staff there. At the same time, the pressure indicator for the suppression chamber of unit 2 showed zero, a value that was logically impossible. With these facts, and the context of the continuing difficulties with unit 2, Yoshida believed |

[35] TEPCO (June 2012) Attachment 2 p. 84
[36] ICANPS, interim, p. 258
[37] TEPCO (June 2012) pp 103-104

that the explosion was at unit 2 there and that the situation had become even more dangerous.

In fact, the explosion had occurred in the reactor building of unit 4. Although there were some workers near there for the changing of the shift in the units 3 and 4 control room, it took them some time to get back to the ERC to report on the situation, since the debris made it impossible to drive on the road, and they did not arrive until 8:11. In the meantime, Yoshida ordered the evacuation.

This order included around 650 staff, who left at 7:00 for Fukushima Dai-ni. The 50-odd people who remained included Yoshida, high-level staff, and the necessary operators to control and operate the plant. These last were nominated by the heads of the teams in the ERC.

Around 9:38 on the 15th, there was a report of a fire in unit 4. The high levels of radiation prevented assistance from local firefighters, but around 11:00 the ERC could confirm that the fire was out. Yoshida decided that the conditions allowed for the staff to return to the plant, starting with managers.

## 3.3 REACTOR 3 CHRONOLOGY

- *LAUNCHING OF EMERGENCY PROCEDURES*

The earthquake at 14:46 on March 11th caused an almost immediate loss of external electricity. Reactor 3 scrammed automatically at 14:47; the emergency generators started, also automatically, at 14:48.

Following the EOPs to manage the cooling of the reactor, the shift team started the reactor core isolation cooling (RCIC) system manually at 15:05 to replace water in the reactor. It stopped automatically at 15:25 when the water reached the designated height. The pressure went up at almost the same time, and the safety relief valve (SRV) opened automatically to release the high pressure into the suppression chamber. The operators didn't turn on the residual heat removal system (RHR) because of the tsunami alert.

The first wave of the tsunami arrived at 15:27. The flooding started at 15:35. At 15:38 internal electricity – the emergency generators – was lost. Nonetheless (unlike units 1 and 2), in the unit 3 which was partially spared by the tsunami, the instruments were still working, and the shift team could confirm that both the RCIC and the high-pressure coolant injection (HPCI) systems were still functioning. At 16:03 the shift team started the RCIC manually.

- *RESIDUAL HEAT REMOVAL*

Since all the instruments and emergency cooling systems were working for unit 3, through the night of March 11th and the morning of March 12th the attention was definitively on units 1 and 2. However, at 11:36 in the morning of March 12th, the RCIC of unit 3 stopped. Some of the unit 3 shift operators went to the RCIC room, where they found a latch open and oily.[38] They closed the latch and restarted the RCIC, but it stopped again, and despite their efforts would not work again. At 12:06 the shift team activated the diesel-driven fuel pump (D/DFP) and then the suppression chamber spray.

Once the RCIC had stopped, the water level in reactor 3 began to go down, and at 12:35 the HPCI started automatically. The shift team managed it by controlling the flow rate, always keeping an eye on the level of water in the reactor.

At 15:36 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.

Around 20:36, the 24-volt direct current source of electricity for the water level gauge of reactor 3 ran out of charge, and the shift team could no longer track the level of water in the core. The restoration team gave them 13 2-volt batteries to power the indicator, and in the meantime the shift team increased the flow rate of the HPCI to avoid having problems of insufficient water. They

[38] ICANPS, interim, p 191

continued to monitor the reactor pressure and the discharge pressure of the HPCI to ensure that it was working.[39]

Originally, the HPCI is designed to inject a large volume of water into the core in a high pressure state (1,03 to 7,75 MPa) and in a short space of time but the pressure was lower, fluctuating from 0,8 to 0,9 MPa and operators were managing it in an unusual way. They had made an alignment by way of the HPCI test line in order to control the flow rate and avoid starts and stops that would have drawn the batteries. That along with the impossibility for the moment of confirming the water level worried them. They believed that they could still open the SRV remotely from the control panel, and they therefore came up with a plan: they would open the SRV to depressurize the reactor, and then reconfigure the line from the D/DFP so that instead of going to the suppression chamber spray it would inject water directly into the reactor. They believed that the D/DFP would be more reliable than the HPCI. They discussed this plan with members of the operation team from the ERC, who agreed with the idea of stopping the HPCI if the D/DFP could in fact be used to inject water, which required depressurization using the SRV. But this information was not shared among all the members of the operations team, including the team leader.[40]

At 2:42 members of the shift team left the MCR to change the D/DFP configuration from the spray to injecting water into the reactor. They had no means of communication with the MCR while they were in the field. More or less at the same time, the shift team members who stayed in the MCR stopped the HPCI. Then, at 2:45 and again at 2:55, they tried to open the SRV from the control panel, but the 'closed' indicator for the SRV did not change.[41] They concluded that the reactor had not been depressurized. The information was reported to the operations team at the ERC, but it was not communicated to the head of that team, nor to Yoshida, nor to the headquarters. The pressure in the reactor was still too high, making it impossible to inject water via the D/DFP, even when the shift team turned it on.

At 3:37 and again at 5:08, the shift team tried to get the RCIC to work again, but they weren't able to restart it. Nor could they restart the HPCI. At 3:55, members of the operations team in the ERC who were aware of the situation, too busy up to that point to report it[42], finally explained it to their team leader. When this information was communicated to the Tokyo headquarters, they demanded to know if the stopping of the HPCI was automatic or manual, and were given to understand that it was automatic. [43]

Once he understood the situation, Yoshida had the teams focus on constructing a line to inject water via fire engine and find batteries to open the SRV.

At 5:08 the shift team started the suppression chamber spray manually. They found that the handle of the suppression chamber spray valve was extremely hot.

Yoshida estimated that the level of water had lowered to the top of the fuel around 4:15, and he communicated this calculation to the authorities at 6:19.

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[39] ICANPS, interim, p. 198

[40] ICANPS, interim, p. 199-200

[41] The ICANPS interim report suggests that the problem was a lack of battery, that enough battery remained to power the indicator lamp, but not enough to open the SRV.

[42] According to ICANPS, interim p. 205

[43] The ICANPS describes this as a misunderstanding (p. 206), but it is also easy to imagine that the operation team tried to protect itself and the shift team.

From dawn the restoration team tried to connect a generator mounted on a truck to the "power center" of unit 4 to have electricity for the standby liquid control (SLC) system of unit 3, which could inject water at high pressure. However, they had many difficulties with connections and cables, and especially with a metal door which had been warped by the tsunami to the point of being impossible to open, delaying the work.

The seawater injection line for unit 3 was complete around 7:00. However, injection still could not be begun until the reactor was depressurized via the SRV, which required 120 volts of electricity. There were not enough batteries on site. Other plants sent 50 batteries to Fukushima Dai-ichi, but they were all 2-volt, and it wasn't practical to connect 60 in a series to reach 120 volts. The team found 12-volt batteries from private vehicles (those of staff and sub-contractors) in the parking lot.[44] They brought them to the MCR for units 3 and 4, where they worked to connect them despite the already high levels of radiation in the control room. Opening the SRV also required compressed air, but they hoped there was enough air left in the system for it to work.

During the morning, the politicians gathered in the office of the Prime Minister discussed the status and the plans for Fukushima Dai-ichi. They were informed that seawater injection was being prepared for unit 3, and asked whether it would be better to inject fresh water first. Hearing these concerns, the divisional director of TEPCO who was in the meeting at the Prime Minister's office called Yoshida and told him they should first exhaust all the fresh water available on site before switching to seawater. Yoshida took this communication very seriously, and told the team of firefighters and Nanmei employees to search for fresh water and begin with that. They therefore started to prepare two lines for fresh water: one to connect sources of fresh water to an emergency cistern near unit 3, and another from that cistern to the injection port for the reactor.

At 9:08 the restoration team connected enough batteries to reach a 120-volt charge and open the SRV. Around 9:25, the injection of fresh water was started, using the fire engines.

- *PROTECTION OF THE CONTAINMENT - VENTING*

However, around 9:28, the pressure in the drywell of unit 3 went up. This increase was attributed to a lack of air pressure to keep the large S/C valve open, inhibiting the depressurization. The restoration team inspected the site and found an air leak caused by a faulty connection, which they repaired temporarily with tape. Finding that there was enough air remaining in the air cylinder, they found a new cylinder but did not change them, leaving the new one to the side to be ready. Seeing white steam in the building and registering high levels of radiation, they evacuated.

Around 11:17 the pressure began to rise again, and the restoration team went in to change the cylinder. The temperature and the levels of radiation were very high, so they worked in relays of 15 minutes each, wearing full protective equipment. At 12:30 it was confirmed that the large S/C valve was open.

When Yoshida was informed that fresh water was running out, he ordered the team to be prepared to quickly change the injection to seawater when the fresh water was exhausted. Around 12:20, the fresh water ran out. The team was prepared for the change, but even so the seawater injection could not be started until around 13:12.

[44] ICANPS interim pp. 209-210

The radiation levels continued to go up through the afternoon, with very high readings at 14:15 and 14:31. At 15:28 the operators in the MCR gathered themselves on the unit 4 side of the control room, to try to avoid as much radiation exposure as possible. The pressure in the drywell was rising again, up to 0.31 MPa abs around 15:30. The ERC decided around 15:53 to use an air compressor, rather than the cylinders, to try to keep the valve open. They found one air compressor of relatively low capacity in the office of one of the sub-contractors, and around 17:52 they transported it by truck to unit 3. They started it at 19:00. The restoration team refueled it periodically.

Since the sea itself was too far from the ground level of the plant for the fire engines to easily access, the source for the seawater injections was a backwash pit behind unit 3 where the tsunami had left a significant quantity of water. Around 1:10 on the 14th of March, the level of seawater in this backwash pit of unit 3 seemed to be falling too low for them to access it. The workers looked for other sources of water to refill the pit but did not find any. Finally they realized that they could find places in the backwash pit where the water was still accessible to their hoses, and around 3:20 they could resume the injection of water into unit 3.

During the early hours of the morning of the 14th of March, the drywell pressure of unit 3 increased again. Around 3:40, the restoration team used a small generator that was connected to the lighting in the MCR to charge the solenoid valve to open and keep open the large S/C valve. They also found a new air compressor from Fukushima Dai-ni and between 3 and 5 am they used this new compressor to replace the one that had been connected to the S/C vent. In case the large vent didn't open, they used the small generator to open the small S/C vent between 5:20 and 6:10. However, the pressure continued to go up.

The increase in pressure and the drop in the water level, which went off the scale at 6:20, worried Yoshida. It seemed to him that the reactor 3 at this point was showing the same signs as unit 1 had just before its reactor building exploded two days earlier. Concerned for the safety of the workers, and after a discussion with the headquarters, between 6:30 and 6:45 Yoshida ordered that workers in the field evacuate to the earthquake-resistant building.

But the minutes ticked on and the explosion did not occur, and between 7 and 7:20 the drywell pressure went down slightly, from 0.52 MPa abs to 0.5 MPa abs. The threat of an explosion remained, but the construction of the line to refill the backfill pit was urgent so that the water injection critical to all three reactors could continue, and at 7:30 Yoshida rescinded the evacuation order.

Around 9 the workers completed a line from the sea to the backwash pit they were using as a source for water injection, making it possible to refill the pit.

Around 10 seven water trucks from the self-defense forces (SDF) arrived at the plant with 35 tons of water. They were assessed and two went towards the backwash pit.

At 11:01 the expected explosion in the unit 3 reactor building took place, injuring some TEPCO and Nanmei staff, and all workers were immediately evacuated to the earthquake-resistant building. Four SDF soldiers, busy working to refill the backwash pit with the water they had trucked in, were also injured, and all seven water trucks left the plant, without unloading the water.

When the explosion happened Yoshida was struck with guilt. Initially 40 staff were unaccounted for, and he was sure that this time someone would have been killed, but little by little people trickled back to the earthquake-resistant building, and although there were injuries, at the end everyone was accounted for and alive.

The indicators of the reactor showed that the pressure in the drywell just after the explosion was above atmospheric pressure indicating that the explosion occurred outside the containment, and the containment was probably intact.

Around noon, Yoshida ordered the teams to restore the water injection lines for reactors 1, 2, and 3 to attempt to control the reactors.

From 13:00, the team of firefighters and Nanmei staff assessed the explosion damages in the field and found that most of the fire engines were damaged and the hoses that had been connected were unusable. The debris made it impossible to reconstruct the same lines. The team decided to construct an injection line directly from the sea to the reactor, via fire engines. The line for unit 3 was complete and the water injection started at 16:30.

# 4 ACCIDENT MANAGEMENT ANALYSIS

Through the analysis of the chronology of actions and events presented in the previous section, we have identified different issues presented hereafter: making sense to the situation (§ 4.1), drastic choices (§ 4.2), challenges for the emergency structures (§ 4.3) and comparison with Fukushima Dai-ni (§ 4.4).

## 4.1 MAKING SENSE OF THE SITUATION

### *4.1.1 THE KEY ACTORS*

Decision-making by individuals, and more specifically by those closest to the problem, the operators on duty in the Main Control Rooms (MCR) of the reactors, was exactly what was supposed to happen in case of an emergency. According to the interim report of the Investigation Committee on the Accidents at Fukushima Nuclear Power Stations of Tokyo Electric Power Company (ICANPS), "*As a rule of the Fukushima Dai-ichi NPS, the shift supervisors were responsible for making decisions in the event of an accident to control and operate the plants in accordance with the* […] *Nuclear Operator Emergency Action Plan at the Fukushima Dai-ichi Nuclear Power Station*" (pp 96-97). This did not mean that the shift supervisors and teams could act entirely on their own; the report continues that "*In some exceptional cases, including when they took action requiring the cooperation of other control rooms or when their actions having great impact on plant behavior thereafter, the shift supervisors had to ask the NPS ERC for advice or direction which would then do so accordingly*" (p 97). The accident management procedures also suggest technical support; the ICANPS quotes the TEPCO Report on Preparation for Accident Management at the Fukushima Dai-ichi Nuclear Power Station that "*For more complicated events, the technical assessment regarding to what accident management measures to select was high and also other resulting impact should be considered. Therefore, support networks should conduct such technical assessments and the like and assist in decision making*" (p. 141).

At least in the immediate aftermath of the disaster, the first part of the guidelines took priority. Particularly for the first 24 hours, it was the shift supervisors and their teams who were deciding the course of the response. It is therefore useful to understand as much as possible about these individuals, their backgrounds, and the cognitive frameworks they brought to their job.

The shift team included a range of ages and experience working at the plant; however, it was those with the most experience, generally in their 40s or 50s, who made most of the decisions. For example, the shift supervisor Izawa was born in 1958 in Futaba Town, graduated from the local engineering high school and found work with TEPCO.

The original 11 shift team members were joined by more and more colleagues, particularly experienced ones, as the gravity of the situation became clearer. In addition to its importance for the ongoing decision-making process and the dynamic of the group overall, the fact that additional operators arrived on their own initiative from off-site is indicative of several general characteristics of these individuals.

- *Local*. Most, if not all, of the TEPCO employees at the operator level were local. Some of them had links beyond the workplace; for example, having attended the same high school.[45]

[45] Kadota, p. 195

They and their families lived in the surrounding area, making them extremely invested in avoiding a nuclear disaster. Beyond that, given the lack of migration into these rural areas, they were likely to have a history on the Fukushima coast going back generations, like many of the townspeople who would later fight to return to live on their own land, even if it was hopelessly contaminated.

- *Long-term*. For many if not most of the operators, TEPCO was their only employer, and they had already spent decades at the plant.
- *Sense of connection to the plant and the reactors themselves.* Kadota describes one operator, who had spent more than ten years working in the MCR for reactors 1 and 2 before being shifted to that of 5 and 6, as "*wanting to go save*" reactors 1 and 2, which he felt had "*brought him up*" or "*educated*" him as an operator; he thought of them "*like a spoiled child.*"[46]
- *Sense of personal responsibility*. Many of the operators described a strong sense of responsibility for managing the emergency. They felt that taking risks in this type of situation was part of their job as operators, saying for example: "*at the end of the day someone had to do it. As operators, there are some missions you have to do. I thought this was a natural conclusion.*"[47]
- *Trust in technical design.* Under normal circumstances, and even during "*normal*" emergencies, the operators worked from the MCR, both observing and acting upon the reactors from a distance. They certainly would have reason to go to the reactor building and other parts of the complex on occasion, but that was not the site of most of their work. Thus, for example, they could visualize routes through the reactor building in preparation for a mission there,[48] but they did not have an intuitive feel of entirety of the complex machinery within the building, and not only needed to look at blueprints to be sure which valves were necessary for reconfiguring a water line, but also had to repeatedly cross-check the numbers while doing so.[49] Their interaction with these machines was almost exclusively mediated by additional machines – indicators, monitors, electrical circuits, switches, valves.

Within this group of operators, the hierarchy seems to have been respected. There is no record of the shift supervisor's decisions being questioned or disputed. Nor was the substitute shift supervisor's authority challenged, even when the regular supervisor Hirano returned to the plant. In addition, there was a recognition of the need for different roles: Kadota documents several cases (March 11$^{th}$ in the evening, March 12$^{th}$ around 00:00) in which the shift supervisor offered to take a dangerous job in the field, only to be reminded by his colleagues that it was important to have a consistent presence in the MCR.[50]

This emphasis on continuity of leadership within the group also meant an extremely long shift for those caught in the MCR during the crisis. They worked from the 11$^{th}$ through the evening of the 13$^{th}$, more than 48 hours. Even then, they remained on site (at the ERC) and continued taking shifts in smaller groups.

