IV. Accident response at TEPCO's Fukushima Dai-ichi NPS

1. Situation and response from the time the earthquake hit until the arrival of the tsunami (from approximately 14:46 to 15:35 on March 11, 2011)

(1) Action taken by the NPS ERC

(i) At approximately 14:46 on March 11, 2011, the Tohoku District - off the Pacific Ocean Earthquake occurred and strong tremors of Japanese intensity scale of 6 strong were recorded at the Fukushima Dai-ichi Nuclear Power Station (hereinafter called “Fukushima Dai-ichi NPS”) of the Tokyo Electric Power Co., Inc. (“TEPCO”).

As described in III-1 above, Emergency Response Centers were established at both the TEPCO Head Office in Tokyo and the Fukushima Dai-ichi NPS, and then reformed with the occurrence of events and the development of circumstances (hereinafter the Emergency Response Centers at the TEPCO Head Office and Fukushima Dai-ichi NPS are generally called the "TEPCO ERC" and the "NPS ERC", respectively).

(ii) The NPS ERC was situated in the Emergency Response Office on the second floor of a seismic isolation building[1] of the Fukushima Dai-ichi NPS. Seated around the main table were Masao Yoshida, chief of the NPS ERC and superintendent of the Fukushima Dai-ichi NPS (hereinafter called "Site Superintendent Yoshida"); unit superintendents; deputy directors; reactor chief engineers; and section chiefs of the function teams including the operation, recovery, engineering, and health physics teams. Staff members of the function teams were stationed in booths behind their respective leaders to enable oral communication between the section chiefs at the main table and the staff members in the booths (see Attachment IV-1).

When a function team obtained information that needed to be shared with all those at the NPS ERC, they reported it to their section chief, who then announced it via

[1] When the Chuetsu-Oki Earthquake occurred in July, 2007, the main administration office building at TEPCO Kashiwazaki-Kariwa Nuclear Station, where the Station Emergency Response Center (NPS ERC) was to be established, sustained heavy damage, requiring initial response activities to be conducted outside the building. Based on the lessons learnt from this experience, a Seismic Isolation Building was newly built and commenced operation at the Fukushima Dai-ichi NPS in July, 2010. This is the building where the NPS ERC was supposed to be established in the event of a disaster. It is of seismically-isolated structure suppressing the base acceleration of an earthquake so that the installations could function properly even against the earthquake of Japanese intensity scale of 7. And there are an emergency response office, meeting rooms, communication facilities, air conditioning facilities and power supply facilities.

microphone so that everyone in the room could hear the announcement directly.

When a decision made by Site Superintendent Yoshida and the other leaders at the main table or information provided from the TEPCO ERC to the NPS ERC through a teleconference system was related to any of the function teams, the leader of the relevant team communicated it to his team members and gave them directions. Therefore, the members could review it and carry out the necessary work.

In addition, people at the TEPCO ERC was able to share information, monitoring the discussions made at the main table at the NPS ERC and give advice and ask questions via the teleconference system.

(2) Action taken at the main control rooms

a. General

(i) At approximately 14:46 on March 11, 2011 when the earthquake hit, Units 1 to 3 of the Fukushima Dai-ichi NPS were in operation and Units 4 to 6 were undergoing the periodic inspections.

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 (see Attachment IV-2).

(ii) 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.

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 aforementioned "Nuclear Operator Emergency Action Plan at the

Fukushima Dai-ichi Nuclear Power Station." 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.

The shift teams also reported all basic information necessary to control the reactors to the operation team of the NPS ERC even when they did not have to ask for advice or direction. The shift team senior operators reported basic reactor parameters, and the leaders provided other information about specific actions, to the operation team using fixed-line telephones from their respective desks.

As a general rule, the members of the operation team of the NPS ERC forwarded every report from the shift teams to their leader and wrote plant parameters and other important information on whiteboards to facilitate the sharing of information within the NPS ERC.

The leader of the operation team announced the content of the reports from the shift teams via microphone at the main table and reported directly to Site Superintendent Yoshida. The TEPCO ERC also received such announcements via the teleconference system.

(iii) The shift teams, the NPS ERC and the TEPCO ERC thought that they could put the reactors into a state of cold shutdown before the loss of all AC power sources due to the tsunami so long as they implement the prescribed procedures.

b. Action taken at the Units 1 & 2 main control room

(i) After the earthquake, the shift supervisor tried to grasp the operating status of Units 1 and 2 from approximately 14:46 to 14:47 on March 11, 2011 and visually checked that red indicator lights were on through the warning windows above the control panels in the main control room for the two reactors (hereinafter called "Units 1 & 2 main control room"). He confirmed that all control rods had been fully inserted and the two reactors were automatically scrammed (see Attachment IV-3).

The shift supervisor gave directions to the assistant shift supervisor and other members at his desk located between the control panels of Units 1 and 2. Operators sitting at the control panels concentrated their attention on monitoring the plants and carrying out the necessary action under the command of the senior operators. The senior operators reported the status and operation of the plants to the section chief.

The shock of the earthquake caused the earthquake and fire alarms to sound in the Units 1 & 2 main control room at that time. The shift supervisor knew that even dust blown up into the air inside rooms activated the fire alarms at TEPCO's Kashiwazaki-Kariwa Nuclear Power Station (hereinafter called "Kashiwazaki-Kariwa NPS") at the time of the Chuetsu-oki Earthquake in July 2007. Since the fire alarm was designed so that it could not be turned off if a fire actually broke out, he tried turning it off to find out whether or not a fire had started. The shift supervisor was able to stop the fire alarm and thereby he judged that there was no fire within or near the Units 1 & 2 main control room.

(ii) From approximately 14:46 to 14:47 on March 11, 2011, the shift team switched the power for the internal use of Units 1 and 2 to off-site power.

However, the external power supply did not work because the switchyard breaker was damaged in the earthquake causing the emergency bus[2] to lose its power supply. Consequently, the power to the reactor protection system (RPS)[3] receiving power through the emergency bus was lost and a signal to isolate the reactor containment was issued, followed by an automatic closure of MSIV.

Almost simultaneously, an emergency diesel generator automatically started and the shift team confirmed that the emergency bus was charged by checking the indicator lamp.

(iii) At approximately 14:50 on March 11, feed water pump of Unit 2 stopped. The shift team manually activated the reactor core isolation cooling system (RCIC) according to prescribed procedures. As the reactor water level of Unit 2 climbed up at approximately 14:51 the same day, the RCIC automatically stopped. At around 15:02 that day, the shift

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[2] The emergency bus is a bus that receives power from off-site grid and on-site emergency diesel generators and supplies power to the safe-reactor-shutdown facilities and engineered safety features such as ECCS, the primary containment vessel (including isolation valves), containment core spray systems and so forth.

[3] The Reactor Protection System (RPS) is a system that is designed to automatically and rapidly shutdown the reactor (reactor scram), in case a transient event that would impair reactor safety occurs or is anticipated to occur caused by components' malfunction or operator's erroneous action.

team manually restarted the RCIC of Unit 2 while monitoring the reactor water level.

At approximately 14:52 that day, the reactor pressure increased as the main steam isolation valve had closed and the steam was confined in the reactor. A "REACTOR PRESSURE HIGH" warning was issued and two emergency isolation condenser (IC) systems (A and B) automatically started.[4]. The shift supervisor received the report from the senior operators and was convinced that the IC systems A and B were in normal operation.

In addition to the IC and the RCIC, a high-pressure coolant injection system (HPCI) was also available as a reactor coolant injector for Units 1 and 2. To control the reactor pressure, the shift team planned to use the IC for Unit 1 and the RCIC for Unit 2 according to standard procedures and decided to use the HPCI for either unit if its reactor water level decreased.

Moreover, the shift team confirmed that Unit 2 was subcritical at approximately 15:01 on March 11 and Unit 1 was subcritical at approximately 15:02. Team leaders reported the situation to the NPS ERC.

(iv) The Unit 1 IC systems A and B had four isolation valves each, two inside and another two outside the containment (see Attachment IV-4), which were all motor-operated (MO) valves.[5]. The system was configured so that they would stop only with the opening/closing of the return line isolation valves (MO-3A and 3B) and the other valves (MO-1A, 2A, 4A, 1B, 2B and 4B) would remain fully open even if the IC systems were shut down[6].

As indicated in Table 37-1 of Section 37-1 of the "Fukushima Dai-ichi Nuclear Power Station Facility Safety Regulations", the allowable rate of temperature change should be 55°C per hour or less and this value was used as the operational upper limit. At approximately 15:03 on March 11, however, the shift team assumed that because the rate at which Unit 1's reactor pressure was dropping was so fast that the reactor coolant

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4 Isolation condensers at Unit 1 are designed to start up automatically, if the RPV pressure reaches or exceeds 7.13 MPa gage with a duration of 15 seconds.

5 An electrically operated valve is a valve where the valve actuator part is driven by a motor in response to the electrical signal from logic circuits in the corresponding system or equipment.

6 The IC valves at Tsuruga NPS Unit 1 are also operated according to the same procedure.

temperature would decrease at a higher rate than the upper limit if they continued to cool down the reactor with the two IC systems.

Thus to manually shut down the two IC systems and they would be unable to abide by the regulation, the shift team closed only the return line isolation valves (MO-3A and 3B) of the two IC systems (A and B), which were in operation at that time, according to the standard operating procedure.

The shift team decided to keep the IC system B at rest and restart only the IC system A to maintain the reactor pressure at 6 to 7 MPa gage. The team's plan was to open/close only the return line isolation valve (MO-3A) according to the standard operating procedure so as to repeat the shutting down of the IC and keep the other isolation valves (MO-1A, 2A and 4A) fully open while the IC was stopped. In the IC System B, they completely closed the return line isolation valve (MO-3B), kept the other three valves (MO-1B, 2B and 4B) fully open and kept the system at rest.

From approximately 15:17 that day until the total loss of AC power sources caused by the tsunami, the shift team opened and closed the return line isolation valve (MO-3A) of the IC system A three times while keeping the other three (MO-1A, 2A and 4A) open for the purpose of maintaining the reactor pressure of Unit 1 at 6 to 7 MPa gage. In fact, the plant data showed that the pressure of Unit 1 repeated a decrease/increase change shaped like a “V” three times from 15:00 till 15:30 that day and continued to fluctuate between 6 and 7 MPa gage (see Attachment IV-5).

(v) The reactor pressure of Unit 2 increased because the main steam isolation valve was closed due to off-site power loss. The main steam safety relief valve[7] (SRV) automatically repeated open/close cycles[8] (see Attachment IV-6). The water temperature of the suppression chamber (S/C) rose due to high-temperature and high-pressure steam blown out from the SRV into the S/C. The shift team started cooling down S/C in S/C cooling mode by activating the residual heat removal system

[7] The main steam safety relief valve (“SRV”) is a valve which opens to release the steam to the suppression chamber automatically or remotely and manually from the main control room to protect RPV from abnormal overpressure amounts. The relieved steam is cooled and condensed in the suppression pool. This valve also has a function of automatic depressurization system (ADS) constituting ECCS.

[8] At Unit 2 eight relief valves are installed. These valves work as relief valves around a pressure of 7.5MPa gage, and as safety valves around 7.7 MPa gage, though working pressures are a little different among each other.

(RHR) from approximately 15:00 to 15:07 on March 11.[9] They started the S/C spray at approximately 15:25 that day.

Since the main steam isolation valve of Unit 1, like Unit 2, was also closed due to off-site power loss, the shift team decided to cool down the S/C in preparation for a possible increase in temperature of the suppression chamber water for fear that the reactor pressure would early or late due to SRVs' operation. Therefore, from approximately 15:04 to 15:11 that day, the shift team successively manually activated in sequence the containment cooling systems (A and B) of Unit 1 in S/C cooling mode.

(vi) At approximately 15:28 that day, the RCIC of Unit 2 automatically stopped again due to a rise in the reactor water level. At approximately 15:39, immediately before Unit 2 lost all AC and DC power due to damage by the tsunami, the shift team manually reactivated the RCIC of Unit 2 monitoring the reactor water level.

(vii) Before the arrival of the tsunami after the earthquake, a member of the shift team who had been in a skill-training building passed by a demineralized water tank on his way to the Units 1 & 2 main control room and found the water leaking from flange portions in the tank.

c. Action taken at the Units 3 & 4 main control room

(i) Dust blown up in the air by the shock of the earthquake filled the main control room for Units 3 and 4 (hereinafter called "Units 3 & 4 main control room"). In the white smoke screen, the shift team waited for the quake to cease and then started the normal scram response operation (see Attachment IV-7).

At approximately 14:47 on March 11, the shift team confirmed that the Unit 3 reactor had been automatically scrammed so they manually stopped the main turbine.

Unit 4 was undergoing a periodic inspection and all fuel assemblies had been transferred from the reactor to the spent fuel pool (SFP).

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9 RHR system is a system that removes the heat from the coolant using pumps and heat exchangers after a normal reactor shutdown, or maintains the reactor inventory by injecting water into the core at emergency. The RHR system consists of six operational modes: the reactor shutdown cooling mode, low pressure coolant injection mode (ECCS), containment spray mode, steam condensing mode, suppression chamber cooling mode, and fuel pool cooling mode. One of the modes is designated as ECCS as shown above.

(ii) At approximately 14:48 that day, Units 3 and 4 lost off-site power due to the earthquake and their main steam isolation valves automatically closed completely. Except for one emergency diesel generator (4A) of Unit 4, which was undergoing a periodic inspection, all other emergency generators of Units 3 and 4 started up normally and the shift team confirmed that the power supply to the emergency bus of the high voltage switchboards was recovered.

At approximately 14:54 that day, the shift team confirmed that Unit 3 was subcritical.

At approximately 15:05 that day, the shift team manually started the RCIC of Unit 3 (quick start). At approximately 15:25, they confirmed that the RCIC had automatically stopped as the reactor water level increased.

The reactor pressure of Unit 3 increased almost simultaneously. As a result, the SRV automatically opened by its safety function, and the steam blown out from the SRV went into the S/C and the chamber water temperature was trending upward. The shift team thought that they should activate the containment cooling system. At that time, however, a major tsunami warning had already been issued. If the tsunami arrived after the pumps were activated, the pumps would run dry and fail because they would be unable to pump water up as the water level fell due to the backrush of the tsunami. Unlike the shift team of the Units 1 & 2 main control room, the shift team on duty at the Units 3 & 4 main control room decided not to activate the pumps for the time being in preparation for the arrival of the tsunami and to wait and see what would happen.

(iii) After the earthquake, the shift supervisor confirmed the safety of his team members and alerted the other people working in and around the reactor buildings (R/B) and turbine buildings (T/B) of Units 3 and 4 of the earthquake and tsunami through paging[10].

The shift team sent all information on their actions to the NPS ERC which then sent the information to the TEPCO ERC via the teleconference system.

(iv) The fire alarm started sounding in the Units 3 & 4 main control room as it did in the Units 1 & 2 main control room. However, the shift supervisor was able to stop the

[10] Paging refers to broadcasting or communicating installations used for the communications on routine work or for emergencies within the NPS site.

alarm. It was therefore confirmed that no fire had broken out in or near the Units 3 & 4 main control room.

(3) Possibility of IC piping rupture immediately after the earthquake

a. The situation just before the earthquake

The Unit 1 at the Fukushima Dai-ichi NPS was in normal operation before the earthquake as indicated in the automatically recorded charts of its parameters including the reactor pressure, water level and temperature that were continuously recorded before the earthquake until the total loss of power.

These recorded parameters were consistent with the action that the shift team took immediately after the earthquake as described in (2)b above (see Attachment IV-5 for the reactor pressure, IV-8 for the reactor water level, and IV-9 for the inlet temperature of the reactor recirculation pump of Unit 1 right after the earthquake).

At present, therefore, there is no ground to doubt the accuracy of the parameters. Based on the parameters, we are going to discuss whether or not the IC pipes were broken right after the earthquake and lost its function.

b. Changes in the main parameters

According to the parameter released by TEPCO, the main steam isolation valve of Unit 1 closed immediately after the earthquake at approximately 14:46 on March 11, 2011, and the reactor pressure exceeded 7 MPa gage. The same parameter, however, indicates that the reactor pressure of Unit 1 plummeted to approximately 4.5 MPa gage at approximately 14:52 the same day and then made a V-shaped recovery to over 7 MPa gage. After that, it fluctuated three times between almost 6 MPa gage and 7 MPa until around 15:30 that day.