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[46] Kadota, pp. 193-194
[47] Kadota, p. 82
[48] Kadota, pp. 170-171
[49] Kadota, pp. 77-79
[50] Kadota, p. 77, 125

Age also played a role in the group dynamics; the older operators were the ones both making the decisions and taking the risks.[51]

All of these factors affected the cognitive framework of the operators on shift duty when the crisis struck. They were experienced in running the reactors, although in a way that was very dependent on specific procedures and remote indicators and controls. They trained for certain types of emergencies, and types that fell outside of their realm did not enter into their training or expectations. They also existed in the larger context of Japan, a high-functioning technical society where trains are rarely late and vending machines offer conveniences on every corner, even in rural areas.

There is another individual who made key decisions during the response, though he was located in the ERC rather than the MCR: the Site Superintendent, Yoshida. He looms large in every narrative of the crisis, in many ways. His role is less clear-cut than that of the operators: some decisions were his at an individual level, but like many managers his role was often to mediate among different actors, and many decisions had structural elements.

According to Kadota's book, Yoshida was a large friendly man, "*the kind of old style business man who would exchange pours with his subordinates. Additionally he was a technical person, faithful to theory and ideal, not going one step beyond his boss*" (Kadota, pp. 96-97). Although Kadota writes that he prided himself on keeping calm, Kadota's book as well as the transcripts of video-conference exchanges show his temper fraying with the stress of the crisis (Kadota, p. 97). It was barely more than 24 hours after the emergency began that he went "*beyond his boss*" by secretly allowing seawater injections to continue, despite being ordered to stop them.

### *4.1.2 SENSE-MAKING*

The process of sense-making has long been considered crucial to crisis management (Weick, 1988 and 1993; Boin et al. 2005). As Weick (1993) notes, "*The basic idea of sensemaking is that reality is an ongoing accomplishment that emerges from efforts to create order and make retrospective sense of what occurs.*" Sense-making is a process of interpretation of often confusing information, and as such is highly mediated by the actors involved: "*Sensemaking is about contextual rationality. It is built out of vague questions, muddy answers, and negotiated agreements that attempt to reduce confusion.*"

In the units 1 and 2 MCR, the operators scoured the emergency procedures and manuals with flashlights, hoping for guidance. They were attempting to connect the chaos they were experiencing with what Weick (1993) refers to as "*structural frameworks of constraint*": "*a framework of roles, rules, procedures, configured activities, and authority relations that reflect and facilitate meanings*". However, procedures had not been prepared for a total station blackout (SBO), and the manuals were not applicable; the operators were left to interpret the chaos themselves. Without instruments, without functioning controls, and without standardized guidance, "*the shift team was forced to predict the reactor state according to a limited amount of information and take such procedures operators think best on the spot instead of following the instructions described in the standard manuals*" (ICANPS Interim p. 111).

After the loss of power, however, the operators for units 1 and 2 had access to none of these indicators. Other than educated guesses based on the last set of parameters and their limited experience with emergency shutdowns, they had no way of understanding the situation of the

[51] Kadota, p. 125

reactor or knowing what, if any, effect their actions had on it. The sense-making process was on-going, and still vulnerable. For unit 3, by contrast, the operators were able to use the water level and pressure indicators to adapt their operation of the RCIC to minimize its use of battery power.

However, if the control room indicators were both the easiest and the most accustomed way to understand what was going on in the reactors, there were other options. Although there was no way to directly observe the water or pressure levels inside the nuclear reactor, by physically going to the reactor building the operators would have access to other gauges that might tell them more about the situation. The shift supervisor sent several different missions to the field simultaneously to assess the situation and try to diagnosis key elements of the crisis: what was working; what could be fixed; and what was useless. These missions were undertaken without the need for approval or suggestions from anyone outside the MCR. The sending of multiple missions more or less at the same time shows the operators' awareness of the complexity of the situation, and the need to explore multiple possible paths to a solution.

The missions also indicate the beginning of what Weick (1988) refers to as "*enacted sense-making*." In order to begin to process an unknown situation, it is necessary to take actions which start to provide data and support interpretation about what is going on; however, these actions also have an impact on the unfolding crisis, which can be positive or negative: "*individual actions involved in sense-making can cause a crisis, but also manage it to lower levels of danger*." So, for example, when the operators wish to learn whether an emergency fire pump is still functioning, they turn it on. This answers their question, but also uses some of the remaining fuel available for the pump, thereby affecting the unfolding of the situation.

Their search for meaning continually impacted the unfolding of the crisis, whether it was the opening of an IC valve to see whether it would open, or running the D/DFP to see whether it would run. When operators trying to confirm IC operation turned back from the reactor building because of unusually high, but far from dangerous, radiation levels, it was a quite literal example of what Weick (1988) describes as "*a delicate tradeoff between dangerous action which produces understanding and safe inaction which produces confusion*."

When the parameters indicators had been partially restored, the operators had information that was confusing in a number of ways. For a group accustomed to conducting all its work based on indicators and lights on a control panel, the return of any of those indicators must have seemed, in itself, to be a positive development, regardless of what it told them about the status of the reactor: it was a slight move towards normalcy. On the other hand, because other indicators, such as reactor water level or discharge pressure of the IC, were not working, the operators were forced to depend on an ad hoc, informal and potentially unreliable indicator: the amount of vapor visible from a distance. This corresponds to what Vaughan calls "*weak signals*," in which "*information was informal and/or ambiguous*" (p. 244). In this case, the operators took these weak signals very seriously, perhaps because of the absence of any more familiar, certain, or scientific data; some information at that point may have seemed more important to them than none.

Where the operators had received mixed and weak signals from unit 1 – the water indicator that worked temporarily (March 11$^{th}$ 16:42), the illumination of the IC vent indicator lamp (March 11$^{th}$ 18:18) and the strange question of the steam – they had gotten almost no information from unit 2. Interestingly, this complete lack of information – positive or negative – seemed to worry at least the ERC more than the mixed, weak, but overall negative signals related to the IC.

It does seem that preconceptions about the IC as a robust emergency water injection system that did not require electricity to function (semi-passive system), as well as a more generalized confidence in the technology they were working with, affected the cognitive balance of assumptions on what was working and what was not. Vaughan (1996) defines a culture as "*a set of solutions produced by a group of people to meet specific problems posed by the situations that they face in common*" which then "*become institutionalized, remembered, and passed on as the rules, rituals, and values of the group*." The IC was a theoretical solution to a problem – loss of cooling function – that had long been seen as equally theoretical. It was also (at least potentially) an *existing* solution, a mechanism that did not need to be constructed or cobbled together in the midst of the crisis, which must have been appealing to the technical staff of the plant. Vaughan (1996) notes that "*Engineering decisions are biased toward making existing hardware and designs work, as opposed to scrapping it and coming up with a better design.* […] *In the short run, a new design brings new uncertainties, not greater predictability*." For the staff of the ERC, believing in the IC despite evidence to the contrary was easier than coming up with an alternative solution (March 11th around 18:00).

In addition, the team from the ERC had been working hard to restore the indicators, had in fact made it a priority. There was a commitment to that strategy, and as Weick (1988) writes, "*The dark side of commitment is that it produces blind spots. Once a person becomes committed to an action, and then builds an explanation that justifies that action, the explanation tends to persist and become transformed into an assumption that is taken for granted.*" Weick in fact uses exactly the opposite situation as an example of this process: "*When people make a public commitment that an operating gauge is inoperative, the last thing they will consider during a crisis is that the gauge is operating*." In this case, there had been a commitment, if not that the gauge was operating, then at least that making it operational was a valuable if not essential first step to resolving the problem. With significant effort spent on that, at an opportunity cost of other possible initiatives for the limited workers and time available, discounting the information it brought them would not have been easy.

The explosion in the unit 1 reactor building (March 11th at 15:36) was in many ways a turning point in the response. Although not completely catastrophic, because the containment building remained intact, it was dramatic and utterly unexpected. If the tsunami had opened up an unforeseen realm of beyond design basis problems, the explosion was perhaps more frightening, in that it suggested that the progression of the accident itself was not well understood.

From the moment the tsunami knocked out power to their control room, the operators were plunged into a situation of extreme, almost complete uncertainty. They did not know at first what had caused the loss of power, and when they did learn it was almost unbelievable, the kind of event that Weick (1995) describes as testing sense-making to the extreme: "*an event whose occurrence is so implausible that they hesitate to report it for fear they will not be believed*." That was, however, just the beginning of the uncertainty; from that point the operators had to work in a way that they themselves perceived as disabled and deprived of their senses. Indicators and remote controls were so much a part of their working culture that without them they felt as though they had lost a part of themselves. (It is worth noting, too, that the most obvious risk to the operators – radiation – was imperceptible except via gauges and dosimeters, further reinforcing their reliance on technological senses rather than their own). The tools and signals that the operators normally used for making sense of the status of the reactor were gone; not only did they have an unprecedented situation to try to understand, but they had to develop new ways of doing so.

This disruption of normal sense-making processes naturally had an impact on the way the shift team processed information and made decisions. From their mindset, it was easy to trust the signals they had always relied on, even when those signals should have been put in doubt by the circumstances (as with the optimistic result of the water level gauge which was almost certainly false), and harder to believe in other types of information. Vaughan (1996) traces a similar dynamic among the engineers at NASA, for whom "*the methods of positivistic science, emphasis on quantitative analysis, and multiple tests with data covering every known condition were the means by which uncertainty was converted to certainty.*" This data-based culture made it difficult for the engineers, and their supervisors, to perceive, understand, or accept other types of signals: "*The original technical culture mandated that engineering recommendations be backed by 'solid technical arguments.' The subjective, the intuitive, the concern not affirmed by data analysis were not grounds for formal action at Marshall [Space Flight Center].*"

The operators demonstrated a more successful method for coping with uncertainty in their insistence on maintaining and even strengthening the social structures within their small working group by continually supporting Izawa's leadership and creating new rules to move on the field. This is all the more remarkable for the fact that the leader of the group was a substitute on that day, and therefore there had not been any opportunity for team-building with that specific shift team-shift leader combination. Not only was Izawa's authority accepted, but when the normal leader for that shift, Hirano, joined the team, just after the earthquake there were no power struggles between them, and there seem to have been no divisions in the group's allegiance. Both the leader and other senior members of the team reinforced the social dynamics by asserting the authority of the leader and insisting that he stays in the control room while others took on field tasks. The fact that the team, in an extremely stressful and dangerous situation over a significant period of time with very little fracturing[52] supports Weick's (1993) hypothesis that resilience can be fostered by "*creat[ing] an inverse relation between meaning and structure (less meaning, more structure, and vice versa). […] When meaning becomes problematic and decreases, this is a signal for people to pay more attention to their formal and informal social ties and to reaffirm and/or reconstruct them*." The next research question, then, is why the group was so successful at this? Can we identify criteria to help determine ahead of time whether groups are likely to be able to maintain cohesion in the face of loss of meaning? Can we build this capacity?

## 4.2 DRASTIC CHOICES

The concept of emergency management *procedures* implies that the emergency can be handled by simply following procedures. It suggests that unplanned choices and decisions will not be necessary, because all the steps are already laid out in the manual, and if decisions do have to be made they will be technical ones which can be based on benchmarks or indicators, not emotional or ethical choices. This approach seemed valid during the period of time between the earthquake and the tsunami. Once the tsunami hit, however, the situation changed completely. The tsunami was not only beyond design basis, it was beyond any predictions. The accident management manual no longer could be directly followed. In this drastic situation the operators, managers, and politicians found themselves facing drastic, often moral choices. Their actions suggest both the underlying belief systems that they used to take such choices, and the questions that should be considered as part of emergency preparedness to reduce delays, stress, and errors during an accident.

[52] After the explosion in unit 1, some younger operators did ask what they were accomplishing by being in the control room, and Izawa let them evacuate to the ERC, but the core structure remained intact for the four days studied here.

### *4.2.1 CHOOSING THE "SUICIDE SQUAD"*

There were two situations during the first twenty-four hours of the crisis in which the operators in the units 1 and 2 main control room had to decide who will perform these potentially dangerous missions. Perhaps it had not occurred to anyone that the operators would be called upon to perform potentially life-threatening work, or that they would have to decide amongst themselves who would take on the most risk, but in any case there were no guidelines for figuring this out. According to Kadota, even when the operators had long realized that venting would be necessary and would require a trip to the highly radioactive reactor building, "*being ordered to 'pick people' was a strange thing for Izawa*" (Kadota, p. 122).

In the first situation (March 11$^{th}$ in the evening), however, it was not an order to pick people, just a necessity. The operators had to configure the line that would transport water between the D/DFP – and, eventually, the fire engines – and the core. Normally this would be a simple matter of flicking switches on the control panel. Without electricity, however, it would be necessary to open and close valves by hand, in the reactor building and choose who would go.

Because doses reaches nearly 100 millisieverts, the shift supervisor on duty, Izawa, was reluctant to send others and offered to go himself, but he was quickly dissuaded by his colleagues, who insisted on the need for consistent leadership in the MCR,[53] an example of an insistence on strengthening the social order in the face of continuing technological and contextual chaos. There was also a reluctance to let younger operators take the risk of radiation exposure.[54] Five operators, all of them senior, of which two had not originally been assigned to control room duty that day, left for the reactor building.

The second case, in which Izawa was ordered to pick teams, was the venting of the reactor (March 12$^{th}$ at 00:00). This order was in fact one of the first examples of a clear command from the ERC to the operators: "*Decide on the team to carry out the venting*" (Kadota, p. 122).

The decision-making process on whom to send for the venting operation was initially quite similar to the pattern of deciding whom to send for the configuration of the water line. The shift supervisor first excluded younger operators from the operation, and then, when no one immediately volunteered, said he would go himself. At that point some of the more senior operators began to offer to go, while at the same time insisting that the shift supervisor needed to stay.[55]

The process then became slightly more elaborate, given the more difficult and dangerous nature of this task. According to Kadota's interviews, the names of the senior and more experienced operators were written on the white board in order of age (p. 127). They then began to decide on teams of pairs to do the required tasks. According to Yoshida "*People who said I know that place well, or in the case of a place physically harder to get to slightly younger people, that's how we arranged it. There were only two places so really we only needed two pairs, but in case we needed a rescue team, or if something came up in the field, we decided on a third pair to go after*" (Kadota, p. 127). Four shift supervisors (not including the one on duty) and two deputy shift supervisors were chosen for the three teams.

In both cases the means of coming to decisions, as well as the results, are important; they influenced not only the immediate outcome of the tasks at hand, but also the cohesion of the group

[53] Kadota, p. 77

[54] Kadota, p. 79

[55] Kadota, pp. 124-125

over time. Weick (1993) writes that in order for an organization to be resilient, "*When meaning becomes problematic and decreases, this is a signal for people to pay more attention to their formal and informal social ties and to reaffirm and/or reconstruct them*." At the time of these events, meaning was extremely problematic. Here is evidence of some fragmenting of the group in the face of this stress; at some point, some of the younger operators asked "*Why should we stay here if we can't control anything or do anything?*"[56] However, the decision-making processes for the difficult decisions of whom to send into danger tended rather to reinforce values and social structures.

They had to think about the good of the whole rather than of the individual. This is further reinforced by the creation of an "extra" third team for the venting; it is a promise that the group would (at least attempt to) rescue anyone who could not return on their own.

The interactions also solidified the role of the team leader via a collaborative process. On the one hand, the team leader showed his solidarity with the group and his willingness to take risks by offering to go on the risky missions. Of course, all of this deliberation and decision-making took time and, presumably, incurred some stress on the individuals and the group. Having guidelines ahead of time would have reduced both.

### *4.2.2 NEGOTIATIONS WITH RADIOLOGICAL RISK*

Missions to the field were not the only times the operators faced danger. As the crisis continued and radiation levels increased throughout the plant, they also climbed within the main control room where the workers were stationed. With their monitoring equipment, the workers were well aware of the danger, but rather than leaving the control room or even taking turns to be stationed there, they made incremental adjustments to their working habits: sitting or crouching on the floor, moving over to the side of the room with the least radiation. Because the situation demanded it, they found ways to reduce their exposure minimally and keep working. Similarly, workers in the field, whether maintaining the fire engines for water injection or laying cable in an attempt to restore electricity, found ways to negotiate their exposure to risk, mainly by taking turn and limiting their time in the field, finding gray areas in safety regulations or changing them altogether.

This tension between worker safety and the "need" to complete urgent tasks is a recurrent theme throughout the crisis. In a sense, it is a false dichotomy: if the workers failed to bring the reactors under control, they would almost certainly be the first to suffer the consequences. Similarly, the safety of the surrounding populations was not in opposition to the worker's concerns: most of the workers, particularly among the operators who were exposed to the greatest risks, lived with their families in the towns around the plant. On several occasions, workers interviewed by Kadota recalled that when confronted by danger, they thought about their homes, their families, and the physical landscape of their hometowns. For the shift leader, "'*when thinking that we will have to vent now, my own family, the place where I live, lots of images came to my mind*" (Kadota, p.123).

Despite having their own interest in avoiding meltdown at any cost, however, it is clear that there was still a negotiation between the risks workers were willing to take and the gains expected from them. When operators attempting to manually open valves to vent reactor 1 found that the radiation levels significantly exceeded what they had expected, they returned to the MCR without completing their mission (09:24 on march 11$^{th}$). The two were evacuated soon after, having passed the legal exposure limit. On the other hand, hours later when the radiation level could be expected

[56] Tepco interim report appendix: voices of operators in the field, p. Appendix-1 (English), p. 40 (Japanese)

to be higher, the operators were ready to launch another mission, thinking it would be the only opportunity to complete the venting.

While the legal limit for radiation exposure was a guideline for making these decisions, it was disassociated from the urgency of the task and, more importantly, impossible to calculate in real time: neither of the teams, because of the protective equipment, was able to check their personal cumulative dosimeters until they had returned to the MCR.

In addition, few on-site monitoring systems remained following the tsunami. Most electronic personal dosimeters, computer systems for activating and recording dose from these devices, and many portable survey instruments were lost in the flooding. Installed radiation monitors, essential for monitoring core, containment, and spent fuel pool conditions, were also lost when the tsunami flooded the electrical distribution equipment [I29]. It was not possible to gather information on access to controlled areas or on personal dose data. The loss of individual monitoring capabilities resulted in the need for emergency responders to share electronic personal dosimeters, with only one worker in a team wearing a dosimeter for many missions, and workers having to log their individual doses manually[57].