According to the parameter, the reactor water levels of systems A and B showed the same trends as the reactor pressure from around 14:46 that day[11].

[11] According to plant parameters released by TEPCO the RPV water level, after the initial IC start-up, repeated a similar up-and-down trend (with a time delay of 30 minutes) to the RPV pressure. This time difference can be explained as follows:
The RPV water level was to be recorded with a chart speed 60 times higher than real time after a scram in order to enable later verification on detailed level changes. However, this setting was reset on the loss of the off-site grid and

In addition, there is no evidence that the SRV of Unit 1 repeatedly opened and closed during the aforementioned period of time.

c. Inferences from the reactor pressure and water level

The changes in the parameters described in (3) b above indicate that the IC systems A and B automatically started at approximately 14:52 on March 11, the shift team stopped the two systems at approximately 15:03 that day and restarted the IC system A, and then they opened and closed the isolation valves of the A system three times to control the reactor pressure from approximately 15:17 that day. Based on this, it is recognized that at the time the IC isolation valves were opened and closed according to the shift team's operation, the IC was operating normally, the pressure of the reactor pressure vessel was maintained, and the pressure rose and fell with the operation of the IC isolation valve.

If the IC pipes broke due to the earthquake (excluding minor damage that would not affect the functioning of the IC), the steam would leak from the broken part and the reactor pressure and water level would fall quickly, except if the broken part was within an area isolated from the reactor pressure vessel by isolation valves.

At the earthquake, the control switch was set to “AUTO” and the return line isolation valves (MO-3A and MO-3B) of the IC systems A and B located outside the containments were closed and the other valves (MO-1A, 2A, 4A, 1B, 2B and 4B) were open. From approximately 14:52 until 15:03 that day, the IC systems A and B were both operating with all isolation valves open.

After that, the return line isolation valve (MO-3A) of the IC system A outside the containment continually opened and closed and the other three valves (MO-1A, 2A and 4A) were kept open. The IC system B was shut down from approximately 15:03 that day and only its return line isolation valve (MO-3B) outside the containment was closed while the other three (MO-1B, 2B and 4B) were kept open. At any moment, therefore, no part of the IC systems A and B pipes was isolated from the reactor pressure vessel as a result of

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it worked effectively only during the period of the scram and off-site power loss. Accordingly, until off-site power loss occurred after the scram caused by the earthquake around 14:26 on March 11 the interval of 1 second is stretched to that of 1 minute on the time-scale axis of the chart due to such a reset.

damaged piping.

Nothing but the changes in the reactor pressure and water level due to the opening and closing of the IC isolation valves can explain such a phenomenon because both the reactor pressure and water level sharply fell and rose once, and then continually rose and fell. In addition, judging from the tendencies of the reactor pressure and water level parameters, it can be reasonably assumed that no rupture that would jeopardize the IC's functions occurred in the piping of the IC systems A and B that were not isolated from the reactor pressure vessel, because the two factors increased a total of four times from the earthquake until the loss of power.

d. Inference from the failsafe function

The IC systems A and B respectively had two isolation valves (MO-1A/4A and MO-1B/4B) inside the containment and another two (MO-2A/3A and 2B/3B) outside the containment. The pipes of the two systems had a circuit (hereinafter called "rupture detection circuit") to detect a pipe rupture based on the difference between the pressures at the outside radius and inside radius of the IC piping. When the rupture detection circuit detects a pipe rupture , it opens and the supply of power is stopped[12]. At the same time, another circuit (hereinafter called "valve drive (closing) control circuit”), which is designed to close isolation valves, shuts down and electric current flows through it[13]. As the isolation valve drive (closing) motor are energized[14], all open isolation valves are closed[15]

12 At the section of L-figured pipe (pipe elbow) constituting IC primary pipe inside PCV, pressure sensing devices are installed to measure the pressure at the inside radius (low pressure side) and the outside radius (high pressure side) of an elbow. The differential pressure naturally increases due to very high flow rate when pipe rupture occurs at any pipe section. When the ratio of the pressure at the outside radius to that at the inside radius exceeds 300% (three times), the pipe rupture detection circuit (PRDC) is switched off and its flowing DC current fails. Considering such a mechanism, therefore, regardless of a real occurrence of pipe ruptures or simple DC current loss (for example, battery depletion) in the PRDC, all valves are activated to the fully closed position in response to DC current loss in PRDC.

13 The loss of current to an electromagnet in a device called an electromagnetic relay (relay) (see Attachment IV-10 (ii)) de-energizes the electromagnet and causes the coil terminal to make contact with a terminal of the valve drive (closing) control circuit, resulting in the valve drive (closing) control circuit being activated (see Attachment IV-10 (iii)).’

14 Current flow from the valve drive (closing) control circuit to the valve drive switch operating coil energizes its electromagnet to operate the valve drive power supply switch and consequently power is supplied from the valve drive power source to the valve drive motor (see Attachment IV-10 (iv)), thus closing the isolation valve.

(see Attachment IV-10). This kind of configuration is called "failsafe function."

At the earthquake, the IC‘s control switch was set to "AUTO" as usual and, except for the return line isolation valves (MO-3A and MO-3B) that were closed, all other valves were open and could be readily closed once a "STEAM PIPING PRESSURE DIFFERENCE HIGH" warning was issued[16].

At least until the arrival of the tsunami after the earthquake, the rupture detection circuit and the valve drive (closing) control circuit did not lose their power supplies as not affected by flooding. It can be assumed that the failsafe of the IC (systems A and B) was able to operate normally[17].

Based upon this assumption, the IC systems A and B would not have automatically started because the "STEAM PIPING PRESSURE DIFFERENCE HIGH" warning would have been issued to the rupture detection circuit if the pipes of the IC system A or B had been broken by the earthquake[18]. The same applies in the event that the DC supply to the rupture detection circuit.

According to Unit 1's alarm typer and the testimonies of the shift team, however, it was apparent that the IC systems A and B automatically started at approximately 14:52 on March 11 and there is no evidence to dispute these facts (see Attachment IV-11 for details about the alarm typer of Unit 1).

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15 If the pipe rupture detection circuit issues a "STEAM PIPING HIGH DIFFERENTIAL PRESSURE" signal and the DC power source to the circuit is lost, an "AUTO CLOSE" signal will be issued to the circuit which otherwise opens isolation valves at a "REACTOR HIGH PRESSURE" signal in order to prevent them from being automatically opened at the "REACTOR HIGH PRESSURE" signal to result in IC activation. When an "AUTO CLOSE" signal is issued as mentioned above, the signal will not be cancelled and the isolation valve will not open unless the shift team presses the reset button in the main control room. In addition, once a "STEAM PIPING HIGH DIFFERENTIAL PRESSURE" signal is detected, the signal will not be cancelled and the isolation valve will not open because of the "SEAL IN" function unless the shift team confirms the absence of high differential pressure and presses another reset button different from that of "AUTO CLOSE".

16 When the control switch of the isolation valve is not set to "AUTO" but to "FULLY CLOSED" or "FULLY OPEN" on the control panel, the isolation valve will not be closed by the operation of the pipe rupture detection circuit. All isolation valve control switches are usually set to "AUTO" when the IC is not in operation.

17 On October 18, 2011, it was confirmed that the supply piping isolation valve (MO-2B) of the IC system B, which must have been open until the arrival of the tsunami, was completely in the closed position. It can be assumed that the DC power source of the pipe rupture detection circuit was lost due to the tsunami and consequently the failsafe function caused the valve drive (closing) control circuit to fully close the valve.

18 In addition, when a "STEAM PIPING HIGH DIFFERENTIAL PRESSURE" signal is issued, the isolation valve will not automatically open even if the closure of all isolation valves leads to a rise in reactor pressure because an "AUTO CLOSE" signal will block the circuit that otherwise opens isolation valves at a "REACTOR HIGH PRESSURE" signal.

Judging from the failsafe device of Unit 1 did not work in a situation where it could function correctly and the IC systems A and B started, it can be reasoned that the pipes did not suffer any damage that could trigger a "STEAM PIPING PRESSURE DIFFERENCE HIGH" warning.

e. Inference from records and the actions of the shift team

According to the following records on the plant control and the actions of the shift team right after the earthquake, it can be presumed that the possibility of any rupture on the IC pipes outside the containment due to the earthquake that was extremely small.

From the actions that the shift team took to control the plant immediately after the earthquake as described in (2)b above, we do not see any evidence that the IC pipes was broken soon after the earthquake.

From the detail investigations of related data and materials, including the operator's logbook, photos on the whiteboard used in the Units 1 & 2 main control room, memo written by NPS ERC personnel who received telephone calls from the shift team, and teleconference discussions transcribed by the NPS ERC and the Kashiwazaki-Kariwa NPS personnel, no evidence to imply that the IC piping was ruptured shortly after the earthquake could be found[19].

The IC systems A and B operated for about 11 minutes from 14:52 that day, with system B stopping at approximately 15:17 and only system A starting and stopping three times after that. If the IC piping outside the containment had broken, the steam containing a large volume of radioactive material would have been released through the broken part and the shift team and the NPS ERC personnel would have been forced to implement countermeasures. If this were the case, discussions regarding such measures must have been taken place between the shift team and the NPS ERC as well as between the NPS and TEPCO ERCs. If such discussions had ever taken place, some mention of such an important event must have been made somewhere in the records and documents that

[19] IC pipes stayed intact after the earthquake – further evidence justifying their use. If anything, there are some records that shift operators on duty entered the Unit 1 R/B for checking the damages and operated the valve opening to construct the water injection line to the reactor without inconvenience.

members of various positions routinely create at the time of an accident without bringing in any subjective points of view. However, no such description or mention can be found anywhere.

A review of the actions that the shift team took after the tsunami confirms the fact that they went into the Unit 1 reactor building (R/B), operated valves and conducted some other necessary work such as a diesel-driven fire pump (D/DFP) start-up test and the configuration of the fire protection system (FP system) lines. If the IC pipes had ruptured, a large volume of radioactive material would have released from the reactor pressure vessel through the broken part and the radiation level in the R/B and T/B of Unit 1 would climbed up high. If the situation that might have endangered the lives of the shift team missions had ever occurred, it should have affected the subsequent missions. Under such circumstances, it would have been difficult for the shift team to enter the R/B of Unit 1 and perform the plant control work including the opening and closing of IC isolation valves at the Units 1 & 2 main control room. In fact, however, such a situation did not take place. It can be logically assumed that the review of the shift team's actions indicates that there was no vital pipe rupture that could significantly damage the IC's function.

In addition, the Committee extensively questioned people involved in responding to the accident at the TEPCO ERC, NPS ERC or as shift team members about the state of the Unit 1 R/B during the period from the occurrence of earthquake until right after the arrival of the tsunami and the specific work that they did. None of them made any testimony implying IC pipe rupture.

Therefore, the possibility of any breakage on the IC piping outside the containment soon after the earthquake is very small. It is rather reasonable to think that there was no such rupture that could affect the function of the IC on the pipe concerned.

f. Summary

Based on the discussion above, there is no evidence that any pipe rupture occurred in the IC systems A and B immediately after the earthquake either inside or outside of the containment that could hinder the function of the IC[20]. If anything, it is rather logical to think there was no such pipe rupture.

2. Situation and response during the period from the arrival of the tsunami to the special event occurrence report as stipulated in Section 1, Article 15 of the Act on Special Measures Concerning Nuclear Emergency Preparedness (from approximately 15:35 to approximately 17:12 on March 11, 2011)

(1) Response by the NPS ERC immediately after the arrival of the tsunami

(i) After the Tohoku District - off the Pacific Ocean Earthquake at approximately 14:46 on March 11, 2011, members of the NPS ERC learned of the tsunami alert issued to Fukushima Prefecture, the estimated arrival time, the height of the tsunami and other information announced by the Japan Meteorological Agency (JMA) from news programs on TV on the second floor of the seismic isolation building and they immediately relayed this information to the main control rooms of the reactor units.

Site Superintendent Yoshida first learned from the news on television that a three-meter high tsunami would hit the Fukushima Dai-ichi NPS then he learned that the estimated height had been changed to six meters. Site Superintendent Yoshida felt an apprehension that the Residual Heat Removal System (RHR) might lose its cooling function if the emergency seawater pump facilities would be damaged by the backrush of the tsunami.

At that moment, however, Site Superintendent Yoshida did not yet expect that more than one units were to lose all AC power sources at once and station blackout would continue for a long time. He thought that even if the emergency seawater pump facility

[20] At Unit 1 both A and B systems of the containment cooling system (CCS) started up in the mode of torus pool cooling around 15:04 and around 15:11 on March 11, respectively. Although CCS also starts up automatically to remove the heat energy on the occurrence of pipe ruptures in the containment, A & B systems are, in such a case, designed to start automatically and almost simultaneously. According to the event data shortly after the earthquake, both systems started, but with the time difference as mentioned above. So it is not reasonable to think of the automatic actuation in this case. In addition, shift operators on duty at Unit 1 as well as Unit 2 testified that they had intended to cool the suppression pool and activated both systems in sequence, in advance, for fear that the temperature and the pressure of suppression chamber, earlier or later, would elevate due to the steam release to the suppression pool via automatic steam relief valves. Such an explanation from operators does not seem to be contradictory with the objective situation about containment cooling system operation.
After all, CCS start-up after the earthquake doesn't necessarily provide a positive basis for the possibility of pipe ruptures inside the containment vessel.

were damaged, the IC of Unit 1 and the RCICs of Units 2 and 3 could be used to cool down the reactors or they could recover cooling capability by restoring the pump facility while constructing power interchange facility between the units.

The NPS ERC also directed all the relevant divisions to quickly confirm the safety of all their on-site workers, evacuated all personnel to the Seismic Isolation Building and ordered the shift teams at the main control rooms to perform the first response after the confirmation of a reactor scram. Therefore, they did not have time to fully check the damages to the NPS facilities, or implement any other protection measures against the tsunami before its arrival such as piling up sandbags around the buildings and other external facilities.

(ii) The tsunami hit the Fukushima Dai-ichi NPS twice at approximately 15:27 and 15:35 on March 11, 2011. The seismic waves reached a platform four meters above sea level and inundated the emergency seawater pump facility and then travelled up to platforms 10 and 13 meters above sea level and flooded the R/Bs, T/Bs and other facilities.

The AC power to all six reactors was supplied by emergency diesel generators (DG) at the time the tsunami reached the Fukushima Dai-ichi NPS. However, the water-cooled diesel generators' seawater pumps and many diesel generators were submerged (except 2B of Unit 2, 4B of Unit 4 and 6B of Unit 6) and most power supply panels were immersed in seawater. As a result, the six reactors completely lost their power sources from approximately 15:37 to 15:42 that day except for Unit 6's air-cooled DG (6B).

The NPS ERC received reports from the three main control rooms that the nuclear reactors were successively losing their power supplies and Units 1, 2 and 4 in particular had lost all of their power sources. Everyone at the NPS ERC was lost for words at the ongoing unpredictable and devastated state.

The TEPCO ERC continually obtained such information via the teleconference system.

Site Superintendent Yoshida understood that a situation that far exceeded any expected major accident had actually taken place. He could not think of anything on the spot and so decided to implement the procedure stipulated by the law. At approximately 15:42 that day, he reported to government offices and other relevant organizations that a specific event (the total loss of all AC power sources) as defined in Section 1, Article 10 of the Act on Special Measures Concerning Nuclear Emergency Preparedness (hereinafter called "NEPA") had occurred[21].

(iii) Usually, the Tokyo and NPS ERC would have been able to instantly grasp and monitor the operational status of all units via the Safety Parameter Display System (SPDS). In other words, detailed data including plant parameters and information on open/close status of valves would have been communicated via the SPDS to the Tokyo and NPS ERC as long as SPDS functioned properly. If so, such data would be displayed on the huge screens at the Tokyo and NPS ERC and the staff members could have understood and monitored the plants. In reality, however, the SPDS was not available because it had lost its power supply after the tsunami.

The NPS ERC had to try to understand the situation at each plant based on information that the operation team obtained from the main control rooms by very limited means such as fixed-line telephones and hotlines. The TEPCO ERC had to comprehend the status of the plants from the conversation relayed via the teleconference system at the main table of the NPS ERC.