The major factor potentially affecting the reliability of the monitoring performed was the use of shared personal dosimeters between March 12$^{th}$ and April 1$^{st}$ 2011. According to TEPCO [I6], the management system for individual dosimetry became inoperable immediately following the tsunami and associated damage, and it was not possible to gather access control information for “Radiation Controlled Areas” or personal dose data. Given the short supply of dosimeters during March 2011, , some reservations remained about the reliability of the external dosimetry performed before 1 April 2011[58].

Numbers of occupationally exposed FDNPS workers with cumulative effective doses for the period from March 2011 to 31 October 2012 in each dose band

| March 2011 Effective dose (mSv) | <10 | 10 - <20 | 20 - <50 | 50 - <100 | 100 - <150 | 150 - <200 | 200 - <250 | >250 | Total | Maximum | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEPCO | 346 | 530 | 539 | 195 | 63 | 15 | 0 | 6 | 1 694 | 670.36 | 31.2 |
| Contractor | 1337 | 461 | 361 | 99 | 17 | 2 | 2 | 0 | 279 | 238.42 | 14.03 |

Source: UNSCAR report 2013

The existing guidelines for worker safety quickly became irrelevant, meaning that negotiations over what made sense in the new context had to happen during the response. The dose limit for workers applicable to an emergency was set at 100 mSv when the Fukushima nuclear disaster began. Following coordination with the Nuclear and Industrial Safety Agency, however, the government raised that limit at a stretch to 250 mSv at 2:03 p.m. on March 14$^{th}$; three days after the crisis broke out. For Yoshida, “*the government’s ceiling made it possible, in institutional terms, for workers*

[57] United Nations Scientific Committee on the effects of Atomic Radiation (2014). UNSCAR 2013 Report. *Sources, Effects and Risks of Ionizing Radiation, New York*.- Annex A, p. 65
[58] UNSCEAR, op. cit., p. 228.

*nearing their dose limits to stay on the front lines a while longer. But the step did not make human bodies more resistant to radiation*"[59].

There is no objective way to determine the "correct" balance between worker safety and managing the crisis, there is also no objective way of predetermining the level of risk faced by the operators in these situations. As Vaughan (1996) writes about NASA's programs leading up to the Challenger disaster, "*work groups were calculating risk under circumstances that made risk fundamentally incalculable*." Radiation adds its own layer of uncertainty, since there is relatively little data about the effects of moderate amounts of radiation. The government legal limit was necessarily somewhat arbitrary; for a given operator in a given situation it could have proven too low or too high.

The mistimed evacuation of workers around unit 3 was another example of the difficulty to manage the safety of others. On the morning of March 14th the pressure was rising in the drywell of reactor 3, and the site superintendent became increasingly concerned about the possibility of a hydrogen explosion. Between 6:30 and 6:45 Yoshida ordered the many workers involved in water injection and power restoration around unit 3 to evacuate to the seismic-resistant building. However, the explosion did not immediately occur, the drywell pressure stabilized, although it remained high, and the work on-site was extremely urgent. Other than subjective judgment, there was no way to reconcile the principles of worker safety and managing an imminent and worsening but extremely uncertain threat. Pulling the workers out too early, when there was no imminent explosion, increased their risks later. At 7:30 the Site Superintendent rescinded the evacuation order, and the work continued.

Three and a half hours later, at 11:01, the expected hydrogen explosion rocked the unit 3 reactor building. Unlike when it had occurred at unit 1 two days before, at this point it was expected and almost immediately identified; the ERC staff reported to Tokyo HQ over the video conference that it felt like the shock of the explosion at unit 1, not like an earthquake.[60] Once again, the first order was to confirm staff safety. Kadota describes Yoshida's feelings of guilt over the explosion, and his initial conviction that this time there must have been fatal casualties.[61] The first number of 40 unaccounted for seemed too high for all of them to be found alive. Each of the functional groups worked to check on its unaccounted for staff, and then numbers were compiled together. As workers made their way back from the field, the number of unaccounted for dropped slowly, finally reaching zero, although four TEPCO workers and three Nanmei staff were injured, along with four members of the Japan self-defense forces who had arrived with water trucks.

### *4.2.3 RADIOLOGICAL RISKS AND SUB-CONTRACTORS*

These decisions were, of course, even more fraught when they involved sub-contractors. Early on March 12th, members of the sub-contractor Nanmei, who were the only ones able to operate the fire engine, were asked to use that fire engine to inject water into reactor 1 via a discharge port. According to ICANPS, "*Though the request was obviously beyond the scope of the services TEPCO entrusted the company with and meant that the Nanmei employees would undertake a dangerous task amid high levels of radiation, the head of the company's local office accepted because of the urgency*" (ICANPS Interim, p. 154). The dynamics of worker safety here have shifted somewhat. The expectations of exposure seem to be lower than for TEPCO employees; there does not seem to have been any discussion

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[59] Kubota, Chapter 3

[60] TEPCO video conferences

[61] Kadota, pp. 238-240

of whether the tasks requested of the recovery team or the shift operators are outside the scope of their job descriptions. In addition, the dialogue here is between TEPCO and "*the head of the company's local office*"; there is no record of the internal discussions, if any, with the Nanmei employees who were bearing the risk. TEPCO was not completely unrepresented in the mission; one member of the operations team joined the Nanmei employees.

However, a few hours later, after the port had been located and the first truckload of water had been pumped in, the cooperative process between TEPCO and the sub-contractor Nanmei hit another blockage. Throughout the night the radiations levels had been steadily rising, and at 4:20, with high levels noted in the area where they were working, the Nanmei workers returned to the seismic-resistant building where the EOC was located. There, "*The head of the Nanmei local office showed signs of disapproval towards any further involvement in injecting water because it meant that he would be ordering his people to engage in a risky task amid high levels of radiation, which was not covered by their contract with TEPCO*" (ICANPS Interim p. 155). Here, TEPCO had very little option. They could not renegotiate the contract on the spot; nor were they able to bring in new, qualified people immediately. They eventually worked out a compromise: one Nanmei staff would accompany the TEPCO firefighting team to operate the fire engine and assist. This negotiation delayed the extremely urgent injection of water into reactor 1.

## 4.3 CHALLENGES FOR THE EMERGENCY STRUCTURES

### *4.3.1 THE ESTABLISHMENT OF EPHEMERAL ORGANIZATIONS*

TEPCO as well as, more specifically, the Fukushima Dai-ichi nuclear power plant, had explicit plans in place for managing disasters, including emergency structures to be established from the moment an accident struck.

Disaster management was therefore explicitly distinguished from "normal" management; although the actors were the same, they held different titles and there were different organizational structures, responsibilities, and even locations of deployment which applied to the special circumstances of a crisis (this parallels the disaster management approach of the Japanese government, as can be seen in section 5). This draws a clear division between normal operations and crisis management; the crisis is not merely an additional task in the list of many for the president of a large company; rather, it is the primary task for the head of the emergency response center. Although the president might have other concerns while he is wearing both hats, this separation of positions makes the distinctiveness of the crisis management, and its importance explicit. The temporary organizational structure, even if the actual lines have not changed much, also signals that this is a changed environment, in which power structures may also be, temporarily, shifted.

Although with the important difference that these structures were planned, often in some detail, before the crisis hit, they can be compared with Lanzara's (1983) ephemeral organizations. In an ephemeral organization the structures put in place by the firm after an accident "*do not assume their own survival or permanence as a requirement for identity and effectiveness of performance*"; once the crisis is over, no one expects the temporary structures or positions to remain in place or to have any effect on the non-crisis, once-and-future organizational structure. Lanzara describes the ephemeral organization in opposition to large formal organizations which, "*programmed and structured to be routine problem-solvers for the everyday ongoing activities, they have a hard time in changing or adapting their normal way of doing or seeing things.*"

The temporary structure also emphasized a significant shift in the hierarchy. Just as it is the operators closest to the reactors who (theoretically) are expected to take the primary role for managing the crisis within the plant, in the context of the broader organization it is the power plant that takes on the accident management. For the most part, it is the site superintendent, in his role as head of the ERC, who is authorized to make decisions related to the management of the accident at the plant site; according to ICANPS "*TEPCO's action plan stipulates that if a nuclear emergency arises at the Fukushima Dai-ichi NPS, decisions regarding individual and specific responses are entrusted to that NPS's site superintendent in his/her capacity as nuclear emergency preparedness manager. The emergency response center at the headquarters is, when required, to provide guidance and advice to the NPS, receives and acts upon requests from the NPS, works with other NPS in procuring materials and equipment, and provides other required support*" (ICANPS Interim, p. 66). Similarly, the NAIIC report states: "*According to accident management rules, the decision-maker on venting, for example, is the site superintendent of a nuclear power plant; and in practice, such decisions are to be made through consultations between the nuclear power plant and the head office […] the primary decision-making authority rested with the site superintendent of the nuclear power plant*" (NAIIC, Chapter 3 pp. 5 and 7).

Beyond this question of decision-making authority, the plant also had a full emergency organizational structure designed to support the efforts to manage the crisis. As more fully explored above, in the chronology of Fukushima accident, the primary responsibility for the operation each reactor rested on the team of operators on duty at the time of the accident, and specifically the shift supervisor. However, there was also emergency structure to facilitate the rest of the employees and sub-contractors on site in providing assistance to the operators. This structure aimed to ensure communication between the operators and the site superintendent, as well as between the site superintendent and the larger TEPCO organization.

The structure at the plant level was primarily divided into teams. According to the ICANPS, "*The accident management (AM) procedure states that, as the NPS ERC' support network, the information, engineering, health physics, recovery and operation teams were supposed to provide advice and direction to the shift supervisor and conduct technical assessments and implement other necessary actions*" (ICANPS p. 142). Each of these teams had a leader, who was seated at a main table along with the site superintendent, the chief engineer, the unit superintendent, and the deputy director; team staff members were then clustered behind their team leaders, for communication streams that ran from staff members to their leaders to the site superintendent or vice versa. The superintendent could assign tasks to specific teams, which would then work more or less independently to complete them. Some of the teams, particularly the operations team, were also directly in contact with the shift teams in the main control rooms (MCR).

The pre-specification of these teams diverges from the idea of ephemeral organizations, which Lanzara sees as "*very close […] to what I should call the zero-degree of organizational phenomena*", in which "*The primacy of activities over established organizational shapes must be emphasized.*" However, within the teams themselves, as they face the conditions Lanzara describes as conducive to the emergence of ephemeral organizations ("*practically every act or decision lacks a precedent […] the range of intelligence is very restricted*"), we can see them begin to shift, becoming less like formal organizations in which "*rules and procedures define the activities*" and more like "*emergent ephemeral organizations [in which] activities tend to generate rules and procedures.*" For a vaguely named group like the recovery team, what they did was defined by what needed to be done; this is particularly clear as the team was often split into several groups, each working on different tasks and in different ways, as they developed ways of managing previously unimagined actions.

Erikson-Zetterquist (2009) compares Lanzara's ephemeral organizations to action nets, in which it is actions, rather than actors, that drive organizations. Czarniawska (2009) draws on this concept to suggest ways to look at improvisation in organizational crisis response as action-driven. Like many others, she compares improvisation in organizations to jazz, in which the balance between structure and breaking the structure is key: "*Organizational plans and structures psychologically increase the feeling of security, but what is needed in threatening situations is the ability to act in conditions of insecurity*." In terms of practice, the establishment of this ERC had been practiced as recently as one week previously during an earthquake drill; team members reported promptly to the designated room on the second floor of the seismic-resistant building and were aware of their roles.

### *4.3.2 CENTRALIZED VERSUS DECENTRALIZED MANAGEMENT OF THE CRISIS*

Improvisation within the groups was not enough, however. The crisis required coordination among these different actors within the power plant. Beyond that, since not all of the materials necessary to stabilize the crisis were available on or near the plant, it also required coordination with the broader organization. Once again, we are confronted with Perrow's contradiction, written somewhat larger. In his seminal *Normal Accidents*, Perrow (1999) articulates the advantages and disadvantages of offering autonomy in crisis management of complex, tightly coupled systems like nuclear power plants: "High-risk systems have a double penalty; because normal accidents stem from the mysterious interaction of failures, those closest to the system, the operators, have been able to take independent and sometimes quite creative action. But because these systems are so tightly coupled, control of operators must be centralized because there is little time to check everything out and be aware of what another part of the system is doing. An operator can't just do her own thing: tight coupling means tightly prescribed steps and invariant sequences that cannot be changed. But systems cannot be both decentralized and centralized at the same time."

Fukushima Dai-chi accident both reflects and to some extent challenges this theory. The plant's emergency management plans encourage autonomous action by those closest to the disaster at every level: within the MCR, the operators; within the plant, the ERC; within the nuclear organization, the utility. The situation is slightly different at the different levels; the system is complex and interactive throughout, but the coupling is tightest at the lowest level, within the plant, where conditions at one reactor can quickly affect the others, and lessens successively from there. This should make decentralization stronger at the higher levels. Besides the looser coupling, the distance between workers at a nuclear power plant and executives at a wide-ranging electric utility seems more demonstrative of Weick's (1988) observation that "T*he person in authority is not necessarily the most competent person to deal with a crisis*" than the relationship between operators and the site superintendent within the plant.

At the level of the plant, the tight coupling among the reactors, particularly in view of the common-mode failure which meant similar and limited resources were required by all of them, suggests the need for some centralized tracking of and authority over the response. At the same time, the multiplicity of complicated and unprecedented tasks (identifying and addressing the power failure; determining how to manually perform procedures; clearing roads; sourcing water; etc.) required a decentralized approach that would allow teams to respond quickly and creatively.

The larger organization was less tightly coupled; a catastrophe at the plant would certainly have consequences for TEPCO, but the numerous intermediary events had little or no effect on, for example, another of TEPCO's power plants or its organizational structure. The complexity of the system remains; we would therefore expect, under Perrow's analysis, a fairly decentralized hierarchy to work well, although still with some degree of contradictory impulse towards centralization (the system was not completely uncoupled, and certain parts of it, like the Dai-ni plant or the off-site center, were tightly coupled with the Dai-ichi plant). As mentioned above, TEPCO's emergency organizational structure reflected this: the plant was supposed to have primary authority for managing the crisis, with the larger firm in a supporting role: providing logistical assistance and procuring resources, as well as serving as a liaison with the government authorities. Once again we shall see how this did not always function in practice according to plan.

The plant ERC was directly linked to the headquarters ERC via a teleconference system, as well as to three other sites: two other TEPCO power plants, Fukushima Dai-ni and Kashiwazaki-Kariwa; and the off-site center which was also supposed to be established immediately after an emergency. Located five kilometers away from Fukushima Dai-ichi, the off-site center was intended to provide facilities for crisis management near to but outside of the plant, and included representatives from TEPCO as well as from national, prefectural, and local governments (for more information on the role of the off-site center in the government's response plan, see section 5).

The teleconference line was, at least in theory, continuously open between all five sites (there was also a Safety Parameter Display System (SPDS) to provide real-time monitoring of reactor parameters, but it was rendered inoperable by the tsunami). Allowing for the difficulties of communicating across somewhat chaotic environments and the possibility of people stepping out of range of the microphones or cameras, there therefore should have been almost complete transparency of information between the plant ERC and the headquarter ERC.

The crisis response was coordinated on multiple levels. Within the plant, there were numerous groups – the operators in the MCR, off-duty operators, the functional teams in the ERC, sub-contractors – each of which with different capacities and limitations. However, the plant also could not weather this crisis in isolation. Coordination was required across the broader TEPCO organization to mobilize the resources and particularly know-how available at the headquarters and at other power plants. There were also some resources available outside of the organization, most notably the Japan Self-Defense Forces (SDF) but also, in theory at least, from the regulatory organization Nuclear and Industrial Safety Agency (NISA), the Cabinet level Nuclear Safety Committee (NSC), and the rest of the government.

### *4.3.3 CROSS-FUNCTIONAL WORK*

Faced with the unexplained loss of electricity Yoshida first tasked two of his ERC teams to deal with it: the electricity team to assess the damages and prescribe a solution, and the restoration team to work specifically on getting indicators back on line. The site superintendent then used the other tool available to him: requesting resources through the larger organizational network. He requested that the Tokyo HQ find power supply vehicles to send to the plant. The HQ responded by opening that request to all the other plants at 16:10 on the 11$^{th}$ of March, less than an hour after the power outage. The other sites were not slow in responding; by 16:50 some vehicles were headed for the stricken plant, although the damaged roads meant it would take them far longer than projected to arrive.[62] The larger organization appropriately played its support role, and did so with a speed that seems to indicate a good grasp of the urgency there as well; what they had not yet grasped was the extent of the damage outside the plant, and how problematic that would make their recovery efforts.

Finding that batteries to power the indicator lamps were not available on site, the recovery team was able to find four 6-volt batteries from sub-contractors and two 12-volt batteries from buses. This realization reflects a kind of improvised solution, comparable in some ways to Lanzara's (1983) example of an ephemeral coffee-making organization which demonstrates "*ability to associate two differing contexts which on the surface shared very little similarity […] The creative capability […] does not consist in inventing a new activity, but in discovering that the same activity could be carried out in two contexts which otherwise are not commonly associated*." A secondary power source for a bus, normally invisible, could become a power source for the instruments of a nuclear power plant. However, the process of improvisation here was complicated and lengthened, firstly by the assumption, which it took time to disprove, that the needed materials would be stocked somewhere on site. Secondly, once the recovery team took the batteries to the units 1 and 2 MCR around 20:00, their use was delayed by the extreme complexity and lengthy process of figuring out how to connect them to the correct indicator gauges. The plant workers were not merely shifting "*a private daily life activity into the domain of social services*" as Lanzara's coffee-maker did; they were attempting to reconstitute a highly technical, specialized construction.

However, these teams did less well at improvising with solutions that fell between the cracks of their organization. Yoshida ordered them to start exploring options for alternative water injection, both those that "*were defined as accident measures and other methods that would be available if the power sources were restored*" (ICANPS Interim, p. 145). Another possibility not defined in the accident measures was the idea of using fire engines as a pumping mechanism for injecting water, which the superintendent considered an important option since "*based on his memory of indoor pipes soundness in the buildings at the Kashiwazaki-Kariwa NPS after the Chuetsu-oki Earthquake*," he "*thought it likely that the outdoor pipes laid from the filtered water tank to the T/B might have been damaged due to the strong earthquake,*" but "*assumed that the indoor pipes would not be damaged in the earthquake*" (ICANPS Interim, p. 145).

However, researching the possibility of using fire engines proved challenging for the teams assigned to the task. According to ICANPS, this was at least in part due to the fact that "*Since the use of fire engines to inject water from the fire cisterns through the FP system line to the nuclear reactor was not defined as an AM measure, the respective roles and responsibilities of the function teams were not clear*" (ICANPS Interim, pp. 145-146). In other words, while dividing the personnel into function teams was useful when tasks clearly fell into the defined functions, when new challenges did not fit easily into the work that the teams expected to do, it would have made it more difficult to assign roles and move forward. This suggests some limits to the strategy of a planned, structured version of an ephemeral organization, or to the idea of practiced improvisation. While some types of improvisation may have been facilitated – the individual teams certainly seem to have had a great deal of flexibility in how they accomplished the broad tasks assigned to them – the existence of the structure did hamper creativity in tasks that crossed structural boundaries.

[62] The Tokyo headquarters also did not hesitate to look for resources outside their organizational network; by 17:50 they were asking about the Japanese military transporting power vehicles by helicopters, although that proved impossible, and by 18:20 they were requesting that another power company, Tohoku Electric, send vehicles, which was more successful. See ICANPS Interim p. 186-187.

### *4.3.4 COORDINATION AMONG TEAMS*

#### 4.3.4.1 Internal coordination

While these efforts to prepare for auxiliary assistance were going on, the organization of the power plant within the ERC was also being mobilized to support the core of the accident management effort: the operators in the MCR. The engineering team was performing calculations based on what data were available, such as, for example, calculating the time until the reactor water level would reach the top of the fuel. These calculations were, however, largely hypothetical: no one knew whether the emergency coolant systems, the IC for unit 1 and the RCIC for unit 2, were functioning completely, partially, or not at all. Moreover, while the estimates were provided to the authorities, they gave the operators very little besides additional urgency.

The ERC operations team, on the other hand, was responsible for being in contact with the operators in the control rooms and providing them technical support as needed. While the operators had the authority to make their own decisions, the ERC operations team offered them the possibility of additional consultation and greater linkages to the resources of the rest of the organization. However, this support also proved more difficult to provide than expected due to the conditions of the emergency. Instead of having constant, multi-channel communications and real-time access to reactor parameters, the operations team was linked to the MCRs by a single (per MCR) dedicated hotline phone, hung up when not in use, and all their knowledge of the conditions of the reactors came from the operators in the MCR themselves, via that single channel.

This apparently led to some communication backlogs and gaps. In particular, despite the calculation that the engineering department had made at 17:15 on the 11th of March suggesting the water level would reach the top of the fuel within an hour, and the reports of increasing radiation within reactor building 1, the ERC did not seem to have the same level of doubt about the IC's continued functioning as the operators within the MCR. It is not clear why this was the case. According to the ICANPS, "*Faced with such an unimaginable situation and confused in the midst of a flood of information on the plant status of Units 1 to 6, however, neither the NPS nor the Tokyo Headquarters had the mindset to presume the operation status of the IC from the information on the falling reactor water level of Unit 1*" (ICANPS Interim, p. 118). There were also mixed signals coming from the MCR. At 18:18 on the 11th of March, the ERC operations team was informed when the IC valve indicator lights came on and the shift team attempted to open the valves, leading the ERC, and by extension via teleconference the Tokyo HQ, to believe that the IC was working. However, the ERC did not seem to have been informed about the subsequent closing of the valves, only seven minutes later at 18:25. According to ICANPS, no description was found in the handwritten memos of the ERC operations team about closing the return line isolation valve (MO-3A) at approximately 18:25 that day. In addition, none of the operations team members, including those who received reports on Unit 1, wrote the memos or belonged to the NPS or Tokyo Headquarters, testified that they recognized that the return line isolation valve (MO-3A) was closed at that time. Instead, members of the NPS and Tokyo Headquarters including Site Superintendent Yoshida said that they thought the IC was in operation at that time. (ICANPS Interim, pp. 134-135)

This gap in communications did not stop both the MCR shift team and the teams in the ERC from exploring alternative means of water injection, since even on the assumption that the IC was functioning it would not be expected to work indefinitely. However, the ERC's delay in grasping how unlikely it was that the IC was functioning did have an impact on the crisis management. Although the operators were able to set up an alternative means of water injection, via the diesel-driven fuel pump (D/DFP) for unit 1, by around 20:50 on the 11th of March, the pressure in the reactor was by that time far higher than the discharge pressure of the pump. The only way for water to reach the reactor would be to depressurize the reactor using the safety relief valve (SRV). Without electrical power to the controls in the MCR, a 120-volt battery (or generator) was required to open the SRV.

While the ICANPS places the responsibility on the operators for this communication gap, writing that "*We therefore think that the shift team did not provide the NPS ERC with a report that was effective in making the staff at the headquarters fully recognize the necessity of procuring and connecting batteries to monitor the operation of the IC and operate the SRV*" (ICANPS Interim, p. 134), it is likely that the single, intermittent communication channel affected the process of interaction and support between these two critical parts of the organization. If the ERC had had clearer situational awareness, they were in a position to catch issues that might slip through the cracks of the smaller, more isolated team in the MCR, just as a continuously open communications link might have allowed the operators to provide more complete information to the ERC, even under stressful circumstances. In the absence of better means communication, a more organized understanding of what was required on a step-by-step basis in the emergency response, or protocols that supported systematic check-ins between the MCR and the ERC might have helped to identify the problem more quickly.

The research into the venting procedure involved more than just pulling books off a nearby shelf: "*To confirm whether an S/C vent valve (air-operated (AO) valve) were of the structure that could be operated by hand, they went to the administration building even though the aftershocks were continuing. In the building to which entry had been prohibited due the impact of the earthquake, they looked for and obtained the drawings necessary for the confirmation*" (ICANPS Interim, p. 165). However, there is some evidence that these investigations were being carried out in parallel to the efforts of the shift team in the MCR, which was also trying to identify the correct valves. It is not clear from the reports whether the examination of blueprints and diagrams was overlapping, with resources being simultaneously spent on the same thing, or whether the two efforts were well-coordinated, with the ERC teams supplementing the MCR with data that the operators could not access.

#### 4.3.4.2 Coordination with subcontractors

In the ERC, in order to confirm the venting procedures, the operations team also tried to contact a sub-contractor familiar with the valves, but they could not reach them until the morning of the 12th.[63] Without access to these experts, they used the blueprints. The preferred method of venting passed through the suppression chamber, where some of the radioactive materials could be filtered. But given the high pressure in the core this risked damaging the pipes and the filters, leaving a direct venting from the containment the only viable option.

Another difficulty to progressing with the fire engines was that TEPCO did not have the in-house capacity to operate them. Although there was a TEPCO fire brigade, the engines themselves were driven and operated by a sub-contractor, Nanmei Kosan Co., Ltd (hereafter "Nanmei"). The firm-subcontractor divide made cross-team coordination difficult. According to the ICANPS, "*Nanmei was contracted by TEPCO to conduct onshore accident prevention. It provided services including the operation of the fire engines within the premises of the Fukushima Dai-ichi NPS*" (ICANPS Interim, p. 146). This meant that TEPCO was dependent on their subcontractor for any work to be done with the fire engines, and also for basic information about them: "*From the night of March 11 until dawn of March 12, the NPS ERC gradually learnt of the status of the fire engines as they asked the*

[63] ICANPS, interim, p. 165

*Nanmei and JNSS (Japan Nuclear Security System) personnel who came to seek shelter in the Seismic Isolation Building and gathered information from the NPS ERC recovery team members who had checked the damage to the NPS*" (ICANPS Interim, p. 147). From these sources they eventually understood that only one of the three on-site fire engines was available for use immediately after the tsunami. They do seem to have taken action to request external assistance from the broader organization before they had full information, however; "[*a*]*fter approximately 19:00 on March 11, the local control center asked the Tokyo Headquarters via the teleconference system to send as many fire engines as possible to the Fukushima Dai-ichi NPS*" (ICANPS Interim, p. 148).

The attempts to inject water into reactor 1 using fire engines, which were a series of trial and error that smoothed the way for later injections into the other reactors, show the challenges of collaboration with a sub-contractor. Specifically, this strategy required the assistance of the sub-contractor Nanmei to operate the fire engines and, in particular, to attach them to the discharge port through which they would connect the water flow with the configured water line to the reactor. According to ICANPS, "*Though the request was obviously beyond the scope of the services TEPCO entrusted the company with and meant that the Nanmei employees would undertake a dangerous task amid high levels of radiation, the head of the company's local office accepted because of the urgency*" (ICANPS Interim, p. 154).

However, attempting was not the same as succeeding. The Nanmei employees and a member of the operations team spent roughly an hour, from 2:00 to 3:00 on March 12$^{th}$, looking for the discharge port among the debris and darkness outside the unit 1 turbine building. They even asked for help from a shift team member who happened to come out of the MCR at that time, but they were unable to find it. This can be taken as an indication of just how disorienting and disrupted the environment was in which they were working: unlit, strewn with debris, showing evidence of the enormous force of the wave.

The team went back to the ERC, where they took two approaches to finding the port: identifying someone who was involved in the installation of the firefighting equipment and therefore had direct experience of the location of the port, and reviewing plans and blueprints to get an idea where it was.[64] They were thus using two different strategies to access the information they needed: experiential, and formalized. Although we don't know the details of how the team coordinated these two avenues (or, more precisely, whether it was a coordinated approach or whether it was simply different people trying different things without conferring), it does mirror other simultaneous efforts in the response, such as the shift team sending multiple missions at a time.

The person who knew the location of the port joined the team, and they returned to the site, where they finally found the port hidden behind a shutter frame bent by the tsunami. At that point, they were able to connect the hose and inject the 1,300 liters of water in the fire engine's tank.

#### 4.3.4.3 Coordination between the ERC and other teams within TEPCO

When radiation levels around unit 3 reactor building continued to rise through the afternoon of March 13$^{th}$, once again learning from the example of unit 1, the site superintendent and the ERC teams became concerned about the possibility of a hydrogen explosion in unit 3. The ERC and the Tokyo HQ discussed how they could avoid this, but, according to the NAIIC report, "*They considered a number of ideas, such as dropping something from a helicopter to penetrate the roof of the reactor building, but could not come up with any effective measures*" (NAIIC, Chapter 3, page 12).

[64] ICANPS Interim, p. 154

The NAIIC report further quotes transcripts of the video conference from the ERC to TEPCO headquarters and others experts to show the efforts and frustrations on both sides:

_Head Office:_

> *"We at the head office are also considering how to respond. Though we are racking our brains, it is pretty tough. Sorry about that."*

_Fukushima plant:_

> *"It may sound like a pretty wild idea, but since we cannot do anything about the blowout panel and it is difficult to approach the building from the ground, we could possibly approach the roof from above . . . by helicopter, and drop something to penetrate the roof. Even if there are some spent fuel rods, we have an inventory way beyond comparison with the spent fuel. I think we have a choice to opt for that."*

_Head Office:_

> *"The same idea was voiced here. But we are worried that it may cause a spark and the building may catch fire and explode after all."*

_Executive Vice President Muto at the Off-site Center:_

> *"I share the same concern. People working on the site could face trouble. We have to be very careful about that, though there might be some differences from the situation at Unit 1."*

_TEPCO Fellow Takahashi at the head office:_

> *"We must also consider the evacuation problem."*

_Kashiwazaki-Kariwa plant:_

> *"I personally agree with the helicopter idea, depending on the direction of the wind."*

(NAIIC, Chapter 3, pp. 12-13).

These brainstorming efforts demonstrate that technical discussions were going on not only between the plant ERC and the Headquarters, but also with other knowledgeable personnel like Vice President Muto at the Off-site Center and with the other nuclear plants run by TEPCO, such as Kashiwazaki-Kariwa. They show a willingness to propose what was considered a "pretty wild idea," and to express dissent. However, this was also a situation that no one in the world had any practical experience with, and the uncertain outcomes and high risks also led to a degree of caution.

### *4.3.5 COMMUNICATION FLOWS*

We have seen that the single, non-continuous line of communication between each MCR and the ERC made assessment and coordination difficult and probably contributed to some of the "errors" in the response. At the ERC, the situation was somewhat more complex: in addition to trying to maintain communications with the two active MCRs, the ERC also had its own teams, which had no means of communicating back to the ERC while they were in the field.

On the other hand, the ERC had continuous teleconference channels open not only with the TEPCO headquarters, but with the off-site center and with the other TEPCO power plants. This system allowed not just audio, but video of most of the emergency response center on a continuous basis and across five sites. The staff in the ERC could directly contact staff at other sites or at the off-site center, and vice-versa; the headquarters crisis management staff could listen in on activity in the plant ERC even when there wasn't a specific message addressed to them.

However, open lines of communication do not necessarily lead to good communication. The teleconference videos show long periods of time when the urgent, chaotic activity going on in the ERC fades into background noise, becoming almost invisible. Perhaps the clearest example of how the teleconference system could actually confound communication was that of the seawater injection. Around 19:00 on March 12th, Yoshida was able to use the teleconference system to effectively misdirect the understanding of the headquarters. They believed that they saw everything that was going on when he gave the order to stop the injection; his off-line explanation to the operators to ignore that order was invisible to them.

At the same time, the teleconference system also did not guarantee that people could reach everyone they wanted to reach. There were multiple occasions when one of the parties to the call attempted to speak with someone specific on the other end, only to be told that they were out in the field or otherwise occupied. The most important instance of this occurred during the effort to depressurize unit 2 on the afternoon of March 14th. Yoshida was faced with an extremely technical problem: whether to attempt to depressurize the reactor via the SRV into the suppression chamber, despite the elevated temperature and pressure there which would impede it; or prioritize the PCV vent line which would release the pressure from the suppression chamber. He wanted to consult with his senior at the company, vice-president Muto, but was unable to reach him because he was traveling between the off-site center and the headquarters, and the question was too urgent to wait. Despite all the technology, resources were not always available as needed.

## 4.4 COMPARISON WITH FUKUSHIMA DAI-NI

### *4.4.1 FUKUSHIMA DAI-NI CHRONOLOGY*

Like the personnel at Fukushima Dai-ichi, the staff of Fukushima Dai-ni had conducted an emergency drill not long before the devastating events on March 11th[65]. When the huge earthquake struck at 14:46, everyone knew how they were supposed to react. The administrative staff "was calm and ducked under tables holding helmets on their heads" even believing that "the roof was going to cave in."[66] After the shaking stopped, they gathered in the parking lot (the designated evacuation site) and then the members of the emergency team went to the crisis management center in the earthquake-resistant building. The shift operators stayed at their posts, grabbing bars on the instrument panels designed to help them stay on their feet during serious tremors.[67]

In less than two minutes, at 14:48, it was confirmed in the two main control rooms (one for reactors 1 and 2, the other for reactors 3 and 4) that the four reactors had "scrammed" (the control rods had been completely inserted to stop the nuclear reaction). The shutdown process continued normally until the arrival of the tsunami, with sub-criticality confirmed.

Unlike Dai-ichi, Dai-ni did not lose all external electricity in the earthquake. The power plant was normally served by four lines, two from Iwaido and two from Tomioka. At the time of the disaster,

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65 Rapport de mission Fukushima Dai-ni, Comité d'orientation sur les facteurs sociaux organisationnels et humains, ASN, 2015

66 Rapport de mission Fukushima Dai-ni, Comité d'orientation sur les facteurs sociaux organisationnels et humains, ASN, 2015

67 TEPCO Daini Chronology, p 82

one of the Iwaido lines was out for routine servicing. The earthquake caused a short circuit in one of the Tomioka lines, and damaged a substation rendering the Iwaido line unusable, but the other Tomioka line continued to function. The emergency generators therefore did not start up.

At this time, just as at Fukushima Dai-ichi, it was the shift operators and in particular their shift supervisors who had the responsibility and the authority to manage the situation, based on the Emergency Operating Procedures (EOPs). As the TEPCO report explains, the Shift Supervisor has the authority to determine conditions and operate: "*The conditions and actions in the control rooms were therefore very important to the management of the accident. Nevertheless, this particular crisis shortly required the coordination of external assistance; a task was beyond the parameters of the control room and managed by the plant's emergency response center (ERC). During the accident, the decision-making procedure where the Shift Supervisor made determinations and the ERC at the power station made verifications was generally adhered to.*"[68]

Immediately after the earthquake, the control rooms were plunged into confusion. As at Dai-ichi, many operators that weren't part of the shift team (for example, those who were on the work management team) went to the control room to assist their colleagues.[69] The fire alarm rang continuously, hindering the communication of instructions. The shift supervisor improvised, using a portable microphone to communicate with his team. He also used the paging system to spread the tsunami alert. This alert was sufficient to initiate procedures to prepare for the waves: the evacuation of non-essential workers; watching the ocean front with security cameras; and turning off the less important seawater pumps (because when the sea pulled back before and after the tsunami it could reduce the amount of water available, making it important to reserve it for the most critical functions). [70]

But the alert was not accurate. The first alert, seen by the director of the power plant, Masuda, on television, was for a three-meter tsunami. The nine waves, the first of which reached the plant at 15:22, reached up to 16 meters in height.[71] The waves were observed via the security camera monitors in the control room for reactors 1 and 2, and by workers sent to the ocean side of the plant to watch. The flooding was not as bad as at Dai-ichi.