In addition, the main control rooms that was the only source of information on the plant status for the two ERCs lost all AC power supplies and Units 1, 2 and 4 also lost DC power sources. They were unable to even obtain the plant parameters using measuring instruments except for Unit 3.

Site Superintendent Yoshida thought it would be impossible to take any action necessary to control the nuclear plants without the plant parameters, especially those for the reactor water level and pressure. He therefore directed the recovery team of the NPS ERC to give priority to restoring the equipment necessary for measuring the main parameters.

However, they did not have any batteries or small generators in the NPS ERC or the main control rooms of the Fukushima Dai-ichi NPS despite that DC or AC power sources were indispensable to the restoration of the power for the measuring instruments at

21 At this point of time Site Superintendent Yoshida made an uncalled-for declaration of the occurrence of SBO at Units 4 and 5 which were not subject to the Act on Special Measures Concerning Nuclear Energy Preparedness (Nuclear Energy Preparedness Act), because they were out of service under the periodical inspection. In April, however, he retracted the notice regarding Units 4 and 5.

emergency. They had to procure such power supplies from inside and outside sources.

(2) Response by the Units 1 & 2 main control room immediately after the arrival of the tsunami

(i) The damage to Unit 1 caused by the tsunami included the immersion of the seawater pump, the power supply panel and the emergency bus and, as a result, both emergency DGs (1A and 1B) stopped. At approximately 15:37 on March 11, 2011, the unit, after all, lost all AC power sources.

At Unit 2, an emergency DG (2A) installed on the first basement floor of its T/B was submerged. Although another emergency DG (2B) in the common fuel pool building was not flooded, the emergency DG power supply panel was damaged as the electrical room located in the basement of the same building was flooded. At approximately 15:41 that day, Unit 2 lost its all AC power supplies just like Unit 1.

As all AC and DC power sources of Units 1 and 2 were lost, the lights gradually went out and the alarms stopped sounding in the Units 1 & 2 main control room. Only the emergency lights remained on in the Unit 1 block of the room while the lights in the Unit 2 block went out completely.

Units 1 and 2 lost all DC power supplies as the DC power supply panel on the first basement floor of the T/B was submerged. By approximately 15:50, they were unable to monitor plant parameters including the reactor water level.

The shift team used lights with portable batteries and LED flashlights to read the event-based and state-based "Emergency Operating Procedure." However, the content of the material could not be applied directly to the actual events taking place. The team members also checked the "Emergency Operating Procedure" for accident management (AM) to identify the operating procedure necessary to control Units 1 and 2.

However, the "Emergency Operating Procedure" for AM contained only internal events as causal events for AM and did not consider external events such as an earthquake or tsunami as causal events. There was no reference taking into account the events where all AC and DC power sources would be lost. In addition, the descriptions of the standards were written on the assumption that the state of the plants can be monitored by the control panel indicators and measuring instruments in the main control room and that the control panel could be manipulated.

As a result, 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.

(ii) It was impossible to determine whether the IC isolation valves of Unit 1 were open or closed right after the arrival of the tsunami because indicators' lamp were "off". Additionally, the shift team repeatedly opened and closed the return line isolation valve (MO-3A) to operate the IC before the tsunami but they could not remember whether the valve was open or closed at the moment when there was a total loss of power[22]. The shift team had not yet realized that all isolation valves were designed to be closed by the failsafe function when all power supplies were lost. Accordingly, the shift team could not identify the operating status of the IC immediately after the tsunami. At any rate, the shift team believed it was impossible to open or close the IC isolation valves remotely from the control panel because all power sources had been lost and all the status indicators on the panel were off.

The shift team confirmed that the status indicator lamp for the high-pressure coolant injection system (HPCI) of Unit 1 was dimly lit on the control panel. However, the indicators finally went out and they deemed it impossible to activate the HPCI due to the total loss of DC power sources[23].

(iii) The shift team manually started the RCIC of Unit 2 at approximately 15:39 on March 11, right before the loss of all AC/DC power sources.

The team was unable to monitor the operation of the RCIC using the control panel

[22] Judging from the plant parameters released by TEPCO , the RPV pressure had turned from decline to rise immediately before the power loss , so that it can be inferred that the IC's return line valve (MO-3A) had been in the closed position at the time of tsunami arrival.

[23] To start up HPCI it is necessary to supply the turbine stop valve and the steam regulation valve with lubricants by activating the auxiliary oil pump, but DC power (battery) had lost its function by flooding. Accordingly, the restoration of the DC power facilities is urgently needed to start up HPCI. However, such large capacity batteries could not easily be procured because of traffic restrictions and heavy congestion following the earthquake and tsunami. Moreover even when they could be procured, there were great difficulties with carrying them downstairs and replacing damaged batteries with new ones in the flooded basement of R/B at Unit 1. Neither procurement nor replacement could be realistically expected in view of the surrounding conditions.

because all the lamps on the panel showing the status of valves were “off” due to the total loss of power sources.

Similarly, all the lamps on the panel at Unit 2 showing the opening and closing of the HPCI valves were off and the shift team deemed it impossible to activate the HPCI due to the loss of necessary DC power source. When the recovery team of the NPS ERC performed a field inspection of the power facilities sometime after 16:39 that day, they found that the DC power for the HPCI on the first basement floor of the Unit 2 service building was submerged.

The seawater pumps of the containment cooling system and the RHR, which were used to cool the S/Cs of Units 1 and 2, also failed due to tsunami.

(iv) Since the shift supervisor could not verify the reactor water level of Units 1 and 2 or determine the operation of the IC and the RCIC, he reported the situation to the NPS ERC by approximately 16:36 on March 11.

At approximately 16:42 that day, the shift team noticed that they could read the reactor water level gage (wide-range) indicator of Unit 1 (see Attachment IV-12). According to the level gage reading, the reactor water level of Unit 1 was -90 cm at wide range, then decreased, finally showing -150 cm at wide-range before it dropped and disappeared at approximately 16:56 that day. To record the continuously decreasing water level with only the emergency lights “on”, the shift team wrote the time of the measurement and the water level values on the control panel surface next to the reactor water level gage (wide-range) and reported the results to the NPS ERC.

Around that time, the Units 1 & 2 main control room and the NPS ERC could not use the PHS phones, their main communication tool, therefore they communicated via the hotlines and fixed-line telephones.

(v) While they were confirming the status of the Units, the shift supervisor received a report from a shift team member who checked the area around the Units 1 & 2 main control room that seawater was flowing into the R/B. He realized that even the R/B was flooded by the tsunami.

(3) Response by the Units 3 & 4 main control room immediately after the arrival of the tsunami

(i) The damage at Unit 3 caused by the tsunami included the immersion of the seawater pump, the power supply panel and the emergency bus (as a result, the stoppage of both emergency DGs (3A and 3B)). At approximately 15:38 on March 11, 2011, the unit lost all AC power sources.

An emergency DG (4A) installed on the first basement floor of the T/B at Unit 4 was submerged. Although another emergency DG (4B) in the common fuel pool building was not flooded, the emergency DG power supply panel was damaged as the electrical room located in the basement of the same building was flooded. At approximately 15:38 that day, Unit 4 lost its all AC power sources. At approximately 15:38 that day, the only interior lights in the Units 3 & 4 main control room were the emergency lights due to the total loss of AC power supplies. LED flashlights that were distributed to the Units 3 & 4 main control room for the field inspection of the facilities in February 2011 were used to light the room. Unit 4 was undergoing a periodic inspection and all fuel assemblies had been transferred from the reactor to the SFP. Due to the loss of all AC power sources, it became impossible to monitor the measuring instruments including SFP water temperature gage powered by AC source. At Unit 3 on the other hand, main parameters such as the reactor pressure and water level could be monitored by measuring instruments because its DC power distribution panel was located in the basement of the T/B and not flooded by tsunami. The shift team used LED flashlights mainly to monitor Unit 3's parameters including the reactor water level.

(ii) In addition, the RCIC and the HPCI, which were operated by DC, could be activated because Unit 3's DC power supply panel was not flooded. The shift team confirmed that the RCIC and HCPI could be activated since the status indicators on the control panel located in the Units 3 & 4 main control room were on.

At approximately 16:03 on March 11, the shift team manually started the RCIC of Unit 3 in the Units 3 & 4 main control room. They monitored the status of the cooling system by checking the readings from instruments including the discharge pressure and the revolutions per minute on the control panel so that they were ready to promptly activate the HPCI in case the RCIC stops. Although both the RCIC and HPCI played an important role in cooling down the reactor and maintaining the reactor water level, they could not bring the reactors into cold shutdown using these systems alone. The shift team had to investigate and implement alternative methods of water injection while the two systems were operable.

The shift team therefore tried to keep the RCIC and the HPCI of Unit 3 operational for as long as possible to ensure an adequate period for the investigation and implementation of an alternative method of water injection. From late afternoon, the shift team cut the unnecessary loads, in sequence per operating procedure to extend the battery life to maintain the RCIC and the HPCI operating time for as long as possible.

(iii) Around that time, the shift team of the Units 3 & 4 main control room became unable to use the PHS phones, their main communication tool, so they communicated with the NPS ERC and the Units 1 & 2 main control room using only the hotlines and fixed-line telephones.

(4) Assessment of the occurrence of a specific event as stipulated in Paragraph 1, Article 15 of the NEPA and related responses

(1) At approximately 16:36 on March 11, 2011, the shift team could not determine the reactor water level of Units 1 and 2. The operating status of the IC of Unit 1 and the RCIC of Unit 2 were also unknown to them. Therefore, they did not know if the water injection was effective or not.

Site Superintendent Yoshida did not think that the failsafe function might have worked due to the total loss of power sources. No one at the NPS and TEPCO ERC pointed out the possibility. Site Superintendent Yoshida thought it impossible to conclude the IC and the RCIC were injecting water into and cooling down the reactors, although he expected that the IC of Unit 1 and the RCIC of Unit 2 were operating effectively. Thus Site Superintendent Yoshida assumed the worst scenario and reported to the relevant authorities concerned the occurrence of a specific event (functional loss of ECCS) falling under Paragraph 1, Article 15 of the NEPA at approximately 16:45 that day.

Considering the state of the nuclear reactor was of the utmost urgency under such circumstances, the recovery team of the NPS ERC decided to give priority to the power supply recovery work for connecting batteries to the DC-powered reactor water level gage to enable the reactor water level of the two units to be monitored and measured from the main control room. The recovery team searched the NPS premises for batteries that could be used for this purpose. By late afternoon, they had obtained four 6V batteries from partner company offices and two 12V batteries removed from motor coaches.

(ii) At approximately 16:45 that day, the shift team reported to the NPS ERC that they had confirmed the reactor water level gage (wide-range) was -90 cm. Thus Site Superintendent Yoshida judged that the reactor water level had been confirmed and the specific event (functional loss of ECCS) as defined in Paragraph 1, Article 15 of the NEPA had not occurred. At approximately 16:55 that day, he reported the relevant authorities concerned that he had withdrawn the specific event occurrence report. Considering the operation status of the IC was not yet confirmed and the reactor water level was trending downward at the time, it can be assumed that it was not yet possible to eliminate the possibility of an event the loss of ECCS function even though the water level gage had been confirmed. Therefore, it is questionable that Site Superintendent Yoshida's declaration to withdraw the report on NEPA event.

(iii) According to the reactor water level (wide-range), the reactor water level of Unit 1 was decreasing after that, and finally showed -150 cm at wide-range before it dropped at approximately 16:56 that day and it became impossible again to check the reactor water level of Unit 1. At approximately 17:07 that day, the shift team reported the situation to the NPS ERC. Thus Site Superintendent Yoshida deemed that a specific event (functional loss of ECCS) as defined in Paragraph 1, Article 15 of the NEPA had occurred and reported it to the authorities concerned at approximately 17:12 that day.

(iv) At approximately 17:15 that day, the engineering team of the NPS ERC calculated the time when the reactor water level of Unit 1 would reach the top of active fuel (TAF) (the core exposed to start). As a result, they estimated it would reach the TAF in one hour if the reactor water level continues falling at its current rate. This means that, at that moment, the NPS ERC was aware of the fact that the reactor water level was falling by approximately 60 cm every 14 minutes and that the reactor core could become exposed in one hour, at approximately 18:15. The TEPCO ERC also obtained the same information via the teleconference system and seemed to have had the same knowledge. If so, the NPS and TEPCO ERC could at least by that time have easily known that the IC's "cooling" capability was inadequate and they had to start an alternative method of water injection regardless of what the two ERCs had previously known about the operating status of the IC.

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 ERC nor the TEPCO ERC had the mindset to presume the operation status of the IC from the information on the falling reactor water level of Unit 1.

3. Situation and response during the period from the specific event occurrence report according to Paragraph 1, Article 15 of the NEPA until the explosion of the Unit 1 R/B (from approximately 17:12 on March 11 to 15:36 on March 12, 2011)

(1) Operation of the IC of Unit 1 and its assessment

a. Operation of the IC of Unit 1

(i) With the exception of the isolation valves (MO-3A and 3B) that had already been fully closed remotely from operating the control panel[24] because the DC supply to the rupture detection circuit was lost, it is assumed that the failsafe function worked in the IC systems (A and B) of Unit 1 automatically to close the isolation valves (MO-1A, 2A, 4A, 1B, 2B and 4B) inside and outside the containment right after the arrival of the tsunami (see 1(3) above for more details on the failsafe function). It is understandable however that the isolation valves could not be fully closed if the valve drive power source[25] was lost in the course of closing. Further consideration is needed concerning the status of the isolation valves.

(ii) According to the results of an investigation of the IC motor-operated valve conducted

[24] Judging from plant parameters released by TEPCO, RPV pressure had turned from a downtrend to an uptrend, right before the loss of all AC power, so it can be inferred that the IC's return line valve (MO-3A) must have been in the closed position.

[25] The IC isolation valves outside PCV (MO-2A & 3A, 2B & 3B) are powered by DC power, while the valves inside PCV (MO-1A & 4A, 1B & 4B) are powered by AC power.

by TEPCO on April 1, 2011, it was clearly identified that;

(a) the supplying piping isolation valve (MO-2A) and the return line isolation valve (MO-3A) of the IC (system A) were fully open.

(b) the return line isolation valve (MO-3B) of the IC (system B) was in a circuit state, completely closed.

(c) the supplying piping isolation valve (MO-2B) of the IC (system B) was in a circuit state, implying it was completely closed.

(d) the isolation valves (MO-1A, 4A, MO-1B and 4B) inside the containment were not fully closed(intermediately open but the detail opening status not identified).

The reason that the supplying line isolation valve (MO-2A) and the return line isolation valve (MO-3A) of the IC (system A) were fully open ((a)) was, according to the NPS ERC' internal records, memos and other evidence describing the on-site response at that time, assumed that the operator performed an opening operation after the loss of the IC pipe rupture detection circuit's DC power source (see (1)b (3) and (1)b (4) below). This is consistent with the operation that the operator actually performed at last.

When TEPCO checked the valves indicators on October 18, 2011 and found that these valves were fully open.

The reason that the return line isolation valve (MO-3B) of the IC (system B) was completely closed ((b)) was thought to be due to the closing operation the operator performed (see 1(2) b(4) above) before the signal from pipe rupture detection circuit by the loss of the DC power source, according to the results of a check of the amount of remaining water in the condenser tank, parameters related to the reactor pressure, testimonies of the shift team members, and other relevant evidence.

When TEPCO checked the valve's gage to measure the degree to which it was open on October 18, 2011, it was confirmed that the valve was completely closed.

As for the supplying piping isolation valve (MO-2B) of the IC (system B), the operator did not perform a closing operation (see 1 (2) b (4) above) so it must have been fully open taking into account its operation. However, it was, in fact, completely closed ((c)). The reason for this may be explained that the failsafe function was automatically activated because the DC power source to the IC pipe rupture detection circuit had been lost by the tsunami. Thus, the valve was completely closed. If so, it means that the failsafe function worked correctly and DC sources for driving valve motor was still strong enough to completely close this valve. Moreover, the rupture detection circuit to activate the failsafe function was not damaged even by the earthquake.

When TEPCO checked the valve's gage to measure the degree to which it was open on October 18, 2011, it was confirmed that the valve was completely closed.