However, there were significant damages. The circulating water pumps (CWPs), which drew water from the ocean to cool the system, thereby linking to the ultimate heat sink (the ocean) were flooded. Seven of eight heat exchanger buildings and one of the reactor buildings (unit 1) were flooded. The damages in the heat exchanger buildings interrupted the electricity sources for, notably, the systems for removing decay heat from the reactors, the residual heat removal closed (RHR-C) cooling systems and the residual heat removal seawater (RHR-S) systems. Among these systems, only one sub-system of the RHR-S, for unit 3, survived the tsunami. The flooding of the unit 1 reactor building damaged the three emergency generators. The damages to the power center and to the pumps in the heat exchange buildings rendered unusable even the generators that had not been flooded, and all the seawater cooling systems dependent on generators were therefore out of service except the subsystems B and H (high pressure cooling system) of unit 3 and the sub-system H of unit 4. After the tsunami, unit 3 was the only one of the four with core cooling capacity.

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[68] TEPCO Fukushima Nuclear Accident Analysis Report 20 June 2012, p 55

[69] TEPCO Fukushima Nuclear Accident Analysis Report 20 June 2012, p 275

[70] EPRI, p 2-4

[71] Rapport de mission Fukushima Dai-ni, Comité d'orientation sur les facteurs sociaux organisationnels et humains, ASN, 2015

The specifics of the damages would have implications for the different paths the accident management would take for each of the reactors, but this was not at all evident for the operators at the moment. From the control room of reactors 3 and 4, the operators could confirm that the CWP was flooded. The alert lights on the control panel of each unit were off, and the lamps flashed on and off, but unlike at Dai-ichi, some of the instruments and indicators for reactor 1 and all of the instruments and indicators for the other reactors continued to function, making it possible to control the reactors. The shift supervisors positioned their operators and monitored the panels to try to understand the conditions of the plant, especially the equipment that was on the ocean side. The indicators showed immediately that the seawater pumps, which had been working after the earthquake, had all stopped.

The operators worked quickly. Less than a quarter of an hour after the first wave hit, at 15:36, the operators of unit 1 had closed the main steam isolation valve (MSIV) and started the RCIC. From 15:55 they used the safety release valve (SRV) to depressurize the reactor.[72] At unit 2, the MSIV was closed at 15:34 and the RCIC started at 15:43, and depressurization with the SRV started at 15:41.[73] For reactor 4, the MSIV was closed at 15:36, the RCIC was activated at 15:46, and depressurization with the SRV was started at 15:54.[74]

Despite the possibility of managing water level (using the RCIC) and reactor pressure (using the SRV), the situation in these three reactors was nonetheless very serious: all the emergency cooling pumps (RHR, HPCS) were out of commission. The RCIC was only a temporary measure. At 18:33 the superintendent of the plant had announced an event according to Article 10 of the Nuclear Emergency Act, specifically the loss of function for residual heat removal.

In the ERC, which monitored the efforts of the operators, the director Masuda “*reflected a lot in terms of analogy among the four reactors*” and later noted as one of the greatest differences between Dai-ichi and Dai-ni the fact that Dai-ni “*had four identical installations: the same phenomena were therefore observed, which minimized the uncertainty*.”[75]

The exception was reactor 3 where the heat exchange building had not been completely flooded. It was difficult to assess the damage immediately, even if the indicator lights, as well as the observation that the flooding in the heat exchange building of unit 3 had been less than the others, suggested that some power centers and the RHR and HPCS systems could still be in working order. However, the shift team began the cooling, according to EOPs, with the RCIC as opposed to the other systems. With all the indicators working, they could control the water level and pressure to manage cooling. At the same time, unlike the other units, which didn’t have the option, the RHR (B) system was used to cool the suppression chamber (S/C).

The operators for all four reactors continued to manage the level of water via the RCICs. At the same time, they tried to prepare for the inevitable next stage: the eventual stopping of the RCIC, and its effects. The alternative means of water injection indicated in the accident management measures was via the make-up water condensate (MUWC) system of pipes. To use this they had to reconfigure the water line in order to direct the water into the reactors. For units 2, 3, 4, this operation could be carried out from the control room using the valves on the accident management

[72] TEPCO Fukushima Nuclear Accident Analysis Report 20 June 2012, p 275

[73] TEPCO Fukushima Nuclear Accident Analysis Report 20 June 2012, p 282

[74] TEPCO Fukushima Nuclear Accident Analysis Report 20 June 2012, p 291

[75] Rapport de mission Fukushima Dai-ni, Comité d’orientation sur les facteurs sociaux organisationnels et humains, ASN, 2015

panel, but for unit 1, which had lost power to those valves, the operation had to be done manually in the reactor building itself. [76] In every case, the operators confirmed the flow rate from the control room.

Given that the RCIC and even the MUWC were only temporary measures, the emergency response center (ERC), in its role of supporting the control room, especially with external measures, began to look for ways of restoring the other systems. At 20:00, the ERC gave the order to confirm the damage to the facilities, while as always using caution during the continuing tremors and tsunami alerts. In fact, these safety concerns were valid, given the lack of lighting in the plant, the debris and rubble caused by the tsunami, and the communication difficulties (most of the communication line were broken), and the mission was delayed until alert procedures for people in the field (i.e., a messenger system) and safety equipment could be prepared. The operators and members of the restoration team left at 22:00 to assess the damages in the heat exchange buildings and confirmed the needs for restoration, which included cable for the electrical connections and motors for the seawater pumps. With the results, the ERC asked the Kashiwazaki-Kariwa power plant, also run by TEPCO, to help with the sourcing of the motors. The procuring of electrical equipment (cables, electricity generating vehicles) was requested from the Tokyo headquarters.

The operators put in place measures to monitor the effects of using the RCIC without being able to use the RHR. The depressurization of the reactor using the SRV led to a rise in pressure and heat in the primary containment vessel (PCV; or drywell, D/W), and eventually in the S/C as well. The operators started the cooling of the PCV in all the reactors, as necessary: at 17:53 for unit 1; at 19:14 for unit 4; at 20:02 for unit 2; and at 20:12 for unit 3.

The transition from the RCIC to the MUWC system to inject water had also progressed in all the reactors according to their needs and their preparation. Unit 3 could make the change at 22:53; the RCIC was manually isolated (because of low pressure in the reactor) at 23:58. Unit 1 made the change around midnight on March 12$^{th}$, and the RCIC was manually isolated at 4:58 of the morning of the same day. Unit 4 was changed from the RCIC to MUWC at 00:16 on March 12$^{th}$, when the RCIC was manually isolated by the low pressure in the reactor. Finally, reactor 2 was changed to MUWC at 4:50 on March 12$^{th}$, with the RCIC isolation at 4:53.

Clearly, the reactors followed parallel sequences, if with different rhythms. This was not lost on the operators. The shift team of reactors 3 and 4 commented that "*discussion occurred between the control rooms for Units 1 & 2 and Units 3 & 4 to communicate the effectiveness of actions being taken.*"[77] Specifically, "*In the main control room for Units 1 and 2, an effect of suppressing a rise in PCV pressure was expected and the D/W cooler (without a cooling source) was manually started up. Immediately after startup, the D/W temperature fell, so the information was provided to the Shift Supervisor at Units 3 and 4. The Shift Supervisor at Units 3 and 4 imitated this to conduct a similar response and confirmed that the D/W temperature decreased.*"[78]

In the work of the ERC was facilitated by the similarity of the four reactors at Dai-ni, which were more alike in type and in damage received than at Dai-chi. A reflection *in terms of analogy among the four reactors* is easiest. The exception was always reactor 3, which had lost less of its function. Already at 00:06 on March 12$^{th}$, the operators of reactor 3 began preparations to change RHR (B), already running for hours in the S/C cooling mode, to the shutdown cooling mode. At 1:23 they

[76] TEPCO Daini Chronology, p 84
[77] EPRI, 2-8
[78] TEPCO Daini Chronology, p 85

manually stopped RHR (B) in preparation for the change, but at 2:39 they started it again, first in S/C cooling mode, changing three minutes later to S/C spray mode. At 7:59 the operators stopped it manually again, to restart it manually in shutdown cooling mode at 9:37.

Fairly early on the morning of March 12th, the temperature in the S/Cs, which were absorbing energy from the reactors, rose above 100 degrees in all the reactors except unit 3: unit 1 at 5:22; unit 2 at 5:32; unit 4 at 6:07. To deal with this increase, after consulting with the ERC the shift supervisors ordered measures to cool the S/C, starting with the flammability control system (FCS) injected via the MUWC, and then changing the MUWC between the drywell spray and the S/C spray.[79]

Reactor 4 had a slight advantage over reactors 2 and 1: it still had high-pressure core spray (HPCS) system capacity. Around noon[80] on March 12th, the operators of unit 4 changed the cooling system from the MUWC to the HPCS.

Despite these efforts, it was obvious both in the control rooms and in the ERC that the pressure in the primary containment vessels (PCV) and the S/C was rising. The shift supervisor for units 3 and 4 described the efforts to cool the S/C as "buying time" until a more permanent solution could be put in place. [81] But it was already clear that the process of restoring the RHR systems would take time. As a precaution, therefore, it was decided to prepare a line for "hardened" venting of the PCV (a line which would only leave one barrier - the rupture disk, which should open automatically – for the suppression chamber venting). This line was configured for all the reactors, including reactor 3 which still had functioning RHR systems, in case the pressure of its PCV should rise too.

For reactors 2, 3, and 4, the configuration of the line could be done remotely from the control room, and took between 5 and 25 minutes: from 10:33 to 10:58 for unit 2; from 11:44 to 11:52 for unit 4; and from 12:08 to 12:13 for unit 3. However, at unit 1, where they process began at 10:21, it was discovered that, as was the case at Dai-ichi, the solenoid valve for the hard venting line, which worked on compressed air, had lost power and could not be opened. The ERC considered the options for opening the valve, and given the rate of the rise in pressure, which left a margin of time, they decided to attempt to restore power to the valve. From 16:00 on March 12th, the possible routes for electricity were confirmed and a circuit was configured, allowing the line to be completed at 18:30.[82]

Unit 3, with the advantage of a functioning RHR, achieved cold shutdown at 12:15 the 12th of March. For the other reactors, however, the end result was not at all certain yet. It was imperative to restore the cooling equipment. The ERC had ordered the restoration equipment during the morning of March 12th, but the transportation, hindered by damage to the roads from the earthquake and tsunami, took longer than expected. The cable, which was transported by helicopter, arrived the same day; this, however, required the staff to find a landing site for it. They chose the baseball field, and prepared it by removing the fence and using truck headlamps as guide lights for the landing. The other equipment, which came by road, took longer. While they waited the ERC teams planned the electrical connections that they wanted to set up, deciding to use the power center in

[79] TEPCO Daini Chronology, pp 84-85

[80] There is a discrepancy in the data: in the TEPCO report of June 20 2012, this action is said to take place at 11:52 (p. 294); in the TEPCO Daini chronology it takes place at 11:17 (p. 79).

[81] EPRI, p 2-8

[82] TEPCO Daini Chronology, pp 85-86

the radioactive waste building. They also worked to prepare the site by clearing the roads, strewn with debris from the tsunami, to facilitate the transport of equipment and the laying of cable.

Around 6:00 on March 13th, the equipment started to arrive. There were around nine kilometers of cable in total, which had to be connected between the radioactive waste building and the heat exchange buildings of units 1 and 2; between the heat exchange building of unit 3 and the heat exchanger building of units 2 and 4; and between a power-generating vehicle and the heat exchanger buildings of units 1 and 4, using a portable transformer. Around 200 people worked on the laying of the cable, which under normal circumstances would have been done with machines and taken many days, if not weeks. The priorities for connection were determined by the conditions of the reactors, monitored from the ERC as well as by the control rooms. Initially, the priority was unit 2, where the PCV pressure was mounting rapidly; however, during the morning of March 13th the rise in PCV pressure of unit 1 passed that of unit 2, and the priority was shifted to unit 1. At the same time, the team worked on replacing the pump motors as these arrived. There were unforeseen difficulties there too: for example, the door of the unit 4 heat exchanger building, damaged by the tsunami, could not be opened, and it was therefore necessary to destroy it to allow the motor to enter.[83] During all this work, the lack of personnel with the specific capacities necessary, such as the operation of trucks or the construction of electrical circuits, was a continual problem.

The cooling systems were put into operation as soon as the motors and electricity were connected. The operators of unit 1 could start the RHR (B) at 20:17 on March 13th, and the RHR (D) at 21:03; these pumps were initially used to cool the S/C.

All the cable was in place by around 23:30 on March 13th. At 3:20 on March 14th the first emergency pump was started for unit 2, followed by the RHR (B) at 3:51 and the RHR (D) at 5:52. For unit 4 the first emergency pump started to work at 11:00 on March 14th, followed by the RHR (D) at 13:07 and the RHR (B) at 14:56.

As with unit 1, these pumps were used first to cool the S/C. When the temperature in the S/C had lowered enough, the RHR (B) was used to inject water from the S/C into the reactor: at 10:05 on March 14th for unit 1; at 10:48 March 14th for unit 2; and at 18:58 March 14th for unit 4. Consequently the temperature of the S/C fell below 100 degrees: at 10:15 on March 14th in unit 1; at 15:52 on March 14th for unit 2; and at 7:15 on March 15th for unit 4.

With all the necessary facilities available, the operators were able to guide the reactors to cold shutdown: unit 1 at 17:00 on March 14th; unit 2 at 18:00 on March 14th, and unit 4 at 7:15 on March 15th. Although the PCV vent lines had been prepared, the venting turned out not to be necessary.

### *4.4.2 COMPARISON OF CRISIS MANAGEMENT AT DAI-ICHI AND DAI-NI: ANALYSIS*

It is difficult to argue that there is any difference in the management of the crises at Fukushima Dai-ichi and Dai-ni that trumps the fundamental advantage for Dai-ni that they did not completely lose grid power. In fact, the difficulties faced by Dai-ni in dealing with the accident despite having electrical power (and thereby not only some cooling functions, but also instruments and monitoring) emphasize how very problematic the situation faced at Dai-ichi was.

For one thing, the case of Dai-ni illustrates that simply having a grid connection was not enough; it was also imperative to have power centers and transformers to manage the current according to the needs. It took most of a day and 200 people to lay the cable and make the connections, even with

[83] TEPCO Daini Chronology, p 87

less flooding, fewer communications and lighting difficulties, and lower levels of radiation than at Dai-ichi. Once the power was connected in a stable manner, the continuation to cold shutdown was fairly straightforward.

Here again we see that the explosion at unit 1 of Dai-ichi, which occurred just as workers were finishing the cable connections to provide power to the plant, was a turning point in the response. The explosion not only upturned the ongoing work, causing long delays in the stabilization of the power system, but also introduced further elements of uncertainty into the process.

The teams at Dai-ni also benefited from not having to guess at the status of the reactors, with instruments giving readings of the key parameters, in particular water level, reactor pressure, and containment pressure. Unlike at Dai-ichi, where uncertainty over the functioning of the emergency cooling systems and over the relative situations of the reactors led to a misguided focus on unit 2 while unit 1 was melting down, at Dai-ni priorities were adjusted in real time, with the workers shifting focus from unit 2 to unit 1 as the rate of pressure rise indicated the greater risk.

Finally, the teams at Dai-ni had, and recognized, the advantage of similar systems undergoing similar disruption in parallel. Unlike at Dai-ichi, where unit 1 had different emergency systems from units 2 and 3 and unit 2 had different types of damages from unit 3, at Dai-ni the four reactors had the same systems. While there were some differences in the impacts of the tsunami, notably with unit 1 more affected and unit 3 less affected, much of the accident unfolded in parallel across the four. The operators took advantage of this, communicating with each other about the consequences of various steps.[84].

In fact, the approaches of the workers, and organizations, at Dai-ichi and Dai-ni were fundamentally similar. Both teams focused initially on finding means to inject water; both identified and attempted to source the material requirements for restoring power; both found it technically challenging to do so, even once the material was at hand; and both teams were aware, relatively early on, that venting might be necessary, and attempted to prepare for it. However, without any on-site electricity, without indicators, and crucially without emergency cooling systems, unit 1 at Dai-ichi had a margin of only a few hours before meltdown. Once this occurred, it had effects on the possibility of saving the other reactors. The proximity of the reactors, useful at Dai-ni in terms of learning and comparisons, was harmful at Dai-ichi.

The comparison of the cases of Dai-ni and Dai-ichi therefore offers us several findings at different level:

1. **Technical context**. Loss of connection to grid electricity was a key factor in the meltdowns at Dai-ichi. More than the other variation in damages, it was the electrical connection that made the difference in outcomes of the two cases. The worsening of conditions at just one of the reactors at Dai-ichi was another key factor of technical context in determining the outcome of the response. Had one of the reactors at Dai-ni been beyond saving, it would have, like unit 1 at Dai-ichi, quickly led to severely worsened working conditions (primarily through elevated radiation levels) and to greater uncertainty. Therefore, while parallel processes and learning were beneficial in some ways, the proximity of reactors can also be extremely dangerous.
2. **Organizational emergency response**. The operational tasks necessary to manage the accident (laying cable, wiring electrical connections, clearing roads, etc) were very difficult

[84] TEPCO Daini Chronology, p 85

even with an electrical connection and without high levels of radiation. The case of Dai-ni demonstrates the importance of having on-site cross-functional capacities for unexpected tasks such as connecting cables, and in particular having sufficient capacitystaff (not sub-contractor) in these areas.

3. **Use of analogies to make sense of highly uncertain situations**. Seeing the accident play out in similar ways across identical reactors was useful for the staff at Dai-ni in making sense of their situation, reducing uncertainty, and learning as they went. At Dai-ichi these possibilities were reduced by the differences in the reactors, by the differences in the damages to the reactors, and by more limited communications.
4. **Media and stress context**. Media attention was focused at Dai-ichi, leaving Dai-ni relatively unbothered by politicians.

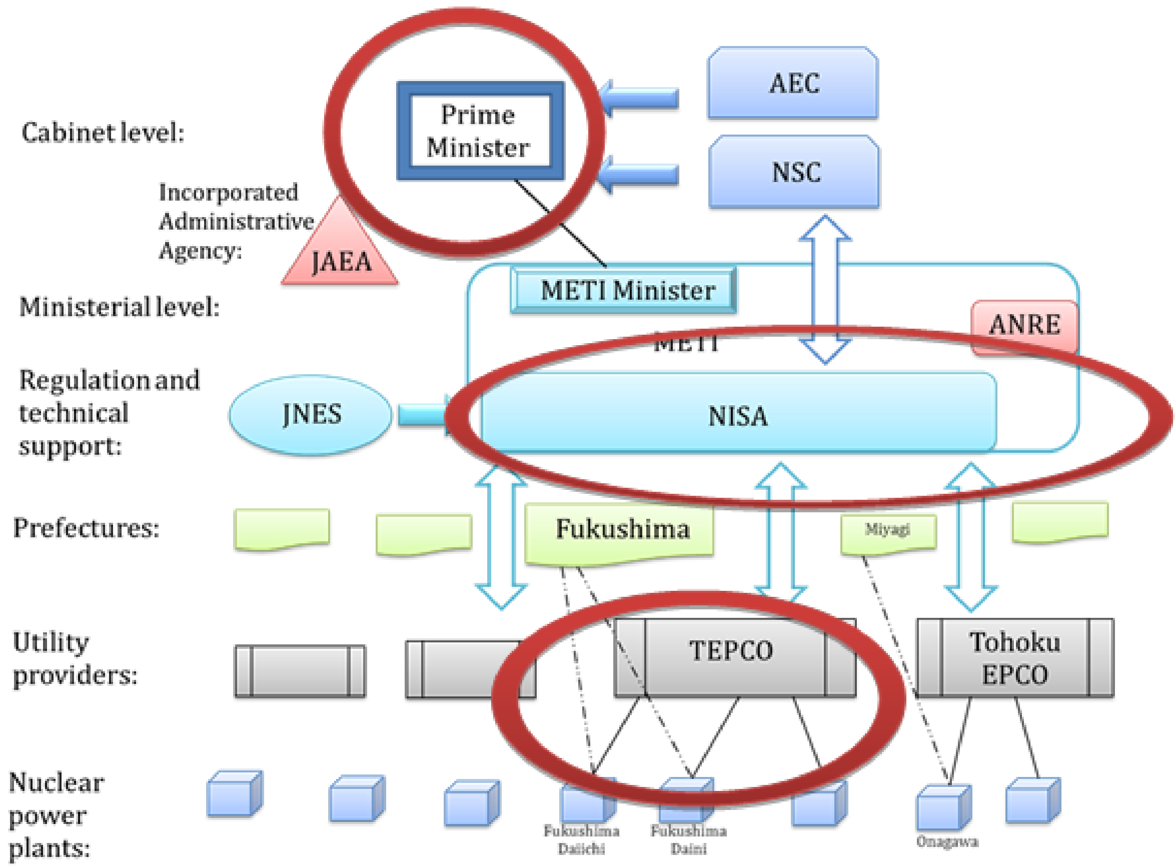
# 5 CRISIS MANAGEMENT AT THE POLITICAL LEVEL

In addition to the ERC in Fukushima Dai-ichi and TEPCO emergency response center in Tokyo, a third emergency response center was established at the Prime Minister's Office. It had a hard time grasping the situation in the initial hours following the accident. For security reasons, the cell phone network did not work in the meeting rooms, and telephone lines were saturated due to the fact that the government had to manage three crises at the same time: the earthquake, the tsunami and the nuclear accident. However, after initially only collecting information, the Prime Minister's Office quickly began to take a more active role and started suggesting solutions. These suggestions were often too late, as the superintendent had already made his decision and given the necessary orders, or based on partial information. However, the Prime Minister's response team did have an influence on certain decisions, such as the injection of sea water into Reactor 1, the depressurization and injection of water into Reactor 2, and the injection of fresh water into Reactor 3.

## 5.1 THE DIFFERENT ENTITIES INVOLVED

The main entities involved at a political level are:

- The Tokyo Electric Power Company (TEPCO), in charge of the Fukushima Dai-ichi plant.
- The Nuclear and Industrial Safety Agency (NISA), the main regulatory body, responsible for licensing and oversight of power plants. This agency is located within the Ministry of Economy, Trade, and Industry. In an emergency, the utility should communicate through NISA to other political actors.
- The Japan Nuclear Energy Safety Organization (JNES), the technical support agency for NISA, assisting with plant inspections among other duties. It has around 400 staff.
- The Prime Minister legally designated as the head of the response for any nuclear emergency. As we will see, the Prime Minister took a particularly active role.
- The Nuclear Safety Commission (NSC), a small committee of five experts at the Prime Minister Cabinet level that both oversees and sets policy for NISA and advises the Prime Minister.




When the Prime Minister issues a Nuclear Emergency Declaration, the Nuclear Emergency Response Headquarters (NERHQ) should be established at the Kantei and the Local NERHQ at the Off-site Center. The Prime Minister serves as the director-general of the National NERHQ, and the Minister of Ecornomy, Trade and Industry as vice director-general. The NERHQ members are minister of each ministry.

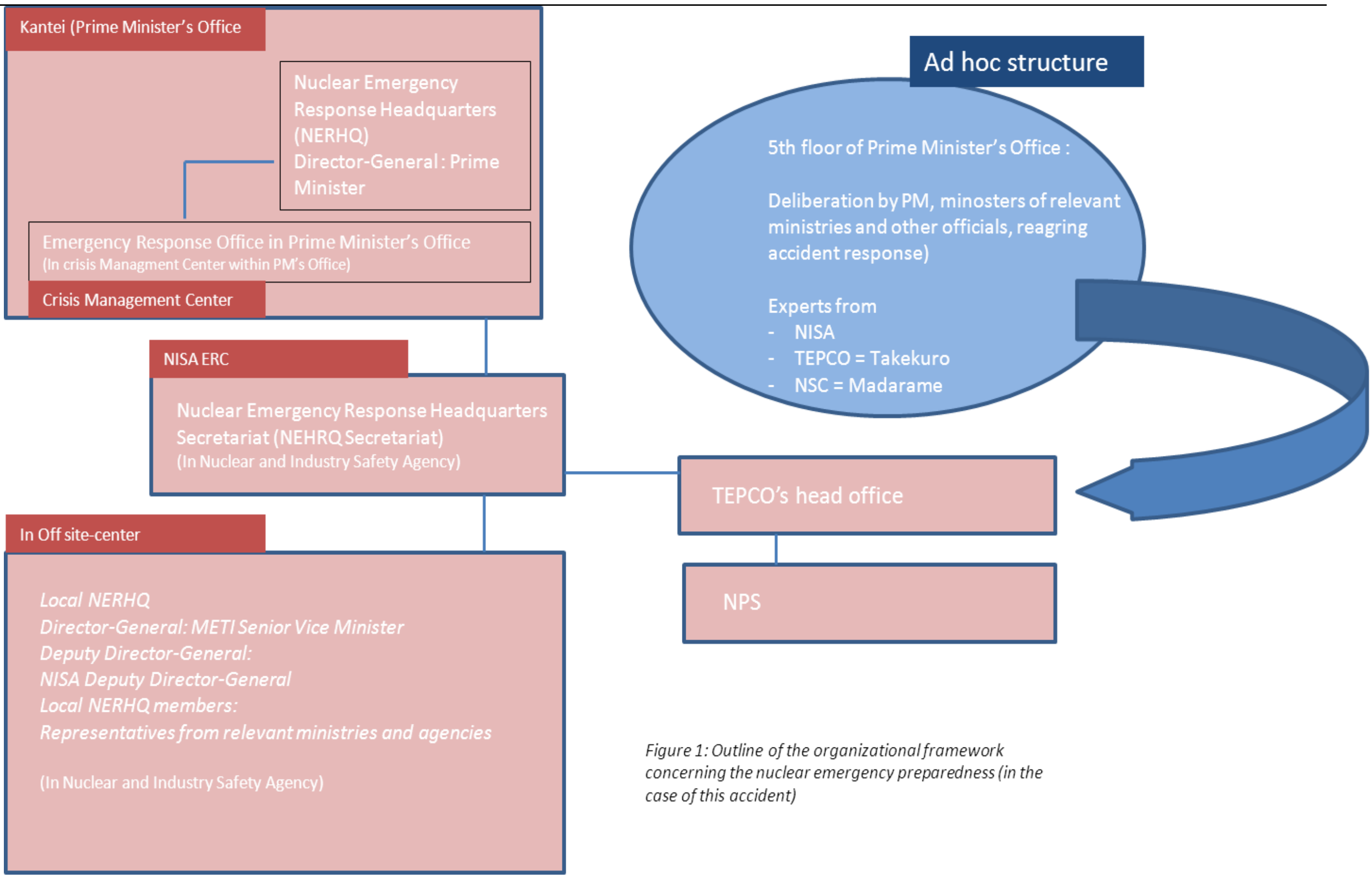



*Figure 1: Outline of the organizational framework concerning the nuclear emergency preparedness (in the case of this accident)*

The central response bodies were established at the Prime Minister's office. The secretariat of the NERHQ is to be established at the safety regulatory ministry/agency for nuclear facilities when an accident occurs. The secretariat of the NERHQ collects and sorts out information from nuclear power plants. The NERHQ and/or the Local NERHQ decide on protective measures and the secretariat of the NERHQ and/or the Local NERHQ give instructions for countermeasures to the relevant parties. The NERHQ local or "Off-site Center" was established 5 km away from the plant, including local and regional authorities and representatives from the central government and TEPCO.

## 5.2 THE ALERT

Within a few minutes of the massive earthquake at 14:46 on 11 March, 2011, various entities of the Japanese government had already established their emergency response headquarters. The office of the Prime Minister, commonly known as the Kantei, established its emergency response office at 14:50 and at the same time summoned the Emergency Operations Team, which includes representatives from various ministries. Even Fukushima Prefecture, where the prefectural building was damaged in the earthquake, immediately identified an alternative location for the emergency response headquarters by 15:00, and began the process of setting it up by 15:05.

The government was therefore already in crisis mode when the tsunami triggered by the earthquake struck at around 15:30[85]. The situation was immediately understood to be dire. Although tsunami

[85] Successive waves struck different areas at different times.

warnings had been broadcast, the scale of the waves was far greater than predicted, overwhelming the seawalls that towns had trusted to for their protection and in many cases swamping designated evacuation shelters, with tragic results. Even the first reports and images of the destruction, from military and police headquarters whose surveillance flights were automatically triggered by the size of the earthquake, showed vast damage to infrastructure, including road and rail networks. There were power and communications outages along the northeast coast, and even the capital Tokyo was thrown into confusion.

It was against this backdrop, as the quickly convened emergency response bodies struggled to undertake their first life-saving operations, that another menace became clear. At 15:42, the TEPCO issued a notification pursuant to Article 10 of the Nuclear Emergency Preparedness Act, informing the relevant authorities of the loss of alternating current power at Fukushima Dai-Ichi Nuclear Power Plant. As per procedure, this notification was communicated directly to the Nuclear and Industrial Safety Agency (NISA), the regulatory body with oversight over the power plant. NISA further communicated this to the Prime Minister's office, METI (of which NISA is a part), and the Nuclear Safety Commission (NSC). There were also eight NISA inspectors present at Fukushima Dai-ichi at the time of the incident; three of them left the plant to undertake the establishment of the mandated Local Nuclear Emergency Response Headquarters (Local NERHQ) at the "off-site center" five kilometers away. At around the same time,[86] employees of the local TEPCO office in Fukushima city went to the prefectural emergency headquarters, which was only a few minutes away by foot, and informed the governor and other officials of the situation. To prepare to manage a potential response, staff returned to the damaged prefectural building to collect manuals and equipment related to nuclear emergencies, including satellite telephones.[87]

NISA's information about the emergency notification reached the NSC at around 15:59. At 16:00, according to procedure, the NSC convened an emergency technical advisory body to provide support to decision makers during the crisis. However, despite this quick action, and the fact that the NSC had already emailed the cell phones of potential members of this body at the time of the earthquake to ask them to be on standby, only four of the 25 were able to assemble that day due to the traffic and communications disruption in Tokyo caused by the earthquake.[88]

At the same time, METI Senior Vice-Minister Ikeda was dispatched to the off-site center to serve as Director General for the Local NERHQ at the off-site center in Fukushima Prefecture. Although he left immediately for a trip that would normally take 3-4 hours, the traffic in Tokyo was so congested by the panic following the earthquake that only by taking a military helicopter was Ikeda finally able to arrive at the off-site center at around midnight, eight hours later.

Although the information trickling out from TEPCO was still very limited, at the power plant the full impact of the loss of power was becoming clear. Without indicators, the operators had no way of knowing whether the emergency cooling systems were functioning correctly or what the status of the reactor was. Although emergency cooling system malfunction had not yet been confirmed, at 16:45 TEPCO reported to NISA a specific event under Article 15 of the Nuclear Emergency Preparedness Act: an event that indicates the occurrence of a nuclear emergency situation.

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[86] According to the ICANPS interim report (p 81), this occurred at "around 15:40"; it seems unlikely that the local TEPCO employees received the information and walked to the Prefectural headquarters before the official notification had been issued, but it is certainly not impossible.

[87] ICANPS interim report, p 81

[88] ICANPS interim report, pp 76-77 (footnote)

Article 15 of the Nuclear Emergency Preparedness Act stipulates that when the Prime Minister receives a report of an event designated in the provisions of Article 15 from the relevant minister, he shall immediately issue the Nuclear Emergency Declaration, and give public notice of the zone where emergency response measures should be implemented. Additionally, under the Nuclear Emergency Preparedness Act, the issuance of the Nuclear Emergency Declaration is required as a precondition for the establishment of a NERHQ, a Local NERHQ and a secretariat of the NERHQ, and is indispensable for initiating emergency responses by the government.

When the article 15 was issued, it was first "validated" by the regulatory body, the Nuclear and Industrial Safety Agency (NISA). Once NISA had determined that the event did in fact fall under article 15 – that it did threaten a true nuclear disaster – they took this confirmation to the head of the METI ministry to which NISA belongs, at around 17:35. Together with METI Minister Kaieda, the NISA director general went to the Prime Minister's office and asked him to issue the Nuclear Emergency Declaration, which would also trigger the formal establishment of the national and local NERHQs. The NAIIC report precise that, rather than a simple formality, this conversation became a long discussion, during which the Prime Minister continued to ask detailed questions about the situation, such as : "*Did they really lose all the batteries?*", "*Shouldn't there be backup batteries there?*", "*Why did this happen?*", "*Are all possibilities really exhausted?*". METI Minister Kaieda and the NISA executive officials pleaded with him to issue the Nuclear Emergency Declaration by saying "*Mr. Prime Minister, we have to do this according to the law*"[89]. The emergency was not declared until 19:03, and a press conference announcing it was not held until 19:45.

With the context of the full response history, it appears to be the first instance of the Prime Minister's determination to take an active, even detailed role in the emergency response. Rather than just accept the idea of a generalized "nuclear emergency," he was asking for details on the specific situation. He attempted to make sense of, and thereby control, the situation. He was not only making sense of the situation for himself, he was also attempting to find ways to make meaning of the situation for the country. Unfortunately, there was little information to be had. Moreover, the situation was extremely technical.

## 5.3 MAKING AN AD HOC ADAPTATION TO THE CRISIS RESPONSE ORGANIZATION INCREASES THE DISTANCE BETWEEN THE GROUPS

The nuclear emergency declaration set into motion other key elements of the response. With it, the Nuclear Emergency Response Headquarters (NERHQ) and Local NERHQ were officially established. The first NERHQ meeting was held in the Prime Minister's office from 19:03 to 19:22; however, it did not include discussion of a formal devolution of authority to the Local NERHQ[90]. It was not until 19:45 that a press conference was held announcing the nuclear emergency declaration and the establishment of the NERHQ. Fukushima Prefecture was not directly notified of the nuclear emergency declaration until nearly an hour and a half after it was made.[91]

The establishment of the NERHQ should have helped formalize the response process, and it was at that point that "*the operation room within the Crisis Management Center began its full-fledged emergency response by separating activities into two booths: one predominantly focused on the response to the earthquake and tsunami disaster; the other predominantly focused on the response*

[89] NAIIC Report, Chapter 3, page 47

[90] This theoretically limited the authority of the Local NERHQ, although in practice it seems to have had little effect, given the limited operational capacity of the Local NERHQ. See ICANPS Interim Report pp, 92-93.

[91] NAIIC Report, Chapter 3, p 77

*to the nuclear disaster*."[92] The Prime Minister, who had called TEPCO officials back to his office around 19:00 to continue discussing the situation, went into the Crisis Management Center at around 20:30, "*in order to take charge of government's response to earthquake/tsunami disaster as well as the nuclear accident*."[93] However, this situation did not last long. The Prime Minister found the Crisis Management Center "noisy" and "*came to the conclusion that it was not appropriate for him to deal with the accident*" there.[94] (A further issue with the Crisis Management Center, which continued to be a problem for those working there, was that due to information security concerns cell phones did not work in that area, hampering communications).[95] The Prime Minister and several close advisors, including METI Minister Kaida, other politicians, NSC Chairman Madarame, and TEPCO officials including TEPCO "Fellow" Takekuro, removed themselves to a separate area in the same building. The fact that the NERHQ was not disbanded led to further confusion, as some actors continued to communicate with the NERHQ, leaving the Prime Minister's group out of the loop, and vice versa.