Finally, it is thought that the isolation valves (MO-1A, 4A, MO-1B and 4B) inside the containment have been open before the tsunami hit the Fukushima Dai-ichi NPS and, in addition, no evidence was found that the operator carried out a closing operation. However, they were actually intermediately open ((d)). If the failsafe function worked correctly and the power was still enough to drive the isolation valves, they must have been completely closed. One possible reason why an investigation of the circuit concluded they were "intermediately open" is that they did not fully close even by the failsafe function.

It is said that it may take approximately 20 to 30 seconds from the start of closing by the failsafe function until the complete closure. Even if the failsafe function works correctly, the isolation valve not be fully closed but remain partially open when the power source is lost in the course of closing operation due to the loss of the DC power source to the rupture detection circuit. This could be the reason why the isolation valves (MO-1A, 4A, MO-1B and 4B) inside the containment were left half open.

The power sources of the breakage detection circuit, the valve drive (closing) control circuit and the isolation valve drive motor[26] were located dispersedly on the first floor and the first basement floor of the R/B and the T/B of Unit 1. Thus they were not submerged and lost their power sources simultaneously. It is not contradictory that some isolation valves were completely closed by the failsafe function just like the supplying piping isolation valve (MO-2B) of the IC (system B).

[26] The power source for both the pipe rupture detection circuit and the valve actuating (to closing) control circuit are AC sources. As for the isolation valves on the IC system, the valves outside PCV are powered by DC power, while the valves inside PCV are powered by AC power.

(iii) The amount of remaining water can give an indication of the operation of the IC.

When TEPCO checked the condenser tank[27] of the IC (system A) inside the R/B of Unit 1 at the Fukushima Dai-ichi NPS on October 18, 2011, the level indicator showed the remaining water of the IC system A was approximately 65 percent of its full capacity and that of the IC system B was about 85 percent.

The usually stored water of the condenser tank is approximately 80 percent of its full capacity and available for IC operation without refilling for six hours[28].

In addition, there was no refilling of the cooling water in the condenser tanks of the IC systems A and B until this report was prepared.

As the water gage indicated, the cooling water of the IC (system B) remained at about 85 percent of the full tank capacity as of October 18, exceeding the usual maximum value. However, the difference was probably within instrumental errors in measurement. In any case, it can be presumed that the amount of evaporated water from the condenser tanks was very small after around 14:46 on March 11. This presumption is consistent with the fact that a duration time of heat exchange between the high temperature steam in the IC pipes and the cooling water in the condenser tank was very short, based on the fact that the IC (system B) was being operated for only 11 minutes from the time of automatic activation at approximately 14:52 that day until the time of manual interruption at approximately 15:03.

As the water gage indicated, the condenser tank of the IC (system A) was 65 percent full as of October 18. It can be said that since the earthquake at approximately 14:46 on March 11, 2011, about 20 percent of the cooling water had evaporated compared to the actually remaining water amount of the IC (system B) and about 15 percent compared to the usually stored amount. The IC system A operated from approximately 14:52 until 15:03 that day like the IC system B. Then, it repeated start/stop operation three times by

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[27] The effective water capacity of the water tanks for IC systems A and B at Unit 1 is about 100 m^3 each. The rated steam flow rate is 100 tons/ hr for both systems A and B.

[28] Some TEPCO personnel involved explained that the water in IC secondary side tank does not need to be made up for a duration of 8-10 hours. While in "the emergency operating procedure (events based)" there is an article for 12-4 SBO "saying that the water source is durable about 6 hours without any make-up operation." If the heat transfer tubes in the tank are exposed to the atmosphere (whether it be earlier or later) they might be endangered by high temperature ruptures. Therefore, the make-up operation is indispensable to maintain the normal performance of ICs.

means of open/close operation of the return line isolation valve (MO-3A) (for about 11 minutes in total) from approximately 15:17 until 15:37. Therefore, the IC (system A) operated longer than the IC (system B) and the temperature of its cooling water rose with the amount of evaporation increasing. The IC system A naturally lost more water by evaporation compared with the IC system B. Although we must take into account the steam temperature and thermal conductivity of the IC pipes and the temperature of the cooling water of the condenser tank, it can be said that the condenser tank was still about 65 percent full as of October 18 reflecting the difference in the duration time of operation.

Additionally, regarding the operation of the IC (system A), it must be taken into consideration that the isolation valves (MO-2A and 3A) outside the containment were thought to have been fully opened from approximately 18:18 until 18:25 on March 11 (see (1)b (iii) below) and that those valves were fully opened again at approximately 21:30 that day and since then they remained open when this report was prepared (see (1)b (iv) below). How effectively the IC (system A) operated during those periods depends on opening position of the isolation valves (MO-1A and 4A) inside the containment. As mentioned above, the investigation of the IC motor-operated valves conducted by TEPCO indicated that detail valve “opening position” was not known but the valves were intermediately open. Thus it is logical to conclude that the water was flowing at a certain rate in the system.

According to TEPCO's parameters, two thermometers of the system A showed the temperature of return water to the reactor was 135.1°C and 141.7°C respectively as of 12:00 on March 24, 2011. Since these values are clearly higher than the 38.7°C and 38.3°C of system B, it can naturally be concluded that a certain amount of water was evaporating and the cooling water continued flowing in the IC (system A) at that time (in other words, the isolation valves inside the containment were not completely closed but intermediately open). In addition, it can be assumed that the decrease in the system A condenser tank water was very limited at this point of time because the water temperature in the tank rose to, at most, 100°C before the arrival of the tsunami according to TEPCO's parameters.

However, since the reactor pressure and temperature increased from approximately 18:18 to 18:25 on March 11 and then kept rising after around 21:30 that day and a very serious situation continued, it would be natural that a large amount of water would evaporate from the condenser tank (the system A) if the IC (system A) operated effectively enough to cool the core by a few degrees. In fact, the condenser tank of the IC (system A) was still 65 percent full as of the time this report was prepared though there had been no refilling of the water. Only 15 to 20 percent of the full capacity of water was lost.

Taking this fact into consideration, it is unlikely that the IC (system A) did effectively cool the reactor due to unsatisfactory heat exchange inside the condenser tank after the arrival of the tsunami. One possible reason is that thought TEPCO's investigation of the circuit concluded that the degree to which the isolation valves (MO-1A and 4A) were open inside the containment were not known, the actual degrees to which they were open were small and thus the rate of steam flow of the IC (system A) was not enough to fully perform its cooling function.

(iv) Based on the discussion above, it is highly possible that Unit 1 lost all AC and DC power sources soon after the arrival of the tsunami and therefore the unit lost almost all the reactor cooling function. It is, therefore, conceivable that the start/stop operation of malfunctioning ICs would have had only an extremely small effect on the final state of the reactor.

In the following paragraphs, "IC" means the "IC system A."

b. Shift team's assessment of the operation of the IC

(i) Immediately after the arrival of the tsunami, power sources were lost and it became impossible to monitor the operating status of the IC and measure the level of the reactor water via the control panel of the Units 1 & 2 main control room. At this moment, the four isolation valves of the IC might have been put into a fully closed or mostly closed position by the failsafe function. No member of the shift team came up with the actuation of failsafe function due to the loss of power sources.

At approximately 16:42 on March 11, the reading on the reactor water level gage (wide-range) of Unit 1 became visible. The water level gage showed that the level of the reactor water of Unit 1 continued decreasing after reaching -90 cm at wide-range. After showing -150 cm at wide-range, it dropped again and disappeared (“downscale”) at approximately 16:56. Since the falling trend of reactor water level was inconsistent with the normal operation of the IC, the shift team thought it possible that the IC was not working properly. Therefore the shift team took into consideration an alternative method of water injection using the D/DFP. Some members of the team entered the FP pump room on the first basement floor of Unit 1's T/B. By approximately 17:30 that day, they confirmed that the D/DFP was operable and put the pump into standby for quick activation.

After approximately 17:19 that day, the shift team decided to go to the 4th floor of Unit 1's R/B to check if a sufficient amount of water was contained or not in the IC condenser tank with a water level gage installed on the side of the tank. The shift team members who were sent to the building did not wear protective masks or protective clothes though they made other plans including a check of the gage location. They left the Units 1 & 2 main control room. When they arrived at the double doors of the R/B approximately 17:50 that day, they found that their dosimeter (GM tube) had gone beyond the maximum value of 300 cpm[29]. So, they abandoned their plan and returned to the Units 1 & 2 main control room.

As mentioned above, the shift team attempted to enter the R/B and actually went into the T/B of Unit 1. As far as the shift team members who actually accessed the site were able to check, there was nothing abnormal such as a steam leakage or an excessive increase in radiation in and around the buildings except for those described before. Since the operating sound had virtually ceased completely after automatic scram, they could hear the sound of gas and water flowing through the pipes more clearly than usual[30].

29 The detected radiation is to be almost γ-rays. Based on this assumption, 300 cpm corresponds to about 2.5 μSv/h. Though very unlikely, if it is alpha-rays, 300cpm corresponds to 50μSv/h.

30 On the white board in the main control room (Unit 1 and Unit 2) released by TEPCO, a short memo (“Hissing sound is heard from the direction of the hallway”) is written. While none of the several duty operators who went to the hallway near R/B at Unit 1 on the evening of March 11 testified that they had heard a hissing sound caused by pipe rupture or steam leaking, or that they saw white mist. Moreover, considering that subsequent missions in the

The only possible reason for much higher than normal radiation levels being detected in and around the R/B of Unit 1 is that more radioactive material than usual was released from the nuclear fuel in the reactor pressure vessel and leaked into the building[31]. As described before, the four isolation valves were completely or almost completely closed right after the arrival of the tsunami, the IC's "cooling" function was almost lost and more than two hours passed with practically no cooling water being injected. If that was the case, we believe it highly possible that exposure of the core had already begun in the Unit 1 reactor so that the radiation level in and around the R/B was high.

However, no one in the shift team was aware of the possibility that the IC's isolation valves had been completely or almost completely closed by the failsafe function and IC's coding capability had been entirely lost.

(ii) No one in the shift team in charge of Unit 1 had experienced the operation of the IC before the earthquake on March 11, 2011. Some members of the shift team were told by their senior operators that as long as the IC functioned normally, the cooling water inside the condenser tank would evaporate by the heat from the reactor and the heated steam would blow horizontally from two exhaust vents (nicknamed "swine's snout") installed on the western wall of the R/B of Unit 1. When the steam is blowing off from the swine's snout, the static electricity is generated and it emits a bluish flash like a lightning and makes a roaring sound.

From the total loss of Unit 1's power source approximately 18:18 that day, however, the shift team did not think of checking the operation of the IC by this steam blow-out or operating noise. In fact, no one in the shift team went to the R/B to visually inspect

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R/B at Unit 1 were not interrupted, there is no ground for the thought that such hissing sound came from steam leaking due to pipe ruptures. If anything, it is highly possible that it came from air or water flowing in the pipes.'

31 When radioactive materials are generated in the RPV, radiation such as γ-rays may lead to a radiation level increase in the neighboring buildings, even when the RPV or the PCV does not sustain damage. In addition, a functional loss of the HVAC system for the building due to power outage also elevates the radiation level in the building. Therefore it cannot be concluded that the rise in radiation level in the building is directly connected with the damages of RPV and PCV (or the pipes around or penetrations). Provided that significant damage had occurred at that point of time, it would be contradictory with the fact that shift operators on duty could conduct field work in the R/B and T/B at Unit 1, such as start-up operation checks of D/DFP and/or the opening/closing operation of valves or others for a period of time after the evening on the same day.

whether any steam, if any, was blowing out from the outlet vents (swine' snout) located at the side of Unit 1 R/B facing the mountains.

(iii) At approximately 18:18 on March 11, the shift team noticed that the green indicator lamps showing the "complete closing" of the supply line isolation valve (MO-2A) and the return line isolation valve (MO-3A) of the IC (system A) were “on” on the control panel and they gathered together in front of the control panel. They thought it was possible that some of the batteries submerged in the seawater had dried and the indicator lamps were energized.

At that moment, the indicator lamps on the control panel showing whether the IC system A's two isolation valves (MO-1A and 4A) inside the containment were open or closed remained off and thus the state of the valves was not fully known. The shift team, however, found that the valve (MO-2A) was completely closed although it must have been open during the normal operation and concluded that it was possible that the valve was shut off by the failsafe function. The team members presumed that the other two isolation valves (MO-1A and 4A) inside the containment may be completely closed like MO-2A.

Since they could not determine whether the two isolation valves (MO-1A and 4A) inside the containment were completely closed and the IC did not certainly function at all regardless of the situation with the two inner side valves if the valves (MO-2A) and the (MO-3A) were completely closed, the shift team operated the control panel to open the two valves (MO-2A and 3A) with the expectation that the other two (MO-1A and 4A) were open albeit slightly.

During the reactor operation, the isolation valves inside the containment for IC system A & B can be opened or closed remotely from the control panel but not by hand[32].

[32] The driving motors of the inner isolation valves for both IC A&B systems are powered by AC power. Accordingly when all AC power sources were lost around 15:37 on March 11, all driving power sources were lost, and all these inner valves fell into an uncontrollable condition where the opening / closing action of valves was not possible. This would have been the case as long as AC power was not expected to restore, even if DC power for remote control of valves from the control panel had been recovered.
The selection of AC motors for inner isolation valves, unlike outer isolation valves, was made on the grounds that AC motors (in comparison with DC motors) were more resistant to the higher temperature / pressure stipulated

In order to confirm the operation of the IC by the amount of evaporation, the shift team went out of the building through an emergency door located on the northwest side of the Units 1 & 2 main control room and observed from there whether there was steam coming out from the IC exhaust vents on the west-side wall of the R/B of Unit 1. From where the shift team conducted their observation, they could only see the eastern and southern walls and the IC exhaust vents were not visible (see Fig. IV-1).

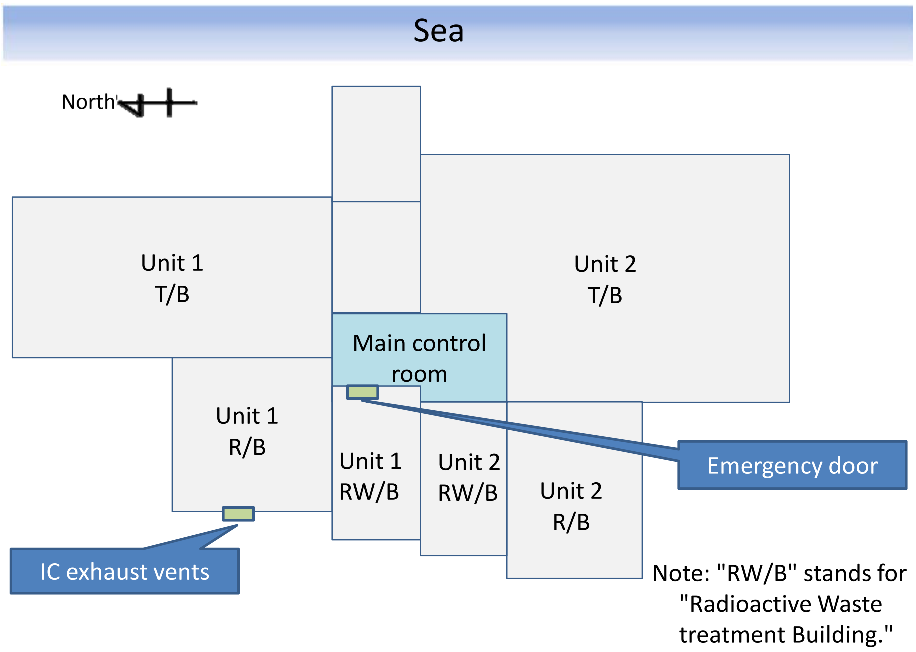

Fig. IV-1 Positions of Units 1 & 2 main control room and IC exhaust vents

At that time, the shift team found a small amount of steam above the R/B of Unit 1. When they checked again shortly after, they could not see any steam above the building. The shift team thought that the amount of steam was small because the amount of cooling water inside the condenser tank was decreasing. The shift team became apprehensive of the following risk: If the volume of cooling water inside the condenser tank was small, high-temperature and high-pressure steam won't be satisfactorily cooled

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inside PCV. In relation to this, the driving motors of IC's inner valves are powered by AC power also at Tsuruga Nuclear Power Plant Unit 1. Going back to F-1 Unit 1, although the inner side valves are equipped with hand-wheels, the shift operators have to get into the containment vessel to open them by hand. As additional information, as the inner side valves are designed to be closed by a fail-safe function in the event of DC power failure, as with this accident, the possibility still remains that all valves were not necessarily fully closed due to the possible loss of AC power in the course of the closing operation. (Please, ref. a (ii) and (iii))' down. If so, uncooled steam may cause IC pipes to break and result in releasing contaminated radioactive steam into the atmosphere.