In sum, very shortly after the beginning of the accident, the initially planned crisis response organization changed which served to partition the various groups of actors and increase the distance between the operational actors in the field and the top of the hierarchy. The crisis response structure diverged almost immediately from the plan, as crisis management fits badly into standard organizational structures (Clarke 1999). The Prime Minister organized his action plan in order to design the required procedures in the response process and revise them when necessary. The temporary organizations, according to Lanzara (1983), can respond to the enacted environment and, by doing so, apply and sustain his actions. At the same time, however, the Prime Minister broke away from the main response team, accompanied by a small group of advisors. When the Prime Minister asked for a TEPCO liaison officer to remain with him at his office, TEPCO had not put in place procedures to maintain open lines of communication with the person concerned, resulting in considerable information being lost or miscommunicated during the first two days. This *ad hoc* structural change fragmented the decision-making process and created parallel lines of communication. Although the information continued to flow both to the NERHQ and to the Prime Minister's group, these flows were not always the same and communication between the NERHQ and the Prime Minister ceased almost completely, leaving the two groups working under different understandings. At the least, the Prime Minister and the NERHQ did not receive the same information and did not communicate much with each other. In conclusion, this *ad hoc* crisis management organization distanced the field response team from the highest hierarchical level.

## 5.4 THE DIFFICULTY OF COORDINATING THE LOCAL LEVEL TO THE NATIONAL LEVEL

It was the Prime Minister's reduced group that discussed issues such as logistics support to the stricken power plant and evacuations. These discussions, however, were not extended to the larger Crisis Management Center; "*the members of the Emergency Operations Team were not fully aware of this process and its development*."[96] According to the manual for Nuclear Emergency Response, it is the Director-General of the Local NERHQ, presumably familiar with the local context and able to

[92] NAIIC Report, Chapter 3, p 40
[93] ICANPS Final Report, p 219
[94] ICANPS Final Report, p 219
[95] ICANPS Interim Report, p 72
[96] ICANPS Interim Report, p 73

communicate with local governments, who should issue evacuation orders, using authority delegated from the NERHQ. However, not only had the NERHQ not delegated authority to its local representative, the Director-General was still in transit to the site, and would be for hours, and he would not find it easy to communicate with anyone, local or national, once he got there. Since the authority had not been delegated, it theoretically remained with the NERHQ; however, it was not that body which eventually decided on evacuation orders, but the small group of advisors around the Prime Minister. These advisors did not have a lot of information on which to make their decisions. They turned to NSC Chairman Madarame and the TEPCO official Takekuro, and the two of them discussed the question, but neither of them had any confirmed information, and so without knowing whether radiation was actually leaking or not, they suggested a three-kilometer radius just in case.[97]

The deliberation on the needed evacuation radius took time, as the politicians and experts tried to figure out how far the danger extended without having much solid information to go on. Was the reactor at the point of meltdown? Would the electricity be restored quickly? How big a factor were the weather conditions? Meanwhile officials in Fukushima Prefecture were becoming increasingly concerned over the situation and the lack of communication from the national government.[98] When two hours had passed since the declaration of a nuclear emergency without any word on evacuations, the prefecture took matters into their own hands, declaring a two-kilometer evacuation zone around the plant. This declaration was followed by a press conference, and thereafter the Vice-Governor of the prefecture was dispatched to the off-site center, where he arrived at around 23:00. Although the press conference made the evacuation order public, the prefecture had difficulty transmitting it directly to the implicated municipalities, especially since the building where the response HQ was located did not have as many communications facilities as the main prefectural government building, originally intended to house the prefectural HQ, which had been damaged in the earthquake and abandoned.[99]

The Prefecture also did not directly notify the national government that it had issued the evacuation order.[100] About half an hour later, at 21:23, the national government gave its own order for a 3-kilometer evacuation around the power plant. The national government as well had difficulty transmitting this order; "*according to a resident survey conducted by the [Nuclear Accident Independent Investigation] Commission, only 20 percent of the residents in the five towns surrounding the plant […] were aware of the accident at 05:44 on March 12, when the evacuation order was issued for residents within a 10km radius of the plant.*"[101]

As the night continued, the off-site center was slowly becoming operational. The Vice-Governor of Fukushima Prefecture arrived at around 23:00 and the Senior Vice-Minister of METI, Ikeda, who had been named the Director-General of the Local NERHQ, arrived around midnight. Additional personnel from the military, the Japan Atomic Energy Agency, the Chemical Analysis Center, and other relevant agencies trickled in throughout the night. Around 01:00 on March 12, power was restored to the off-site center, and around 03:00 the staff moved operations back in to the original building. However, Director-General Ikeda was still having great difficulty getting any useful information. The NISA inspectors who had left the power plant immediately after the earthquake had little updated information, and the lack of communications made it difficult for Ikeda to talk to

[97] Kadota, pp 113-114

[98] NAIIC report pp. 61-62

[99] NAIIC Report, Chapter 3, p 74

[100] NAIIC Report, Chapter 3, pp 77-78

[101] NAIIC Report, Chapter 3, pp 82

anyone who knew more. When he called METI on a satellite phone in the early hours of the morning and was told that the METI Minister would be giving a press conference on venting, it was the first he had heard of the possibility.[102]

The government's most important role was in the evacuation of the local populations. These evacuations should be determined by the local Nuclear Emergency Response Headquarters (NERHQ), which was designed to include representatives from local and prefectural government as well as from the utility and the METI Ministry. According to the theory, the national level NERHQ, established with the declaration of emergency and based in the Prime Minister's offices, would immediately delegate authority to the local NERHQ, allowing them to use their hypothetical greater knowledge of the situation, based on geographic proximity, to take important decisions like those of evacuation. In fact, this delegation did not happen at the initial meeting of the NERHQ at 19:03.

While this was probably just an oversight, a legal technicality which could have easily been fixed, in practice it did not matter because the local NERHQ was almost totally impotent. The earthquake had knocked out power and communications to its site, and the transportation snarls caused by the disaster delayed the arrival of most of the participants, so that the high-level officials from TEPCO, METI, and even Fukushima prefecture did not arrive until evacuations had already been ordered. Some of the local municipalities, overwhelmed by dealing first with tsunami damages and then with the evacuations, never showed up at all, severely reducing the local NERHQ's ability to coordinate. On the other hand, NISA inspectors who happened to be at Fukushima Dai-ichi when the tsunami hit evacuated themselves to the off-site center almost immediately, meaning that while the regulatory body was represented there, they had no information from the plant to share.

## 5.5 LACK OF CONFIDENCE, TIGHT CONTROL

At the Prime Minister's office, despite the collection of experts he had gathered around him and the urgency of the situation, there was little more information to be added. They did know about the growing likelihood of venting: despite the fact that legally the decision to vent rested with the operator, around 01:00 TEPCO had informed the Prime Minister, METI Minister Kaieda, and NISA about the intention to vent and obtained their approval of that decision.

At 03:06 METI Minister Kaieda, along with NISA Director General Terasaka and TEPCO Managing Director Komori held a press conference about the venting. However, this press conference only served to further illustrate the communications difficulties among the decision-makers. At the time, NISA Director-General Terasaka had received information that the emergency cooling system of unit 2, the RCIC, was functioning, and therefore he understood that the priority for venting would be unit 1. However, TEPCO Managing Director Komori had not yet learned that the unit 2 RCIC was still functioning, and believed instead that the unit 1 emergency cooling system, the IC, was running, thereby believing that unit 2 would be vented first. Unable to confirm either belief, the officials attempted to avoid the question during the press conference.[103]

The Prime Minister was becoming increasingly frustrated with the lack of solid information. Around 02:00, he became convinced that the local NERHQ was not working, failing to use its proximity to the power plant to gather information and putting the burden for decision-making on the Prime Minister's office. Since he didn't feel that he was getting enough information to make these

[102] Kadota, pp 104-105.
[103] ICANPS Interim p 173

decisions, he decided that it was important for him to visit the power plant himself to understand what was going on.[104] Through the early morning, frustration was growing both for the Prime Minister and with his advisors; they had been informed about the plan for venting, and NSC Chairman Madarame was clear that venting was increasingly urgent to save the plant, but the venting was not happening. The TEPCO liaison in the Prime Minister's group tried to explain the conditions, but he also did not have much information to go on, and "*the team at the fifth floor of the Kantei began to wonder if they were being told the whole story, and were frustrated by the inability to accurately grasp the situation. Some in the group even felt that TEPCO was hesitant to implement the venting*" (NAIIC, chapter 3 p. 52). The NERHQ seemed to understand by this time that high levels of radiation were slowing the process, but despite the short distance between them, the Prime Minister and his group were not communicating with the NERHQ. Meanwhile those in the NERHQ imagined that the high-ranking politicians with the Prime Minister would already have the latest information directly from the source, so they did not proactively share information with them.[105]

Conditions were worsening at the plant and radiation levels were rising. The five NISA inspectors remaining at the plant, who had been communicating with their office via a satellite phone in their vehicle, found it increasingly dangerous to go outside into the contaminated air to the vehicle to use that phone, and around 04:00 or 05:00 on March 12[106,] with the approval of the NISA Director of Emergency Preparedness, they evacuated to the off-site center.[107]

Also arriving at the off-site center before dawn was TEPCO Vice-President Muto, dispatched by the company to be part of the local response headquarters. Having toured both Fukushima Dai-ichi and Fukushima Dai-ni before continuing to the off-site center, as well as visiting the local government of Okuma, the town where the off-site center was located, he was somewhat better informed than the others there.

Concerned that the delay in venting might lead to an explosion which would have impacts beyond the three-kilometer evacuation radius, at 05:44 the Prime Minister increased the evacuation radius to 10 kilometers. This put the off-site center, which was five kilometers away from the plant, within the evacuation zone. This had an immediate impact on the Local NERHQ's ability to perform its functions, since one of these was communicating with the press and no press visited the site.[108] In addition, although there were supposed to be representatives from affected municipalities at the Local NERHQ, because of the evacuation orders only Okuma town, where the off-site center was located, was able to send an official, and the other municipalities involved were not represented.[109] Over time, this also had further effects, as it became harder and harder to procure food, water, and other essentials within the zone.[110]

Shortly after, at 06:00, the final decision about the Prime Minister's visit to the plant was made[111,] although not without some conflict among his advisors. Chief Cabinet Secretary Edano warned the Prime Minister that the visit was likely to bring criticism; Special Advisor Terata felt that the

104 ICANPS Final p 220

105 NAIIC Report, Chapter 3, p 52

106 The NAIIC Report puts it at 04:00 (p 35) and the ICANPS interim at 05:00 (p 80)

107 ICANPS Interim p 80

108 NAIIC Report, Chapter 3, p 38

109 ICANPS Interim p 89

110 NAIIC Report, Chapter 3, p 38

111 ICANPS Final p 221

possibility of the visit was already public, and to back out at that point would make things worse.[112] The Prime Minister, however, felt that the lack of information necessitated the site visit, and he left at 06:15 with Special Advisor Terata and NSC Chairman Madarame.[113] During the brief helicopter flight, the Prime Minister asked NSC Chairman Madarame technical questions about the emergency cooling systems and the issues associated with venting, as well as whether hydrogen would cause the building to explode.[114] Madarame said that there were protections to prevent a hydrogen explosion.

When they arrived at the power plant at 07:11 on March 12, the Prime Minister was met by TEPCO Vice-President Muto and METI Senior Vice-Minister/Local NERHQ Director-General Ikeda, who had come from the off-site center to receive him. The Prime Minister asked why the venting had not yet happened.[115] The group went to the conference room, where they had to wait briefly for Site Supervisor Yoshida. When he did arrive, the Site Supervisor was able to explain to the Prime Minister some of the difficulties impeding the implementation of the venting. Something in his manner, or perhaps his use of the term “suicide squad” to describe the team preparing for to open the valves for the venting, seemed to help the Prime Minister to get a real view of the situation.[116]

The political authorities placed little trust in the management of the accident by TEPCO, which notably could be more concerned with preserving its reactors than with protecting the populations[117]. This mistrust regarding the loyalty of TEPCO seems fairly legitimate given the size of the stakes, which are too high for such a risk to be acceptable. Certainly this mistrust of the utility company played a significant role in the actions of the politicians. Onishi and Fackler (2011) show that the Prime Minister’s “outsider” position in a party new to power contributed to his abiding suspicion towards both industry and the mechanisms that his predecessors had set up to regulate it. As a result, the Prime Minister was not content merely to receive a status report of events. This is why, feeling that he was not receiving enough information to understand the delay in venting, he decided that it was important for him to visit the power plant himself to understand what was going on[118], even though this visit may have delayed the emergency work by diverting necessary time and resources[119].

At 08:04, somewhat reassured, the Prime Minister and his entourage departed from the power plant. However, despite the stated goal of venting by 09:00, the difficulties for the operators continued, and venting was not completed until 14:50 that afternoon. In the meantime they did achieve some success with the injection of water through fire engines. However, by 14:53 the stock of freshwater on-site had run out, and Site Superintendent Yoshida had ordered preparation for the injection of seawater. Yoshida had communicated this with TEPCO headquarters and TEPCO officials at the off-site center, and although it had not been directly discussed with the Prime Minister’s office, TEPCO official Takekuro, NSC Chairman Madarame, and the other experts in the Prime Minister’s group were aware of the likely necessity of this step.[120] At 15:04, apparently frustrated by

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[112] NAIIC Report, Chapter 3, p 52
[113] ICANPS Final p 221 (footnote)
[114] Kadota, pp 140-142
[115] Kadota, pp 148-149
[116] Kadota, pp 151-154
[117] NAIIC, Chapter 3 p.53
[118] ICANPS Final p 220
[119] NAIIC, p. 53
[120] ICANPS interim pp 157-158

the delays, METI Minister Kaieda indicated that he might issue an order for injections to continue. At 15:20, Site Superintendent Yoshida notified the authorities of the intention to inject seawater.

The risk that a high-level politician may try to influence the crisis management is that he or she may try to set up a system of impersonal rules that differ from the actual needs and requirements in the field (Crozier, 1964). As a result, when the Prime Minister left the plant Yoshida himself set a deadline of venting reactor 1 at 09:00. This deadline could not be met because TEPCO had enormous difficulties in doing so without any electrical power. The failure to meet the deadline resulted in greater suspicion and increased the mistrust and the control exerted by the Prime Minister.

This mistrust peaked a few hours later, after reactor 1 was finally vented at the beginning of the afternoon on March 12, 2011. At 15:36 there was an explosion at the plant. The TEPCO executives surrounding the Prime Minister learned of this explosion through the TV news rather than through official channels[121]. The Prime Minister's office itself, meanwhile, received the first and second reports of this explosion from the National Police Agency rather than from TEPCO[122]. This unexpected risk emphasized the complexity element of Perrow's formula, whereby unforeseen interactions in a highly dynamic system caused new and terrifying changes in the accident. Rather than encouraging decentralization to allow for flexible and creative responses, however, it led to a tightening of control at higher levels.

## 5.6 THE ENDORSEMENT OF POWER

At 15:36 there was an explosion at the plant. Takekuro and the other TEPCO executives surrounding the Prime Minister learned about this explosion from the television news, rather than through official channels.[123] The Prime Minister's office itself, meanwhile, received the first and second reports of this explosion from the National Police Agency rather than from TEPCO.[124] The explosion turned out to be a hydrogen explosion in the containment building; according to the NAIIC report, it was at this point that the politicians' "*distrust towards those nuclear experts peaked*," since Madarame had previously said that there would not be a hydrogen explosion.[125]

The explosion had a serious impact on the work at the power plant, damaging the hoses and fire engines that were being used to pump water, as well as scattering radioactive debris over the working area. There was an initial need to assess injuries, as well as to confirm that it had in fact been a hydrogen explosion and that it had not damaged the containment or the core itself. It took some time before Site Superintendent Yoshida allowed workers back to the site, and then the reconstruction of the line of hoses for injecting seawater took further time. Once again, the impatience of the politicians waiting at the Prime Minister's office grew, and at 17:55 METI Minister Kaieda gave a verbal order for seawater injection to proceed, which was received by TEPCO and by the emergency response center at the plant at 18:10.[126] According to the NAIIC report, "*The reason why this order came about was based on distrust towards TEPCO, which was seen as being concerned about the decommissioning of the reactor. It was also based on the vague logic of the government supporting TEPCO by taking responsibility for decisions*." However, the report finds,

[121] ICANPS interim p 76
[122] NAIIC Report, Chapter 3, p 40
[123] ICANPS interim p 76
[124] NAIIC Report, Chapter 3, p 40
[125] NAIIC Report, Chapter 3, p 50; see also p 45
[126] NAIIC Report, Chapter 3, p 54

"*The Commission has seen no evidence that any concrete deliberation was conducted within the government regarding the necessity of issuing this order. And we see no evidence that the on- site seawater injection operation was advanced because of this order*."[127]

When the Prime Minister met with his advisors, beginning a little before 18:00, he still had concerns about seawater injection. Possibly unaware of the METI Minister's order shortly earlier, or possibly believing that in any case the injection had not yet begun, leaving time for questions, he asked repeatedly about the possibility of causing recriticality. NAIIC report indicates that NSC Chairman Madarame told the Prime Minister that "*The possibility of recriticality is not zero*" which apparently spurred these fears.[128] Although NSC Chairman Madarame and his deputy Kukita explained the Prime Minister that "*We consider the possibility of recriticality to be almost none*", Prime Minister Kan responded, *"But a hydrogen explosion actually occurred after you had denied the possibility of it"* and the two men were unable to say anything further.[129] He charged TEPCO official Takekuro with getting information about seawater injection, the readiness for it and its effect on the ability to control the plant.[130]

While this meeting was going on, at 19:04, the team at the plant was finally able to begin injecting seawater into the reactor of unit 1. Although this information was transmitted to the authorities and announced at the Emergency Operations Team table, it did not reach the group in the meeting. When the meeting was over, TEPCO official Takekuro immediately telephoned Site Superintendent Yoshida at the plant to try to get information from him to relay back to the Prime Minister. When he started to ask about the seawater injection, Yoshida responded that it was on-going. Takekuro was first disbelieving, then horrified: "*Really? Sure, why? That's terrible! Why? Stop it*"[131]. Yoshida was confused by Takekuro's reaction, thinking:"*Why don't they understand that there's no other way besides injecting sea water? If you think about it simply, to remove a lot of heat there's nothing but using the ocean.*"[132] But when he tried to protest, Takekuro told him, *"Shut up, you! The Prime Minister is grumbling."*[133]

Concerned that stopping the seawater injection would be dangerous, Yoshida checked with TEPCO headquarters and with TEPCO Vice-President Muto at the off-site center, but they agreed with Takekuro that "*as long as the PMO [Prime Minister's office] had not made a decision, it was hard to continue the seawater injection without the Prime Minister's approval thus they had no option but to suspend the injection*."[134] Still concerned, Yoshida arranged to pretend to stop the injection without really stopping it. In the meantime at the Prime Minister's office, Takekuro was planning to tell the Prime Minister that the initial injection of seawater had been a test injection, but he did not get the chance.[135] The efforts to convince the Prime Minister that it was necessary had continued and around 19:55 he gave his approval.[136] This allowed the plant to pretend to restart an injection that had never really been stopped.