The shift team judged that the IC was not working properly and, at approximately 18:25 that day, they shut down the IC by closing the return line isolation valve (MO-3A) via the control panel (see e(b) below as for the report to the NPS ERC). At that time, the shift team left the supply piping isolation valve (MO-2A) fully open in accordance with the normal operating procedures.

Around that time, the shift team thought that they had to implement an alternative method of water injection while the IC was not functioning normally. However, they only thought of using the D/DFP to inject water into the nuclear reactor through the FP system piping. Thus the shift team activated the D/DFP and put it in standby mode at approximately 17:30 that day. After around 18:30 that day in the R/B and T/B of Unit 1, they manually switched the operation of the valves necessary to enable the injection of water into the nuclear reactor from the FP system line through the Make-Up Water Condensate (MUWC) system line.

(iv) At approximately 21:30 on March 11, the shift team found that the green lamp on the control panel in the Units 1 & 2 main control room indicating the closure of the isolation valve (MO-3A) was fading. They also felt anxious that the MO-3A valve would be unable to be opened if the power supply was lost. By around that time, the shift team had checked the operating procedures and realized that they did not need to refill the condenser tank even if they operated the IC for several hours.

The shift team thought it more likely that the reason why the amount of exhaust steam from the condenser tank decreased after approximately 18:18 that day was not from the decrease of the cooling water but from the closure of the two isolation valves (MO-1A and 4A) by the failsafe function.

The shift team thought that as long as the return line isolation valve (MO-3A) was kept closed, it would be impossible to open the MO-3A valve if the isolation valves (MO-1A and 4A) inside the containment were found to be even slightly open. Moreover, they found that they did not need to refill the condenser tank even if they operated the IC for several hours. The shift team also determined that they could refill the condenser tank using the FP system line by operating the valves necessary to send water to the tank because the D/DFP was operating.

The shift team decided the possibility of starting the IC was not zero and opened the return line isolation valve (MO-3A) of the IC. At that moment, the shift team heard a noise like steam being released but it soon ceased and they did not think the IC was operating normally[33].

The shift team reported to the NPS ERC that they had opened the return line isolation valve (MO-3A).

c. The TEPCO and NPS ERCs' assessment of the operation of the IC

(i) At approximately 15:37 on March 11, Unit 1 completely lost all AC and DC power sources and the NPS ERC received a report on the situation from the shift team. At that moment, however, no one pointed out the possibility that the four isolation valves of the IC had been completely or almost completely closed by the failsafe function.

In addition, the NPS ERC received another report from the shift team that the reactor water level gage had become visible. By approximately 17:07 that day, however, the NPS ERC received another report that the reactor water level gage indicated -90 cm at wide-range at approximately 16:42 that day, showed a decrease, and dropped and became unable to be measured (“downscale”) after it showed -150 cm at approximately 16:56. The two ERCs shared this information via the teleconference system. At approximately 17:15 that day, the engineering team of the NPS ERC estimated the water level would reach the TAF in one hour. At that time, however, no one at the NPS or TEPCO ERC associated such events and evaluations with the IC's function or pointed out that the IC was not operating normally.

The NPS ERC received a report from the shift team that they had encountered a high radiation level when they went to the R/B of Unit 1 to inspect the condenser tank water

[33] A member of the operation shift team testified that the steam blowing sound had not continued a long time, although he had not given direct visual contact to the exhaust vent through which the steam generated in the IC water tank is released, This fact coincides with evidence that the water level remained at about 65 percent of the condenser tank capacity even 200 days after the accident. In any case it would be concluded that the IC was not in the state of normal steam generation at that point of time.

level at approximately 17:50 that day. The NPS ERC shared the information with the TEPCO ERC via the teleconference system. Not even at that time did anyone at the NPS or TEPCO ERC point out the possibility that the level of reactor water decreased and a large amount of radioactive material was generated in the reactor pressure vessel due to the IC's malfunction.

(ii) At approximately 18:18 on March 11, the NPS ERC received a report from the shift team that the team had opened the valve (MO-2A) and the valve (MO-3A) of the IC (system A) and they became aware that the IC was operating. Like the NPS ERC, the TEPCO ERC also came to understand via the teleconference system that the IC of Unit 1 was operating.

No evidence was found that the NPS or TEPCO ERC tried to find and review the cause and timing of the valves' closing while being conscious of the problem that the opening action of the two isolation valves implied that those isolation valves had been kept closed until then, the IC had been inoperative for approximately three hours since the loss of all AC power sources, and there had been no injection of water to the core.

(iii) Concerning the fact that the return line isolation valve (MO-3A) of the IC (system A) was closed at approximately 18:25 that day, there was effective communication between the Units 1 & 2 main control room and the NPS ERC located in the Seismic Isolation Building and the NPS ERC continued to believe that the IC was still operating.

Therefore, the NPS ERC was more worried about Unit 2 than about Unit 1 as they had a strong sense of crisis that the level of reactor water at Unit 2 would fall, the core would be exposed and a core meltdown may occur since the NPS ERC could not confirm the operation of the RCIC of Unit 2 or measure the level of its reactor water until 22:00 that day. The NPS ERC reviewed the action necessary for the subsequent plant control of the six units based on the assumption that the IC of Unit 1 was operating normally and its cooling function was operating effectively.

Memos written in the notebooks of the NPS ERC personnel and other records, however, imply that the NPS ERC obtained information on the shortage of cooling water in the IC's condenser tank, which the shift team was worried about. However, water in the condenser tank was not refilled by the D/DFP and there was no evidence that an alternative method of water injection by fire engines or any preparation for the reactor depressurization of Unit 1 was made on March 11, 2011. The TEPCO ERC received information via the teleconference system that the IC of Unit 1 was operating and assumed, just as the NPS ERC did, that the cooling function could be maintained for the next several hours. The TEPCO ERC reported to the Emergency Response Center (ERC) of the Ministry of Economy, Trade and Industry that the IC of Unit 1 was operating.

(iv) At approximately 21:30 on March 11, the NPS ERC received a report from the shift team that they had opened the return line isolation valve (MO-3A) of the IC. However, no one at the NPS and TEPCO ERC, including Site Superintendent Yoshida, raised concerns that the report meant the MO-3A valve of the IC had been closed until that time. The NPS and TEPCO ERC still thought that the IC was operating normally and did not ask the shift team whether they had closed the MO-3A before.

Around that time, the TEPCO ERC, like the NPS ERC, also believed the IC of Unit 1 was operating normally without knowing that the shift team had closed the return line isolation valve (MO-3A) at approximately 18:25 that day.

d. Response by Nuclear Safety Inspectors

According to the Nuclear and Industrial Safety Agency (hereinafter called "NISA"), Nuclear Safety Inspectors stayed on the second floor of the Seismic Isolation Building after the earthquake at approximately 14:46 on March 11, 2011, until the early morning of the next day. However, they remained in a meeting room adjacent to the Emergency Response Office, NPS ERC and just reported the information from NPS ERC to the Off-site Center and the Government ERC using mobile phones or satellite phones.

However, the Nuclear Safety Inspectors were in such a position that they could have easily obtained the same information concerning the operation of the IC as the NPS and TEPCO ERCs. They could have made an effort to accurately understand the situation by questioning the NPS ERC about the operation of the IC and taking other necessary action instead of only receiving the information that the NPS ERC provided them. In some cases, they could have provided necessary direction or advice.

In fact, no evidence that the Nuclear Safety Inspectors gave direction or advice to the NPS ERC was found at all. There was no such circumstance under which the presence of the Nuclear Safety Inspectors in the Seismic Isolation Building contributed to any accident response.

e. Identified problems (related to the assessment of the operation of the IC and response based on such an assessment)

(a) Assessment by the shift team

(i) At the time when all of Unit 1's AC and DC power sources were lost around approximately 15:37 on March 11, 2011, no member of the shift team questioned whether the isolation valves of the IC had been closed by failsafe function.

Around that time, the shift team was not able to clearly judge yet whether or not the IC was operating. After approximately 16:42 the same day when monitoring the reactor water level, however, they confirmed that the water level had decreased. After the reactor water level became unknown ("downscale") again, the shift team tried to enter the R/B of Unit 1 to check the amount of water in the condenser tank of the IC but turned back because they encountered a high radiation level on the way.

In spite of all this, the shift team did not think of observing whether or not steam was being released from the IC exhaust vents on the west wall of the R/B of Unit 1 to check the operation of the IC. One of the main reasons was that no one in the shift team had experienced the operation of the IC at Unit 1 or had been trained or educated, which would have enabled them to make an appropriate action as the situation changes.

(ii) Though the shift team was not able to take appropriate action to confirm the operation of the IC, at approximately 17:30 on March 11 they already started taking into consideration the possibility that the IC was not operating effectively based on the decreasing reactor water level and thus activated and put the D/DFP in standby mode in order to established an alternative method of water injection.

Though the shift team kept the three isolation valves, except the return line isolation valve (MO-3A), open and controlled the operation of the IC only by opening and closing the MO-3A valve before the arrival of the tsunami, they confirmed that green lamps were "on" on the control panel indicating that not only the MO-3A but also the valve (MO-2A) which was supposed to be open, were all closed[34]. Based on this, they thought it was possible that the failsafe function had been triggered and assumed it was very likely that the other inner-side isolation valves (MO-1A and 4A) were also completely closed by failsafe function.

At around that time, the shift team eventually thought of confirming the operation of the IC based on the steam released from the IC exhaust vents. However, they just observed it over the R/B of Unit 1 and did not try to conduct a visual inspection though they were not sure whether or not it was steam released from the IC exhaust vents.

At that time, the shift team considered the possibility that the remaining volume of cooling water in the condenser tank of the IC was small based on the small amount of steam and judged to close the return line isolation valve (MO-3A) at approximately 18:25 that day in order to prevent the pipe from break.

As long as the IC was not functioning and no alternative method of water injection was possible due to the loss of power sources, the shift team thought that the FP system water injection by the D/DFP was the only option and started the manual operation of the valve to enable the water to be injected from the FP system line to the reactor at approximately 18:30 that day.

Though the shift team's judgment was a bit too late, its content was reasonable.

It can be assumed that the IC was hardly functioning at approximately 18:25 that day so that the shutdown of the IC by the shift team scarcely affected the state of the reactor at Unit 1.

(iii) Because of the relationship between the discharge pressure of the D/DFP and the reactor pressure, it is physically impossible to use the D/DFP to inject water into the reactor without depressurizing the reactor by opening the SRV and the shift team fully understood this status.

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34 The indicator lamps on the control panel for IC's inner side valves (MO-1A & 4A) were off, so the open or closed status of the valves was not confirmed at that point of time.

Since the shift team in Units 1 & 2 main control room could not remotely control the SRV due to the loss of power sources, they had to report such problems related to the IC operation to the NPS ERC and request NPS ERC for the support of procuring batteries necessary for opening the SRV and connecting batteries to terminals located on the back of the control panel for the provision of implementing an alternative method of water injection,.

However, the NPS ERC did not recognize that the abovementioned support was necessary because of their mistaken presumption that the IC was operating normally. In addition, there was no evidence showing that they had tried from late afternoon until that evening to collect batteries with a total voltage of 120 V in the premises of the Fukushima Dai-ichi NPS for the reactor depressurization.

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 ERC fully recognize the necessity of procuring and connecting batteries to monitor the operation of the IC and operate the SRV.

(b) Report on the closing operation of the return line isolation valve (MO-3A)

(i) Memos handwritten by members of the operation team who received reports at the NPS ERC are also the evidences that the shift team opened the supply line isolation valve (MO-2A) and the return line isolation valve (MO-3A) at approximately 18:18 on March 11 and opened the MO-3A valve at approximately 21:30 that day.

However, no description was found in the handwritten memos of the operation team of the NPS ERC about the closing operation of the return line isolation valve (MO-3A) at approximately 18:25 that day. In addition, none of the operation team members, including those who received reports on Unit 1, wrote the memos or belonged to the NPS or TEPCO ERC, testified that they recognized that the return line isolation valve (MO-3A) was closed at that time. Instead, members of the NPS and TEPCO ERCs including Site Superintendent Yoshida said that they thought the IC was in the operation at that time.

(ii) Concerning the report to the NPS ERC that the shift team closed the return line isolation valve (MO-3A) at approximately 18:25 on March 11, the shift supervisor who was on duty at the time testified as follows: "I reported a problem with the operation of the IC via the fixed-line telephone to the operation team of the NPS ERC and told them that there was little steam generation when we activated the IC and that I was afraid there was not enough water in the condenser tank and that the IC was not functioning." However, he did not have any recollection of explicitly reporting that the shift team closed the return line isolation valve (MO-3A) and shut down the IC.

Regarding this matter, the member of the operation team who received the reports on Unit 1 said, "I received a report from the shift supervisor stating that 'we activated the IC, but there was a small amount of steam generation. It is possible that there is not enough water in the condenser tank.' At that moment, I thought they were able to activate the IC. And if there was not enough water in the condenser tank, it was possible to refill it using the FP system line. I thought that such a simple task could be done by the shift team alone. At that time, I didn't know the shift team had stopped the IC."

As a matter of fact, the shift supervisor testified that he had the impression that this operation team members received the report from the shift supervisor that he always replied as if he had mistaken the task of establishing a water refilling line from the FP system line to the reactor using the D/DFP for the task of establishing a water refilling line to the condenser tank. No matter how many times the shift supervisor explained, he could not make the operation team member understand it correctly.

In such a case, the shift supervisor should have fully explained and corrected the misunderstanding because of the importance of the information. If the shift supervisor clearly told him, "The IC is not working because we closed the isolation valves. It is necessary to inject water into the reactor using the D/DFP but we don't have a battery to open the SRV for depressurization. So, we need help from the NPS ERC", it would have been easy to clear up the misunderstanding. However, the member of the operation team who received reports on Unit 1 testified that he did not receive such a clear explanation. In fact, there was no evidence that the NPS ERC had made any preparation for an alternative method of water injection for Unit 1.

(iii) There is no doubt that the operation status of the IC, the most vital information, was not accurately communicated to the NPS ERC and there was a discrepancy in awareness between the NPS ERC and the shift team. It can be concluded that there was no effective communication between the two parties.

(c) Assessment of the NPS and TEPCO ERCs

(i) Though the shift team was performing various control work for a cold shutdown of Unit 1 in such devastated working conditions that they could not measure parameters including the reactor pressure and water level necessary for the control of the unit and there were no lights, they generally provided the NPS ERC with significant information on evaluating the operation of the IC as mentioned below with the exception of closing operation of the return line isolation valve (MO-3A) at approximately 18:25 on March 11.

(ii) The fact that the IC, which is to perform an essential cooling function at emergency, is designed to close the four isolation valves by fail-safe function when DC power source is lost is a basic knowledge about the structure and function of the vital facility.

At the hearing of the Committee, many parties related to TEPCO mentioned in detail the features of an isolation condenser, something like "Only Unit 1 has an isolation condenser and thus it is very special." However, when the Committee asked, "If the power source is lost and necessary operation becomes impossible, the so-called containment isolation valves are to be closed or remained open, based on containment isolation logic?," they all answered, "I think they will close." Regardless of the features of Unit 1 and the IC, it can be concluded that they could have easily recognized, without knowing the details about the rupture detection circuit and failsafe function, the possibility that the isolation valves of the IC were in the closed position when the power sources were lost as long as they had basic knowledge about the "confinement" function.

If so, there was a good chance the NPS and TEPCO ERCs suspected that the four isolation valves of the IC had been closed and the isolation condenser system had lost its function because the two ERCs knew that the total loss of AC power sources occurred at approximately 15:37 on March 11 and, almost simultaneously, all DC power supplies were also lost.

In reality, however, none of the two ERCs raised such a question or pointed out the possibility. No evidence that preparations were made to depressurize or to perform an alternative method of water injection to the nuclear reactor has been identified. If anything, they still mistakenly believed that the IC was in normal operation at approximately 21:00 that day.

(iii) It was reported to the NPS ERC that the reactor water level of Unit 1 was decreasing from approximately 16:42 until 16:56 on March 11 (when the reactor water level (wide-range) was measurable), and then went off scale ("downscale"). The NPS ERC was also informed that the shift team could not confirm the water level of the IC's condenser tank because a high radiation level was detected near the R/B of Unit 1 at approximately 17:50. Moreover, as of approximately 17:15 that day, the engineering team of the NPS ERC estimated that the reactor water level of Unit 1 would reach the TAF in one hour taking into account the decreasing rate of the reactor water level.

The TEPCO ERC also received such information via the teleconference system.

If they had evaluated the information correctly, the NPS and TEPCO ERCs would have known that the IC of Unit 1 was not operating normally. If the IC had functioned properly, its cooling capability would have worked for approximately six hours or until approximately 21:30. Therefore, the ERCs would have easily noticed that the IC was not operating normally and that they could hardly expect its cooling function if they had correctly interpreted the symptoms identified from 16:00 until 18:00 that day. It can also be said that they did not siege the situation correctly as they did not immediately start preparations for the depressurization of the reactor and/or an alternative water injection though they recognized those symptoms.

(iv) The IC of Unit 1 at the Fukushima Dai-ichi NPS was usually activated, controlled and stopped only by opening/closing operation of the return line isolation valve

(MO-3A) outside the containment while the other three isolation valves were kept open and they were not subject to the opening/closing operation. It is quite implausible that no one at the NPS or TEPCO ERC (which was in the position of supporting the shift team) knew such a basic operation of the IC. If so, their ignorance of the basic operation procedure is a problem in itself and a drastic reform in the educational and training programs is indispensable.

The shift team at least provided the NPS ERC with the information that the shift team opened not only the return line isolation valve (MO-3A) but also the supply line isolation valve (MO-2A) at approximately 18:18 on March 11.

Under these circumstances, the NPS ERC should have noticed that the supply line isolation valve (MO-2A) and the return line isolation valve (MO-3A) had been closed and the IC had been out of service. Since the NPS ERC would have suspected that the reactor core would be uncovered or damaged according to duration of the IC's downtime, the NPS ERC should have asked the shift team when the IC had finally lost its functional capability. However, the NPS ERC did not suspect this potential problem with the reactor or ask the shift team.

If the NPS ERC had been aware of basic knowledge such as the normal sequential procedure of the IC's isolation valves and the failsafe function at approximately 18:18 that day, they would have noticed that the shift team opened the supply line isolation valve (MO-2A) because the valve had been closed although it was normally kept open. Furthermore, they would also have easily noticed the possibility that the valve had been closed by the failsafe function triggered by the loss of power sources. If they had been aware of these fundamental matters, they would have naturally suspected that the two isolation valves (MO-1A and 4A) inside the containment[35] were also completely or almost completely closed by a signal from the failsafe function. The shift team was copying with the unstable situation bearing this particular concern in mind.

[35] As the isolation valves inside the PCV on the IC systems can’t be opened by hand on the spot under the loss of a power source, there was no other choice but to open the valves remotely from the control panel after the power restoration.

The TEPCO ERC which could have obtained the same information through the teleconference system are exactly alike in this respect.

However, neither the NPS ERC nor the TEPCO ERC checked the operation of the IC by speculating;

(a) why the isolation valves which are normally to be open, were in the closed position

(b) that the two isolation valves (MO-1A and 4A) inside the containment must also be closed if the outside valves are closed by the failsafe function due to the earthquake or tsunami

(c) that an alternative water injection must be quickly implemented if the IC could not effectively cool the reactor. The two ERCs did not provide the shift team with necessary advice or direction.

In addition, the NPS and TEPCO ERCs mistakenly believed that the IC be normally running because they received a report at approximately 21:19 that day that the water level of Unit 1 was 200 mm above the TAF. It is hard to think that the water level remained above the TAF considering that more than 5.5 hours had already passed since the loss of all AC power sources at approximately 15:37, with almost simultaneous loss of DC power sources and in addition, IC lost its function, and no alternative method of water injection had been carried out. They should not have fully trusted the readings of the reactor water level gage. Though the reactor water level gage indicated the level of 200 mm above the TAF, the two ERCs would not have been misled by the readings of water level gage or mistakenly believed that the IC was still operating if they correctly understood the failsafe function, checked if the IC's isolation valves were open or closed, and appropriately evaluated the fact that the reactor water level was decreasing from 16:42 to 16:56 and then dropped, and a high radiation level was detected near the R/B of Unit 1 at approximately 17:50 that day.

(v) When the shift team closed the return line isolation valve (MO-3A) at approximately 18:25 on March 11, the NPS ERC received some reports from the shift team that the amount of steam generated at the time of the IC activation was small and IC operation status was a matter of concern.

Not to mention whether or not the cause of the IC's malfunction was the shortage of water in the condenser tank, the NPS ERC as a matter of course noticed the possibility that the IC had some kind of function problem.

Even if the NPS ERC had not received an explicit report that the IC was subjected to a sort of functional problem, isolation valve (MO-3A) of the IC was closed at approximately 18:25 that day, they could have asked the shift team for a report on the operation of the IC.

If the NPS ERC had asked the shift team for a detail explanation on the report, they would have correctly and promptly understood that the return line isolation valve (MO-3A) of the IC was closed at approximately 18:25 that day.

In fact, however, the NPS ERC did not question the shift team about the operation of the IC including working status of the MO-3A and they were convinced that the IC was normally operating until they received a report that the MO-3A valve was opened at approximately 21:30 that day.

(vi) At approximately 21:30 on March 11, the shift team reported to the NPS ERC that they had opened the return line isolation valve (MO-3A) of the IC.

The detail investigation of TEPCO’s internal records by the Committee concludes that the NPS ERC did not receive any report on the MO-3A valve for more than three hours till 21:30, after the report on the opening operation of the valve was provided to the NPS ERC at approximately 18:18 that day.

Considering all these circumstances, they should have asked the following questions:

(a) Since when has the MO-3A valve been in the opening position?

(b) Is the IC operating normally or not?

However, the NPS ERC did not raise such questions or ask the shift team of the Units 1 & 2 main control room about the IC’s status.

(vii) Judging from the discussion above, if the NPS and TEPCO ERCs had appropriately evaluated the vital information described in (ii) to (vi) above, they would have had an opportunity (enough time) to question the operation of the IC even if they did not clearly understand the meaning of the report that the return line isolation valve (MO-3A) of the IC was opened at approximately 18:25 that day.

(d) Expected roles of the NPS and TEPCO ERCs

(i) "Report on Preparation for Accident Management at the Fukushima Dai-ichi Nuclear Power Station" prepared by TEPCO states, " 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."

Though the NPS ERC (with a support network consisting of several function teams including the operation and the recovery teams) was forced to cope with a large amount of incoming information including data on the status of Units 1 to 6, it is not acceptable as an inevitable outcome that the NPS ERC misunderstood the operation of the IC at Unit 1 which was the most fundamental and vital information, on the grounds of difficult circumstances when we take the role of the support network into consideration.

It is natural that, especially at emergency, a great deal of contradictory or conflicting information spreads here and there. It is therefore necessary to appropriately evaluate and choose which pieces of information are the most important in light of ever-changing situations.

As for Unit 1, the information on the operation of the IC was very basic and the most vital piece of information for making preparations for a cold shutdown because the isolation condenser was the only equipment expected to be able to perform the "cooling" function in such circumstances as the measurement of plant parameters was almost impossible in the aftermath of the tsunami. It was natural in the course of events that their measurements were delayed as they had overlooked such important information. Furthermore, their ignorance might have resulted in an irreversible wrong action.

The NPS ERC was divided into 12 function teams[36] including the operation, recovery, engineering and health physics teams. Each team had team members in charge of the Units 1 & 2 and Units 3 & 4. One person should not be totally responsible for handling a large volume of information, on the status of Units 1 to 6, into the NPS ERC. The function teams and sections should sort information based on their importance to their specific roles and take measures based on information significant to the corresponding responsibilities. They were structured to manage and handle the information in such ways.

It must be said that the NPS ERC was able to and had to evaluate such information on the operation of the IC when the shift team provided it. If the team had not provided such information to the NPS ERC, the NPS ERC would have been able to and would have actively collected such information from the on-site team. The accident management (AM) procedure states that, as the NPS ERC's 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. What is more, those teams had to fully understand all necessary information in preparation for those purposes.

(ii) The TEPCO ERC also had counterparts to the function teams of the NPS ERC. The function teams of the TEPCO ERC were expected to obtain such information relevant to their respective roles via the teleconference system, to evaluate the information objectively from a viewpoint a step further back from the NPS ERCwhich was busy specifically responding to the accident, and to support the NPS ERC. The TEPCO ERC should have made an effort to understand information on the operation of the IC to provide timely support to the NPS ERC. When such information was sent in from outside sources, the TEPCO ERC should have evaluated it and when no information was forthcoming, they should have actively collected the information. We assume that the TEPCO ERC could have provided

[36] The in-house fire-fighting team belongs to a recovery team in the emergency management system, so it is not designated as an independent functional team.’

appropriate advice to the NPS ERC in this way.

(iii) Neither the NPS ERC nor the TEPCO ERC seemed to appropriately sort or evaluate such vital information regarding the operation of the IC.

Concerning this point, Site Superintendent Yoshida said, "We encountered a situation that we had never imagined, and couldn't afford to spend sufficient time comprehensively assessing relevant vital information amid incoming information up to that time, while too much occupied with successive information."

For those people who had been trained and educated only on the condition that they could promptly obtain information about the state of the nuclear plants through the Safety Parameter Display System (SPDS), it is easy to imagine that it would be very difficult to appropriately select and evaluate information necessary for the plant control of the six units from a massive volume of complicated information in the formidable situation that the SPDS was not functioning and multiple nuclear reactors had lost their entire power sources almost simultaneously due to a very serious natural disaster. Even if the selection or evaluation of information was not appropriate at that time, we are not implying that it was the result of a lack of motivation or effort on the part of the people who were engaged in actually responding to the situation. However, we believe it is necessary to point out that although everyone made every possible effort to control the accident, the above-mentioned issues were obvious in hindsight.

In conclusion, they did not assume that a situation in which multiple nuclear reactors losing all power sources almost simultaneously would occur and thus did not provide the training and education necessary to implement measures to control such a serious situation. Thus the NPS and TEPCO ERCs could not accurately understand or appropriately evaluate important information. As a result, they could not correctly assess the operation of the IC. We believe it highlights the crucial importance of such training and education.

(2) Preparations for an alternative method of water injection into Units 1 and 2

a. Site Superintendent Yoshida's direction on an alternative method of water injection

At approximately 17:12 on March 11, Site Superintendent Yoshida thought it might have become impossible to inject water into Units 1 and 2 using the emergency core cooling system. He concluded that an alternative method of water injection should be implemented as soon as possible. Around that time, the reactor water level was trending downward and finally became incapable of being monitored at Unit 1 again, while the operation team of the NPS ERC estimated that the water level of Unit 1 would reach the TAF in one hour.

As part of AM measures, interconnecting pipes and remote-control motor-operated valves were installed between the FP and the MUWC systems for all reactors at the Fukushima Dai-ichi NPS. In addition, flow meters and remote-control motor-operated valves were placed on the connection pipes between the MUWC and the core spray (CS) systems at Unit 1, and between the MUWC system and the RHR at Units 2 to 6. It was therefore possible to inject water into the reactors passing through the connection piping from the FP to the MUWC via the CS or the RHR once the motor-operated valves were opened[37].

After the Chuetsu-oki Earthquake in July 2007, three fire engines were deployed to the premises, additional embedded water discharge ports were installed outside the T/B and fire cisterns were constructed against a fire in the R/B and T/B of the Fukushima Dai-ichi NPS.

By establishing an alternative water injection line from the FP system to the reactor and connecting the fire hoses of the fire engines to the embedded water discharge ports outside the T/B, an alternative method of water injection would be possible[38].

Since Units 1 and 2 had lost their entire power sources, the restoration of power supplies was expected to take some time. The only available alternative method of water injection defined by the AM measure was the use of the FP, the MUWC and the RHR (or CS)

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37 The total facilities of enabling alternative water injection where the FP system, MUWC system and RHR (or CS) system are interconnected by tie-lines were completed on November 26, 1999, July 16, 1999 and June 22, 2001 for Unit1, Unit 2 and Unit 3 respectively.

38 Such alternative water injection facilities, however, had not been designated as AM measures before the accident.

systems with D/D FP which required no electricity.

Site Superintendent Yoshida 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 because those pipes were not of strong seismic structures. Therefore Site Superintendent Yoshida doubted that the water injection system of water through the FP system by D/D FP using the filtered water tank as a water source could be counted on[39].

On the other hand, based on his memory of indoor pipes soundness in the buildings at the Kashiwazaki-Kariwa NPS after the Chuetsu-oki Earthquake, Site Superintendent Yoshida assumed that the indoor pipes would not be damaged. He instructed the NPS ERC personnel to consider injecting water using fire engines, although such a method was not defined as an AM measure, in addition to the injection of water through the FP system line, specified as an AM measure.

b. Fire engines at the Fukushima Dai-ichi NPS

(i) At approximately 17:12 on March 11, the operation and recovery teams received the directive from Site Superintendent Yoshida and started reviewing plans for an alternative method of water injection using the FP, MUWC and RHR (or CS) systems, which were defined as AM measures, and other methods that would be available if the power sources were restored.

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. Despite Site Superintendent Yoshida's instruction, there was no specific review or preparation including verifying the availability of fire engines, locating embedded water discharge ports, positioning the fire engines and laying fire hoses till dawn of March 12.

(ii) From lessons learnt in the fire that broke out at the Kashiwazaki-Kariwa NPS during

[39] Around the evening of March 11 there were several pipe breaks found in the outdoor piping, heading for each Unit starting from the filtrate water tank, which is the water source for water injection via FP system using D/D FP. Furthermore it was also recognized that water was gushing from more-than-one fire hydrants directly connecting to the filtrate water tank. So the in-house fire-fighting team shut all the valves on the concerned pipe lines (except the valve closest to the tank) at around 19:00 on the same day in order to preserve the water source. In fact, Site Superintendent Yoshida had been concerned with the possible occurrence of such events from the beginning.

the Chuetsu-oki Earthquake, TEPCO had deployed fire engines to all its nuclear power stations by February 2010. The Fukushima Dai-ichi NPS had three fire engines within its premises.

Before the earthquake hit, TEPCO entrusted Nanmei Kosan Co., Ltd. (presently Fuel TEPCO Limited) (hereinafter called "Nanmei") and Japan Nuclear Security System Co., Ltd. (hereinafter called "JNSS") with the driving and operation of the fire engines.

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. The company had its office near the main gate of the NPS where 11 Nanmei members including the leader were stationed. The fire engine crew consisted of nine members. They worked in three shifts over a 24-hour period driving and operating the two fire engines.

JNSS was contracted by TEPCO to provide onshore accident prevention services and take responsibility for the operation of a fire engine. In addition, JNSS security service members were in charge of security including conducting entry and exit inspections at a physical protection (P/P) gate at the north of the NPS's premises.

(iii) One of the two fire engines that Nanmei was responsible for was used for training the crew near Units 5 and 6 when the tsunami hit the Fukushima Dai-ichi NPS. The area between Units 5 and 6 and the rest of the NPS premises was closed to traffic as the connecting road was damaged and blocked with rubble and debris carried in by the seismic waves. The fire engine was unavailable for service unless an accessible route was secured.

The fire engine that JNSS was responsible for was parked near the North P/P gate located in the vicinity of the T/B of Unit 1 before the arrival of the tsunami. JNSS members heard the tsunami alert via the PA system and evacuated leaving the fire engine behind. The fire engine was so badly damaged by the seismic waves that it became unusable.

Therefore, only one fire engine that was parked in a warehouse next to the Nanmei office near the main gate of the Fukushima Dai-ichi NPS was available for service right after the tsunami.

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 Nanmei and JNSS 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.