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[127] NAIIC Report, Chapter 3, p 53
[128] NAIIC Report, Chapter 3, p 53; see also Kadota p 222-223
[129] NAIIC Report, Chapter 3, p 53
[130] ICANPS Interim p 197
[131] Kadota, p 220
[132] Kadota, p 221
[133] Kadota, p 220
[134] ICANPS interim p 198
[135] ICANPS interim p 198
[136] NAIIC Report, Chapter 3, pp 53, 55

Although this incident did not in reality affect the injection of seawater, the NAIIC report notes that "*The reality—that seawater injection was continuing on-site—was not conveyed to the TEPCO head office, so they also believed that the seawater injection had been temporarily suspended. Subsequent explanations by TEPCO and the government regarding seawater injection differed from the reality, arousing further mistrust among the Japanese people*."[137]

However, this event highlights a strong desire to show the centralization of the decision-making. It was not simply a matter of submitting to the hierarchy—it was also the opportunity for TEPCO not to be alone in the decision to inject seawater, with all the uncertainty that this involved[138]. In times of extreme threats, power and authority tend to shift up hierarchies to meet in the hands of political leaders and chief executives (Hart, Rosenthal and Kouzmin, 1993). In a way, the political authorities were summoned to assume the responsibility of the decision-maker. This desire to show the centralization of decision-making was so strong that it paralyzed the chain of actors in the actions to take.

The consequence of major centralization is very often the development of parallel power relationships that are adapted to the requirements in the field (Crozier). In this case, Yoshida was caught between loyalty to the hierarchy and being firmly convinced that the injection should continue. As a result, he arranged to pretend to stop the injection without really stopping it. When the Prime Minister finally gave his approval, this allowed the plant to pretend to restart the injection although it had never actually been stopped.

As Perrow (1984) argued, there is evidence of a considerable conflict between the tendency towards centralized decision-making and the need to make decentralized decisions in an emergency in order to respond quickly to unexpected developments. This situation can lead to the emergence of power struggles and parallel decision-making by the actors closest to the accident.

## 5.7 CENTRALIZATION-DECENTRALIZATION CONUNDRUM

The plant did not exist in a vacuum. There was a regulatory, political, and financial environment that affected the design of the plant, its operations, and the planning that occurred before the disaster, as well as the management of the crisis once it did occur. There were also infrastructures and organizations that were assumed to be functioning in accident management plans. Just as natural disasters were considered "beyond design basis", there was also an expectation that beyond-plant systems – crucially, the power grid and the road network – would be in place to support accident management.

Similarly, the government – at local, prefectural, and national levels – had a role to play, one that was explicitly foreseen in the Act on Special Measures Concerning Nuclear Emergency Preparedness and in the emergency plans. The government's most important role was in the evacuation of the local populations. These evacuations should be determined by the local Nuclear Emergency Response Headquarters (NERHQ), which was designed to include representatives from local and prefectural government as well as from the utility and the METI Ministry. According to the theory, the national level NERHQ, established with the declaration of emergency and based in the Prime Minister's offices, would immediately delegate authority to the local NERHQ, allowing them to use their hypothetical greater knowledge of the situation, based on geographic proximity, to take

[137] NAIIC Report, Chapter 3, p 55
[138] NAIIC, Chapter 3, p. 30

important decisions like those of evacuation. In fact, this delegation did not happen at the initial meeting of the NERHQ at 19:03.

While this was probably just an oversight, a legal technicality which could have easily been fixed, in practice it did not matter because the local NERHQ was almost totally impotent. The earthquake had knocked out power and communications to its site, and the transportation snarls caused by the disaster delayed the arrival of most of the participants, so that the high-level officials from TEPCO, METI, and even Fukushima prefecture did not arrive until evacuations had already been ordered. Some of the local municipalities, overwhelmed by dealing first with tsunami damages and then with the evacuations, never showed up at all, severely reducing the local NERHQ's ability to coordinate. On the other hand, NISA inspectors who happened to be at Fukushima Dai-ichi when the tsunami hit evacuated themselves to the off-site center almost immediately, meaning that while the regulatory body was represented there, they had no information from the plant to share.

While local NERHQ practically out of commission, the national NERHQ builds. But, shortly after its establishment, the Prime Minister removed himself and a small group of close advisors from the crisis management center where the NERHQ was meeting. The Prime Minister selected a small group trusted, which included politicians as well as experts from the NSC and a liaison from TEPCO. That may explain why the fact that venting was being postponed to allow populations to leave the immediate vicinity of the plant seems not to have been communicated to the national government. Early in the morning of March 12$^{th}$ the Prime Minister became so incensed over the fact that venting, which all his advisors assured him was imperative, had not happened yet that he went to the plant himself to demand it.

This trip was assuredly not part of the government's role, and certainly not the Prime Minister's. He was criticized for it on several fronts: for risking his own safety at a critical time; for being away from the crisis management center when decisions had to be made; and perhaps most importantly for micro-managing the response. Decisions on the plant's response should have been made at the plant level, not by a non-nuclear expert who was at the same time managing a major national disaster response.

The Prime Minister's continued requests for information and details were in part a function of the poor communications in the aftermath of the disaster. Receiving little information from TEPCO, the Prime Minister, already suspicious of industry, had difficulty believing that the lack of information was because TEPCO itself did not have the answers. Similarly, personality and rhetorical conflicts led to misunderstandings with technical experts; when scientists like the NSC chairman Madarame were reluctant to state unequivocally that salt water injection would not lead to recriticality, the Prime Minister could not understand that the probability of such a thing was extremely low.[139]

However, it also seems likely that this also had to do with Kan's leadership approach. Boin et al. (2005) claim that "*successful crisis management depends not so much on critical decision making but on the facilitation of crisis implementation and coordination through the response network*." The Japanese Prime Minister appears to have followed the opposite of this dictum. By attempting to be active, informed, and involved in decisions caused additional stress and complexity on the key actors. His insistence on personal knowledge and engagement undermined existing coordination networks and information flows, as TEPCO started to reroute its communications to the liaison in the Prime Minister's group of advisors rather than to NISA and the NERHQ.

[139] NAIIC Report, Chapter 3, pp 52

The damage was compounded when others started to use the Prime Minister's imperiousness to impose decisions on the plant, even when the Prime Minister himself had not clearly stated his opinion. This occurred in the case of the saltwater injection, when TEPCO liaison Takekuro took the Prime Minister's questions about the procedure as a sign that it should not be undertaken until he approved. It happened again in the case of the injections to unit 3, when a discussion which did not even include the Prime Minister led to Yoshida believing he had an order from the Prime Minister's office to exhaust all the fresh water on site before switching to seawater, an approach that led to serious delays in injection with no apparent benefits.

Finally, after the extended misunderstanding of TEPCO's evacuation plans, the Prime Minister formally combined the national and TEPCO emergency response headquarters. As with the other levels that we have examined here, the theoretical decentralization of emergency management proved impossible to maintain in practice.

# 6 CONCLUSION

Human and organizational factors were key in determining the way the Fukushima Dai-ichi accident unfolded. With circumstances completely unforeseen in the manuals and procedures, actions at every level of the response structure – shift team, plant, utility, national emergency response – were determined by individual decisions and group dynamics. By looking at each of these levels as well as the relationships between them, this report describes the way the organizational structures and their accident management procedures contribute to or hinder the resolution of the crisis.

1/ The uncertainty in the case of this accident was worsened by the fact that it was what Weick (1993) refers to as a "cosmology episode," one in which the departure from the norm is so drastic that "people suddenly and deeply feel that the universe is no longer a rational, orderly system" (Weick 1993, p. 633). As noted earlier, this suggests disruptions not only in situation, but also in the ways people go about gathering information on the situation. ***People had to make sense of what happened and create new indicators***. Since instruments and controls, as well as many communication technologies, were knocked out by the tsunami, all the standard means of determining the status of the reactors were impossible. Although they were under normal circumstances almost completely dependent on these indicators, and although (or because) their lives were most directly at risk, it was the operators who managed this uncertainty best, at least according to Weick's (1993) prescription of strengthening social ties. They reaffirmed collective values (excluding younger operators from dangerous missions) and reinforced the existing hierarchy and roles (by refusing to let the shift supervisor leave the control room for risky work in the field).

However, the operators were also hampered by something that deepened the uncertainty: lack of knowledge about and practice with the emergency systems. Confusion about the functioning of the IC at all levels and the differences across the reactors hindered the operators' ability to effectively address the response, even with a robust approach to uncertainty. While their experiential knowledge and feel for the reactors proved useful to some extent, the amount of training and practice they had for the IC does not seem to have been enough to give them a sense for that technology in the same way.

2/ The Emergency Response Center (ERC) operations team was responsible for being in contact with the operators in the control rooms and providing them technical support as needed. The ERC support was more difficult to provide than expected due to the conditions of the emergency. Instead of having constant, multi-channel communications and real-time access to reactor parameters, the operations team was linked to the MCRs by a single (per MCR) dedicated hotline phone, hung up when not in use, and all their knowledge of the conditions of the reactors came from the operators in the MCR themselves, via that single channel. ***It is crucial to maintain the communication flow between the ERC and MCR in all circumstances***.

In addition, the operators were limited in the impact they could have on the accident management. With their mandate limited to the control room and the reactors, the accident was soon out of their hands, as venting and the use of fire engines took it beyond their domain.

3/Faced unexpectedly with a multi-reactor disaster, the ERC had to prioritize needs by reactor in real time. An analogical reasoning was helpful: what happened to the reactor 1 was used as a frame of reference for others. In particular, the difficulties that emerged to venting the reactor used to anticipate the venting action sequences for other reactors. However, identifying priorities across the reactors was not easy with the lack of information. The ERC had difficulty managing the supervision of the three reactors simultaneously. ***The ERC must make adjustments according to the number of reactors involved***.

4/The idea of using fire trucks came up early, but its implementation was delayed while attempting the other possibilities and understanding the procedures. On the one hand, restoring lost capacities is not necessarily faster than the development of new possibility. On the other hand, there is a reluctance to make the decision to test new approaches in the context of a crisis. ***Internal coordination is necessary to implement an unforeseen solution. Cross-functional teams can be very useful in coming up with new solutions***.

5/ The uncertainty and the lack of foresight about this specific accident were also highlighted in the number of decisions that had to be made during the emergency response because they had not been considered beforehand. One particularly crucial area was worker safety. Over and over throughout the response policies were unclear or had to be adjusted. The decision over sending operators into a radioactive environment for the venting, the final issue of partial evacuation were all debated during the crisis, taking time and energy and adding to stress on actors who should have been entirely focused on taming the reactors. While this is obviously a delicate issue, nonetheless ***worker safety policies should be as clear and specific as possible before accidents occur***.

This became even more fraught during negotiations with sub-contractors. As it became clear that TEPCO did not have in-house basic non-nuclear capacities needed to manage the response – such as operating fire engines and providing and managing necessary equipment – the firm was revealed to be extremely dependent on the subcontractors providing these services. The resulting situation put sub-contracted workers at risk, delayed the response, and threatened the utility's ability to deal with the situation. ***Where sub-contractors are involved, clear policies on worker safety and degree of commitment are even more important***.

***6/ Those farther away from the danger, in the TEPCO headquarters and in the Prime Minister's office, seemed to have greater difficulty dealing with uncertainty***. Unable to grasp the situation, metaphorically and literally, they made efforts to control it that were often counterproductive, such as giving orders that could not be followed (as, for example, the METI Minister did several times on March 12) or second-guessing decisions made in the field (as the TEPCO president did as regards the venting of unit 2).

The accident management procedures for the plant, the firm, and the national response all emphasized decentralization with communication links that were supposed to provide some of the big-picture overview. However, as we have seen, the crisis did not play out as planned. At all levels, the organizations tended to drift from established procedures towards greater centralization. The consistency of this trend towards centralization across the three levels studied –micro, meso, macro - here is striking, suggesting that ***decentralization, even when planned and professed, may be difficult to maintain in practice, particularly as crisis become drawn out***.

Examples of nuclear accidents like that of Fukushima Dai-ichi are hopefully rare. The crisis quickly passed expectations and procedures, pushing the actors and organizations involved to improvise at the limits of their response capacity. It continued long enough to include a range of interventions, outcomes, and narratives across three active reactors (as well as another four at Fukushima Dai-ni) and the several urgent days covered here, as well as months and years of stabilization and clean-up. By analyzing across three levels – operators, plant management, and the larger political context – this study has been able to draw insights about the organizational and human factors that impacted the unfolding of the accident. While the tsunami that devastated Japan's coast on March 11, 2011 may have been an extremely rare event, there are many other potential causes of a prolonged station black-out that would lead to the same type of drastic situation. It is our belief that these findings can be applicable to a far broader range of crisis management, and can provide insight in emergency preparedness measures.

# 7 BIBLIOGRAPHY

BIMBER, Bruce. *The Decentralization Mirage: Comparing Decision making Arrangements in Four High Schools*. RAND Institute on Education and Training, 1994.

BOIN, Arjen, Paul 't Hart, Eric Stern, Bengt Sundelius. *The Politics of Crisis Management : Public Leadership Under Pressure*. Cambridge University Press, 2005.

Clarke, Lee and James F. Short, Jr. Social Organization and Risk: Some Current Controversies. *Annual Review Sociology* (1993) 19, pp 375-399.

Crozier, Michel. *The bureaucratic phenomenon*. 1964. Transaction Publishers, 2009.

CZARNIAWSKA, Barbara. "Conclusions: plans or well-practiced improvisations?" In Czarniawska, Barbara, Ed.. *Organizing in the Face of Risk and Threat.* Translated from Swedish by Richard Fisher. Edward Elgar, Cheltenham, UK, Northampton, MA, USA 2009, pp. 166-169.

EPRI Fukushima Daini Independent Review and Walkdown 1023422, Final Report. Electric Power Research Institute, August 2011.

http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001023422

Eriksson-Zetterquist, Ulla. "Risk and organizing – the growth of a research field." In Czarniawska, Barbara, Ed. *Organizing in the Face of Risk and Threat.* Translated from Swedish by Richard Fisher. Edward Elgar, Cheltenham, UK, Northampton, MA, USA 2009, pp. 9-24

Hutter, Bridget M. "'Ways of seeing': understandings of risk in organizational settings." In Hutter, Bridget and Michael Power, Eds. *Organizational Encounters with Risk*. Cambridge University Press, 2005, pp. 67-91

Interim and Final Reports, Investigation Committee on the Accident at the Fukushima Nuclear Power Stations. 2012. http://www.cas.go.jp/jp/seisaku/icanps/eng/final-report.html

Kadota, Ryusho. The Man who looked in the Absym of Death: Masao Yoshida and his 500 Days at Fukushima Dai-ichi (Japanese). PHP Research Institute, 2012.

Kawamura, Shinichi. Kawano Akira. Facts and lessons of the Fukushima Nuclear Accident, "Severe Accident Assessment and Management: Lessons Learned from Fukushima Dai-ichi", San Diego California, November 11-15, 2012.

Kreps, Gary A. "The Organization of Disaster Response: Some Fundamental Theoretical Issues." In Quarantelli, E.L. (Ed.) *Disasters: Theory and Research*. Sage, London and Beverly Hills, 1978, pp. 65- 85.

Kubota, Ryiuji. “Key HOF related topics from Investigation Reports and the Situation of Progress in and around the Fukushima site”. 13th meeting of the Working Group on Human and Organisational Factors - Committee on the Safety of Nuclear Installations from OECD, 18-19 September 2012

LANZARA, Giovani Francesco. “Ephemeral Organizations in Extreme Environments: Emergence, Strategy, Extinction.” Journal of Management Studies, 20, 1, 1983.

The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission Report. 2012. http://warp.da.ndl.go.jp/info:ndljp/pid/3856371/naiic.go.jp/en/report/

PERROW, Charles. *Normal Accidents*, Princeton University Press, 1999.

Tokyo Electric Power Company Interim and Final Reports. 2011 and 2012.

United Nations Scientific Committee on the Effects of Atomic Radiation. (2014). UNSCEAR 2013 Report. *Sources, Effects and Risks of Ionizing Radiation, New York*.

VAUGHAN, Diane. *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA*. University of Chicago Press, Chicago, 1996.

WEICK, Karl E. “Enacted Sensemaking in Crisis Situations.” *Journal of Management Studies* 25:4 July 1988.

WEICK, Karl E. “The Collapse of Sensemaking in Organizations: The Mann Gulch Disaster” Administrative Science Quarterly, Vol. 38, No. 4. (Dec., 1993), pp. 628-652.

WEICK, Karl E. *Sensemaking in Organizations*. Sage 1995.