(iv) The connecting roads within the premises of the NPS were impassable at several points due to damage caused by the earthquake and tsunami including slope failures, surface cracks and blockage by rubble and debris. For example, the road in front of the old administration building was blocked by a heavy oil tank washed up by the tsunami. Since the two P/P gates located at the northern and western sides were motor-driven, they were rendered inoperable due to the loss of their power sources.

To move the fire engine for water injection services, deploy power-supply vehicles for power source restoration work and secure a means of transportation for site workers, they had to repair the damaged roads and remove rubble and debris in order to establish traffic routes.

Thus the NPS ERC checked if there were any passable roads within the premises of the Fukushima Dai-ichi NPS. At approximately 19:00 on March 11, they broke the lock on the western P/P gate located between Units 2 and 3 and opened it to create a passageway between the two units connecting the Seismic Isolation Building and the seaside yard. From the night of March 11 until dawn of March 12, the recovery team of the NPS ERC and partner companies repaired the roads around Units 5 and 6 and then the roads around Units 1 to 4 using a backhoe and other equipment. None of the TEPCO employees could operate the backhoe. The NPS ERC had to leave the operation of the backhoe to a member of a partner company.

As a result of the repair work, the fire engine parked near Units 5 and 6 was available for use.

(v) The NPS ERC thought they would probably need more fire engines to implement the FP system water injection. After approximately 19:00 on March 11, the local command center asked the TEPCO ERC via the teleconference system to send as many fire engines as possible to the Fukushima Dai-ichi NPS.

The TEPCO ERC asked all TEPCO branch offices and power stations and other companies including the electric power companies to provide fire engines to the Fukushima Dai-ichi NPS. Roads in the Tohoku and Northern Kanto regions were devastated and closed at many points. To go to the rescue of the wide-spread disaster-stricken area, a number of fire engines, power-supply cars and other vehicles came from other areas and thus roads were congested in some areas. It actually took time to dispatch fire engines to the Fukushima Dai-ichi NPS.

On the morning of March 12, one fire engine from the Kashiwazaki-Kariwa NPS and two SDF fire engines finally arrived at the Fukushima Dai-ichi NPS. Then more fire engines began to arrive at the NPS.

However, the NPS ERC could not even appoint a single person to review and implement the FP system water injection using fire engines though the NPS ERC had already asked the TEPCO ERC to dispatch fire engines after approximately 19:00 on March 11. Although fire engines were arriving, no specific preparations had begun yet.

c. Preparations for an alternative method of water injection to Units 1 and 2

(i) From approximately 15:37 until 15:47 on March 11, Units 1 and 2 lost all AC power sources. The two units also lost DC power sources almost simultaneously. Measurement equipment was of no use at all and the operations of the IC and the RCIC remained completely unknown. Thus the readings from measuring instruments became impossible, and an unidentified situation of IC and RCIC operation continued.

Taking this situation into consideration, the shift supervisor checked the "Emergency Operating Procedure" for AM at his desk in the Units 1 & 2 main control room to confirm the procedures for the preparation of an alternative method of water injection. The shift supervisor thought that the preparatory operation for an alternative water injection was to be needed before radiation level went up higher.

At that time, an alternative method of water injection requiring power sources for the standby liquid control (SLC) system and other equipment could not be implemented for the two reactors unless power sources were restored. The only alternative method of water injection that the shift team was able to implement was activating the D/DFP and injecting water through the FP system line into the reactors. The shift supervisor was aware of the situation.

(ii) At approximately 16:35 on March 11, the shift team noticed on the control panel in the Units 1 & 2 main control room that the lamp indicator for the D/DFP showed that the pump had been in the status “halted”.

Since the reactor water level was trending downward from approximately 16:42 until 16:56 that day, when the shift team was able to see the reactor water level on the reactor water level gage (wide-range), the shift team thought that the IC of Unit 1 might not function normally. So, the shift team decided to confirm whether the D/DFP was operable in preparation for the water injection through FP system using the D/DFP.

At approximately 16:55 when the tsunami alert was issued and the aftershocks were continuing, the shift team went down to FP pump room on the first basement floor of the T/B of Unit 1 where the D/DFP was located in order to check the operation of the diesel-driven fire pump. On the way, however, their PHS received information that another tsunami might hit so they turned back to the Units 1 & 2 main control room.

At approximately 17:19 that day, the shift team confirmed that there would be no tsunami and headed for the FP pump room on the first basement floor of the T/B of Unit 1 again. Since the first basement was flooded, the shift team members put on rubber boots for an outdoor inspection and entered the pump room. At approximately 17:30 that day, the shift team confirmed the failure indicator lamp on the FP control panel was ”on”. When they pressed the reset button on the control panel, the D/DFP was automatically activated.

However, the configuration work of a water injection line through the FP system had not yet started. If they allowed the D/DFP to continue running, either the pump would burn out or the fuel would be wasted. In the Units 1 & 2 main control room, the shift team members therefore took turns holding the operation switch/lever in the "stop" position to keep the D/DFP of Unit 1 in standby mode until a water injection line via the FP system to reactor is completed[40].

The NPS ERC was aware of the D/DFP operation at Unit 1 through reports received

40 D/DFP was designed to start by releasing the switch lever.

from the shift team and the TEPCO ERC also learned of the situation via the teleconference system.

(iii) The shift team tried to go to the FP pump room on the first basement floor of the T/B of Unit 2 in order to check the operation of its D/DFP. However, they could not check the operation of the D/DFP because the vicinity of the pump room was flooded by the tsunami and was not accessible. At that time, the shift team judged that the D/DFP at Unit 2 was probably submerged and inoperable because the FP pump room was so deeply flooded that the shift team could not access it.

Afterwards, a member of the shift team who was watching for the tsunami waves found the smoke coming out from the exhaust duct of the D/DFP at Unit 2's T/B and thought the D/D FP was running. At approximately 01:20 on March 12, however, the shift team noticed that no smoke was coming out of the exhaust duct and judged that the D/DFP of Unit 2 had been in the status “halted”. Thereafter, the shift team did not try to enter the FP pump room on the first basement floor of the T/B to check the operation of the D/DFP of Unit 2.

The NPS ERC was aware of the operation of the D/DFP of Unit 2 through the reports from the shift team and the TEPCO ERC also learned of the situation via the teleconference system.

(iv) To establish a line capable of injecting water from the FP system line to the nuclear reactor, the shift team had to open motor-driven valves on connecting lines between FP, the MUWC and the RHR (or CS for Unit 1) systems located at Units 1 and 2. However, it was impossible to remotely control the valves from the Units 1 & 2 main control room due to the impact of the tsunami, thus the shift team had to enter the T/Bs of Units 1 and 2 to operate the valves by hand.

The shift team checked the location of the motor-driven valves to be opened.

As described in (1)b above, the shift team judged that the IC was not functioning properly and closed the return line isolation valve (MO-3A) to stop the IC at approximately 18:25 on March 11. The shift team decided to quickly make preparations for an alternative method of water injection and went into the R/B and T/B of Unit 1 at approximately 18:30 that day so as to configure a line for injecting water through the FP system to the reactor. On the way to where the motor-driven valve was installed, the shift team visually checked the pipes but did not find any damages.

The shift team manually opened the motor-driven valve necessary for setting up a water injection line through the FP system to the Unit 1 reactor. From the reasons that the location of the motor-driven valve was not uncertain, the wheel-handle for manual operation was hard to move, and they had the wrong key to the door of the room in which the valve was installed, they wasted a lot of time. Each time they encountered trouble, the shift team left the building to ask for assistance or the correct key thus taking a long time.

At approximately 20:50 on the same day just after the reactor water injection line was completed, the shift team activated the D/DFP of Unit 1 that they had been in standby mode by keeping the operation switch/lever in the "stop" position. The team made it possible to inject water into the reactor if the reactor is depressurized.

When the shift team went into the R/B of Unit 1 and measured the reactor pressure with a reactor pressure gage, the reactor pressure read 6.900 MPa gage at approximately 20:07 that day. Conversely, the discharge pressure of the D/DFP at Unit 1 was as low as 0.69 MPa gage. To inject water into the reactor, it was therefore necessary to open the SRVs to depressurize the reactor and lower it below the discharge pressure of the D/DFP.

Around that time, it was impossible to open the SRV via the control panel in the Units 1 & 2 main control room due to the loss of power sources. To open the SRVs, they had to bring the batteries with a total voltage of 120 V (connected in series) into the Units 1 & 2 main control room and connect them to the terminals of the control panel to restore the power source.

At that time and thereafter, the shift team, however, did not depressurize the reactor of Unit 1 by restoring a power source to open the SRV.

(v) After they completed the configuration of the FP system water injection line at Unit 1, the shift team went into the R/B and T/B of Unit 2 and configured a line capable of injecting water through the FP system into the reactor by manually opening a motor-driven valve on the pipe line connecting the FP system to the MUWC system.

Although it took time to open the motor-driven valve, the line configuration was completed by the end of March 11.

(vi) As described above, as the shift team went into the R/Bs of Units 1 and 2 and manually opened the motor-driven valves connecting the FP to the MUWC systems and finished switching to a line capable of injecting water into the reactors, the FP system water injection by fire engines was ready for the operation. If the switching of water injection line had been delayed, the entry to the R/Bs would have been banned because the radiation level inside the R/Bs would have increased. If so, even the FP system water injection using fire engines must have been impossible.

This implies that once an extremely serious accident like this earthquake occurs, the working environment deteriorates with time due to an increase in radiation level / other factors and we encounter the more serious environment to perform the necessary missions. Thus the preparations and implementation as early as possible must be requisites.

(3) Implementation of an alternative method of water injection into the Unit 1 nuclear reactor

a. Preparation for freshwater injection by fire engines

(i) After approximately 20:50 on March 11, the D/DFP at Unit 1 was running. As the reactor pressure did not fall below the pressure of the D/DFP and water was not injected into the reactor. In the meantime, at approximately 01:48 on March 12, the shift team confirmed that the D/DFP was in the halted state. At approximately 02:03, the shift team reported to the NPS ERC that the D/DFP at Unit 1 had stopped.

The shift team and the NPS ERC thought that the diesel-driven fire pump's battery might have been depleted or it might have run out of fuel. Though they replaced the battery and replenished the fuel, the D/DFP did not restart and the cause of the malfunction remained unknown.

(ii) The reactor pressure gage indicated the pressure of Unit 1 was 6.900 MPa gage at approximately 20:07 on March 11. It dropped to 0.800 MPa gage by approximately 02:45 on March 12 with no depressurizing operation. The NPS and TEPCO ERCs shared this information. After approximately 15:37 on March 11, the cooling function of the Unit 1 IC became ineffective and no alternative method of water injection was implemented. As of 02:45 on March 12, more than 11 hours had passed without water injection and the level of radiation level inside the R/B of Unit 1 had climbed up. With no depressurization operation using the SRVs, the reactor pressure at Unit 1 decreased significantly to 0.800 MPa gage (= approximately 0.901 MPa abs.) according to the reactor pressure gage of the unit. The pressure at this point of time was very close to the drywell pressure of 0.840 MPa abs.. Therefore, it can be assumed that the core meltdown progressed considerably and there must have been the openings through which the RPV pressure was relieved.

The NPS ERC judged that the discharge pressure of fire engines was high enough for water injection because the reactor pressure of Unit 1 was much lower than 1 MPa gage. No depressurization by opening the SRV was conducted.

The D/DFP of Unit 1 did not recover from its malfunction. As long as the reading on the reactor pressure gage (0.800 MPa gage) at approximately 02:45 on March 12 was correct, however, the pump could not be used to inject water into the nuclear reactor without the reactor being depressurized even if the pump had not failed because its maximum discharge pressure could not exceed 0.69 MPa gage.

(iii) At approximately 02:03 on March 12, the NPS ERC received a report from the shift team on the stoppage of the D/DFP at Unit 1 and recognized that water injection by the D/DFP was in despair. So the NPS ERC decided that they had no other choice but to use fire engines to feed water through the FP system line to the No. 1 reactor by connecting fire hoses to the embedded discharge ports of the Unit 1 T/B.

However, none of TEPCO's employees could operate a fire engine and so they had to ask Nanmei to inject water with the fire engine.

The NPS ERC requested Nanmei staff, who were on standby in a hallway of the Seismic Isolation Building, to locate the discharge ports of the Unit 1 T/B and to inject water into the reactor using the fire engines. 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.

However, the NPS ERC could not yet locate the discharge ports of the Unit 1 T/B.

One member of the operation team of the NPS ERC was chosen to look for the location of the embedded water discharge port with Nanmei workers.

From approximately 02:00 until approximately 03:00 on March 12, they drove the fire engine to the T/B of Unit 1 and found that the shutter at the entrance to the building had been opened by the force of the seismic waves and several cars had been swept out of the building and piled up on the ground. Amid such chaos, they used searchlights of the fire engines to look for the embedded water discharge port. However, they could not find it. A member of the shift team happened to come out from the large equipment service entrance of the Unit 1 T/B to get extra fuel for the D/DFP and the group asked him to help them look for the water discharge port. After all, they could not locate it. The Nanmei workers and the operation team member returned to the Seismic Isolation Building.

When the Nanmei workers and some members in charge of accident prevention at the NPS ERC reviewed plot plans at the NPS site to locate the embedded water discharge ports, a person (who was actually involved in installing firefighting equipment at the Unit 1 T/B and knew the location of the embedded water discharge port) was identified.

From approximately 03:00 until 04:00 that day, Nanmei workers and the man who knew the location of the embedded water discharge port went to the T/B of Unit 1 by fire engine again and finally found the embedded water discharge port hidden from view by a shutter frame which had been bent by the tsunami.

(iv) At approximately 04:00 that day, they connected a hose to the embedded water discharge port of the Unit 1 T/B and started feeding 1,300 liters of freshwater from the fire engine's tank through the FP system line to the nuclear reactor. When they emptied the tank, they connected a fire hose to the JNSS fire engine that was abandoned near the north P/P gate and transferred 1,000 liters of water to their fire engine.

b. Full-scale injection of freshwater with fire engines

(i) At approximately 04:20 on March 12, the radiation level near the T/B of Unit 1 was high and Nanmei workers temporarily returned to the Seismic Isolation Building without injecting the water they had transferred from the JNSS fire engine.

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.

However, the NPS ERC had no choice but to ask for Nanmei's cooperation as there were no TEPCO personnel capable of operating the fire engine at the Fukushima Dai-ichi NPS. The local command center offered to let their firefighting team go with them and requested Nanmei send someone to operate the fire engine and help the team with injecting water. The head of Nanmei eventually accepted the request.

At approximately 05:00 that day, the in-house firefighting team and a Nanmei worker left for the T/B of Unit 1.

(ii) The in-house firefighting team of the Fukushima Dai-ichi NPS and Nanmei employee took water from a fire cistern in the seaside yard, returned to the building, and connected the vehicle's hose to the hose which was permanently connected to the embedded water discharge port of the Unit 1 T/B to feed water into the nuclear reactor. They shuttled the fire engine back and forth between the seaside yard and the T/B of Unit 1.

However, objects were strewn around the T/B of Unit 1 as a result of the seismic waves and the shuttle trip took time. Thus they decided to construct a line configuration that would enable water to be continuously injected instead of being inefficiently fetched.

First, they parked the fire engine near the fire cistern in the seaside yard of the T/B of Unit 1, then connected the fire cistern and the vehicle with a hose, and linked the fire truck and the embedded water discharge port with another hose, so that a line configuration of continuous water injection was complete (see Attachment IV-14).

At approximately 05:46 that day, the in-house firefighting team and Nanmei employee started a fire pump to draw water up from the fire cistern and feed it into the reactor. They reported the start of the water injection to the NPS ERC.

From then on, Nanmei workers took turns going to the site with TEPCO firefighters to inject water while keeping an eye on their personal level of radiation exposure. In the beginning, they changed the flow rate from $1m^3$ to $2m^3$ every ten minutes.

(iii) From 06:00 to 07:00 that day, two fire engines from the Self Defense Force (SDF) arrived at the Fukushima Dai-ichi NPS and one fire truck arrived from the Kashiwazaki-Kariwa NPS at around 10:52.[41]

Two of the three fire engines were used to transfer freshwater shuttled from a fire cistern in the seaside yard of the Unit 3 T/B to the fire cistern in the Unit 1 seaside yard, which was the source for the FP system water injection for the No. 1 reactor.

Another fire engine and fire hoses were positioned to draw up freshwater from a fire cistern near the R/B of Unit 2 and transfer it to a water reservoir, which was the source for the FP system water injection for the Unit 1 reactor (see Attachment IV-15).

The fire cisterns had only one opening for a fire hose to be inserted so that they could not use two hoses to simultaneously draw up and replenish water. Every time they refilled the fire cistern they were using as the source for the FP system water injection for the Unit 1 reactor, they had to stop the water injection and pull out the injection hose.

The Nanmei employees from the Kashiwazaki-Kariwa NPS and SDF personnel not only provided the fire engines but also operated the vehicles and were involved the water injection task.

c. Preparation for seawater injection into Unit 1

(i) At that time, there were not enough fire engines and the Fukushima Dai-ichi NPS premises were so severely damaged by the tsunami that moving the fire trucks was difficult. Therefore, it was practically impossible to inject freshwater from all the fire cisterns into Unit 1 and the amount of available freshwater was limited.

Before dawn on March 12, TEPCO requested other electric power companies to send sprinkler trucks to Fukushima but the NPS ERC had no idea when they would arrive.

At around 12:00 that day, Site Superintendent Yoshida decided to inject seawater into the nuclear reactor when the freshwater in the fire cistern near Unit 1 ran out. He

[41] As with Fukushima Dai-ichi, it is not TEPCO employees but Nanmei-Kosan employees that operate fire engines at Kashiwazaki-Kariwa NPS.

ordered the recovery team of the NPS ERC and the in-house firefighting team to research a line configuration for seawater injection.

The SDF personnel and Nanmei workers involved in the injection task searched the vicinity of Unit 1 for any other water sources including seawater.

First, they considered directly pumping seawater from the North Shallow Draft Quay. However, it was far from the T/B of Unit 1 and the difference in elevation between the ground and sea level was too great. They deemed it physically difficult.

While they looked for more water sources, they found that a large amount of seawater had collected in a reversing valve pit in front of the T/B of Unit 3 due to the tsunami. They reported it to the NPS ERC.

Site Superintendent Yoshida received the report and decided to use the seawater in the reversing valve pit in front of the T/B of Unit 3 when the current freshwater source for the injection into the Unit 1 nuclear reactor ran out and directed the relevant staff members accordingly.

The Managing Director, Mr. Akio Komori (hereinafter called "TEPCO Managing Director Komori"), and other members at the TEPCO ERC and Executive Vice President, Mr. Sakae Mutoh (hereinafter called "TEPCO Executive Vice President Mutoh"), and other members at the Off-site Center were made aware of Site Superintendent Yoshida’s abovementioned decision via the teleconference system. They understood that injecting water into the Unit 1 nuclear reactor was the top priority and no one was opposed to injecting seawater into the reactor.

A Fellow of TEPCO, Mr. Ichiro Takekuro (hereinafter called "TEPCO Fellow Takekuro"), the chairman of the Nuclear Safety Commission (NSC), Mr. Haruki Madarame (hereinafter called "Chairman of NSC Madarame"), and NSC officials who were stationed at the Prime Minister's Office of Japan (PMO) recognized that, as a matter of course, seawater would be injected into the nuclear reactor when the freshwater was completely used up, even though they had not directly communicated or discussed it with the NPS ERC and/or the TEPCO ERC of TEPCO.

(ii) At approximately 14:53 that day, the water injection by fire engines had used up its entire freshwater source[42] and it was quite difficult to immediately secure a new freshwater source. At approximately 14:54 that day, Site Superintendent Yoshida again ordered the injection of seawater into the Unit 1 nuclear reactor.

The in-house firefighting team and Nanmei workers received Site Superintendent Yoshida's instruction and began constructing a line configuration to use the seawater collected in the reversing valve pit in front of the T/B of Unit 3. To draw up and pump water from the reversing valve pit, they lined up three fire engines and connected them with hoses and then anchored the hoses to the ground.

At approximately 15:18 that day, Site Superintendent Yoshida reported to the relevant government offices and other organizations that they would start injecting seawater into the Unit 1 nuclear reactor soon after the preparations were complete. In fact, the line configuration to feed seawater to the reactor was almost complete at approximately 15:30.

(iii) At approximately 15:36 that day, however, there was an explosion in the R/B of Unit 1 with its probable cause thought to be hydrogen gas. Three TEPCO and two Nanmei workers were injured in the explosion.

Some workers rescued the injured from the site and the others evacuated to the Seismic Isolation Building.

After that, they had to investigate the site near the R/B to check the aftermath of the explosion. They could not start any recovery work until the area was deemed safe.

After the explosion, the steel frames of the upper part of the Unit 1 R/B were exposed and white smoke was observed.

The fire hoses laid on the ground to form a line for injecting water from the reversing valve pit in front of the T/B of Unit 3 to the embedded water discharge port of the T/B of Unit 1 were damaged by debris and rubble blown off and scattered in the explosion. Fortunately, however, the three fire engines used for injecting water were not damaged and were still operational.

Site Superintendent Yoshida was disappointed because, though they had almost

[42] At this point of time, the total quantity of the water injected into the Unit 1 reactor was about 80 tons.

completed this preparatory work as they had finished constructing a seawater feed line with the fire engines and almost restored the power sources necessary to activate the SLC system pump right before the explosion, they were forced to start preparations for injecting water into the Unit 1 nuclear reactor again from the beginning.

Though the explosion had scattered debris and rubble and high levels of radiation were detected in the vicinity of the R/B of Unit 1, it was urgent that the alternative method of water injection into the Unit 1 nuclear reactor be implemented and Site Superintendent Yoshida issued an order to restart the on-site preparations at approximately 17:20 that day.

While a radiation safety staff was monitoring the levels of radiation, the in-house firefighting team and Nanmei workers again started configuring a water feed line to Unit 1 as they moved steel plates and other debris dispersed in the explosion out of the way and quickly gathered hoses from outdoor fire hydrants.

d. Problems identified (in the preparation and implementation of the alternative method of water injection into Unit 1)

(i) At approximately 17:12 on March 11, Site Superintendent Yoshida had already issued directions to consider the FP system water injection using fire engines as an alternative method of water injection to the reactors at Units 1 and 2 in addition to the method of water injection method defined as AM measures.

In fact, however, it was from 02:00 to 03:00 on March 12 when they started looking for the location of the embedded water discharge port of the Unit 1 T/B. Thereafter the preparation and implementation of initially planned water injection was executed not by TEPCO's in-house firefighting team but by Nanmei workers.

At approximately 04:20 that day, the Nanmei workers who had been involved in the water injection operation finally returned to the Seismic Isolation Building. After the NPS ERC was told by Nanmei that the radiation level at the working site was so high that the Nanmei employees could not continue the missions by themselves, the NPS ERC finally sent the in-house firefighting team to the working site to assist the Nanmei workers with the water injection operation at approximately 05:00. It was at around

05:46 on the same day that the water injection started on a constant basis.[43] More than 14 hours had passed since 15:37 on March 11 when IC lost its function due to all AC/DC power sources.

(ii) One of the causes for the delay of the water injection is that the NPS and TEPCO ERCs misunderstood the operating status of the IC from the beginning.

The two ERCs finally had not any doubt about the normal operation of the IC until knowing the fact that radiation level became so high that entering the R/B of Unit 1 was prohibited at approximately 21:51 on March 11 and the D/W pressure gage of Unit 1 indicated 0.600 MPa abs at approximately 23:53 that day. Accordingly, they believed that the situation at Unit 2 was more serious than that at Unit 1.

As described in (1)e (c) above, the NPS and TEPCO ERCs could have noticed that the IC was not functioning effectively soon after the arrival of the tsunami if they had correctly understood the open/closed status of IC's valves by failsafe function and had appropriately assessed the information provided by the shift team.

If the two ERCs had accurately comprehended the operating condition of the IC, they could have also realized that the IC had failed right after the reactor scram (a large amount of decay heat is released) and Unit 1 had been in an extremely dangerous situation since then. If so, they would have deemed Unit 1 as being in a riskier condition than Unit 2 and also they should not have delayed the start of an alternative water injection for such a long time.[44]

In conclusion, since the NPS ERC had misunderstood the operating condition of the IC, they could not understand correctly how dangerous the situation at the Unit 1 was and also they failed to timely response to depressurizing the reactor to implement an alternative method of water injection due to little sense of impending crisis to be forwarded to Unit 1. In terms of whether they had sufficient materials and equipment

[43] The shift team operators on duty tested initial operation of the valves on the connecting line between the FP system and MUWC inside the building at around 18:30 on March 12 and the water injection system via the FP system inside the building had been ready for use at around 20:00 on the same day.

[44] Not limited to Unit 1, no evidence can be found even for Unit 2 during March 11 that the Station Emergency Response Center (NPS ERC) started on the preparatory work such as deploying fire engines, laying hoses and collecting the batteries for RPV depressurization. The only thing that the shift team operators on duty performed during this period was to have switched the water injection system from FP system line inside the building to the reactor water injection line with MUWS.

enabling earlier water injection, they had a fire engine available anytime and the freshwater in several 40-ton fire cisterns within the premises of the NPS after late evening on March 11.

Until approximately 02:45 on March 12, the reactor pressure was much higher than the discharge pressure of the fire engine according to the readings[45] and thus it was not possible to use the fire engine for injecting water through the FP system without depressurizing the reactor by opening the SRVs. Therefore the NPS ERC must have been able to understand such situation.

If so, they needed to obtain batteries of at least a total voltage of 120V (even connected in series) because the power source necessary for operating the SRV via the control panel had been lost. We understand that it was not easy to procure batteries as such backup batteries were not stored at the Fukushima Dai-ichi NPS. From late afternoon until the night of March 11, however, the recovery team of the NPS ERC had already removed batteries from the motor coaches of partner companies and TEPCO's service vehicles in order to restore the measuring instruments. In these circumstances, we think that they were aware of the skills and techniques necessary for utilizing vehicle batteries as power sources. Considering the number of company and private cars within the premises of the NPS, it was possible to secure battery's capacity to operate the SRV for depressurization.

As mentioned above, since they had the materials and equipment necessary for an alternative water injection, the recovery team of the NPS ERC could have collected small generators and batteries from inside the NPS and brought them to the Units 1 & 2 main control room; recovered the power supplies for temporary lighting and measurement equipment; and connected batteries to the SRV for depressurizing the reactor, and, in addition to these indoor tasks, made preparations for an alternative method of water injection using the fire engine outside the building, even though it was impossible to know the parameters of Unit 1 due to the loss of power sources.

We understand it was more difficult and would take much more time than usual to

[45] The pump discharge pressure of the fire engines generally used by TEPCO is 0.85MPa in gage.

work in the yard where there were rubbles and debris worrying about the aftershock or the recurrence of tsunami.

Considering the brave workers who carried out their duties with total disregard for their own safety, we believe that the NPS ERC should not have waited until around dawn on March 12, 2011, but could have initiated similar efforts for Unit 1 and conducted depressurization and implemented an alternative method of water injection (the implementation of venting of the containment, if required) into Unit 1 much earlier if the NPS ERC had accurately understood that the situation at Unit 1 was deteriorating as the IC was not operating normally after the No. 1 nuclear power plant lost its AC and 125V DC power sources completely and no alternative method of water injection was implemented.

A hasty conclusion should be avoided as to whether or not the damage to Unit 1 could have been prevented or mitigated by depressurization and alternative water injection in the earlier stage because there were many uncertain factors including the possibility of an earlier alternative water injection and the state of the reactor core at the time. If Unit 1 had been depressurized much earlier and the alternative method of water injection through the FP system had been conducted smoothly, the progress of the core damage might have been slower. Naturally it was very likely that the amount of radioactive materials released inside the reactor might have been less and the subsequent operation might have progressed better.

(iii) Another reason for the delayed water injection was that there was no specific section assigned the task of water injection using fire engines that Site Superintendent Yoshida directed.

After the emergency response arrangements of the first level was announced, an Station Emergency Response Center was set up at the Fukushima Dai-ichi NPS with 12 function teams, namely the communication, intelligence, public relations, health physics, engineering, recovery, operation, infrastructure, medical treatment, general affairs, guard-guidance, and the procurement teams. An in-house firefighting team was organized under the recovery team. An emergency preparedness system appropriate for their respective roles in nuclear disaster prevention was established.

However, the respective roles of the function teams were only defined in accordance with previously assumed situations. It was not clearly specified which function team or group was in charge of implementing actions, such as water injection using fire engines, which were not defined as AM measures. It was the responsibility of the operation team to change the indoor section of the FP system line but the outdoor section was not within the scope of their responsibility. The in-house firefighting team was to extinguish fires, rescue and evacuate but the use of fire engines for water injection was beyond their duties. Water injection using fire engines was not the responsibility of the recovery team because the task was possible with the existing facilities, equipment and fire engines and did not require any kind of restoration work.

At approximately 17:12 on March 11, Site Superintendent Yoshida issued the directions to consider injecting water using fire engines, no group in the NPS ERC had seriously considered the directed tasks as their roles or responsibilities till approximately 02:00 on March 12.

From approximately 02:00 to 03:00 that day when Nanmei workers went to the T/B of Unit 1 to locate the embedded water discharge ports, the TEPCO member who accompanied them was from the operation team. No one from the in-house firefighting team went with them on the grounds they do not know the location of the embedded water discharge port.

Moreover, the in-house firefighting team did not participate in the water injection, which began at approximately 04:00 that day.

The Nanmei workers complained that the water injection task was impossible because of the high levels of radiation around the building but the NPS ERC requested they continue the work and eventually the in-house firefighting team left to join the Nanmei group for the water injection task using fire engines.

This was how the in-house firefighting team got involved in injecting water into Unit 1. In the first place, no member of the Fukushima Dai-ichi NPS's in-house fire brigade had the skills or knowledge to activate the fire pumps and inject water into the reactor. When Site Superintendent Yoshida ordered the injection of water using fire engines at approximately 17:12 on March 11, they did not realize it was their role or responsibility.

(iv) Taking these circumstances into consideration, one possible reason as to why no specific preparatory action was made by any of the function team members despite that Site Superintendent Yoshida's directive issued at approximately 17:12 on March 11 to them to consider the feasibility of using fire engines for injecting water into the Unit 1 nuclear reactor, was that none of them recognized it as their role.

If the NPS ERC had properly understood that the IC of Unit 1 was not operating and no function team or group was specifically appointed to inject water using fire engines at the time when Site Superintendent Yoshida issued the order, preparations for the water injection using fire engines and the preparations to depressurize the reactor and/or vent the pressure of the containment necessary for the water injection could have been made much earlier.

We think that the more fundamental reasons for the delay of their on-site responses were that water injection using fire engines had not been defined as AM measures and no specific function team or group had be assigned that mission.

(4) Preparations for the containment venting of Units 1 and 2

a. Considerations on containment venting before Site Superintendent Yoshida's direction

(i) After late afternoon on March 11, the shift team of the Units 1 & 2 main control room could not confirm the operation of the IC of Unit 1 and the RCIC of Unit 2 and believed that the cooling function of the Unit 1 IC was not working effectively. They therefore recognized that it was possible that the pressure vessels and the containments of Units 1 and 2 would fall into such a state that they would have to conduct containment venting.

In the Units 1 & 2 main control room, the shift supervisor started preparations for the containment venting under the loss of power sources. He checked the Emergency Operating Procedure for AM and used valve checklists to identify and locate the valves necessary for the containment venting.

(ii) From around that time, the operation team of the NPS ERC also started checking the procedures for the venting of the containments in the event power sources were lost, referring to the Emergency Operating Procedure for AM.

In the Emergency Operating Procedure for AM there was the identifying numbers of the vent valves to open, so that in a normal situation those valves could be operated simply by pushing the control buttons in the main control room. However, the remote control was impossible in the event that all power sources were lost.

The shift team had to study the layout and configuration of the vent valves to determine which ones they should open, identify the location of those valves and understand how they could open them manually.

The recovery team of the NPS ERC cooperated with the operation team in checking the Emergency Operating Procedure for AM and identified vent valves they needed to operate. 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. The team also tried asking a partner company that were familiar with the types and structures of valves. However, they had a hard time reaching the partner company and it was around dawn on March 12 that the team was finally able to contact with the firm.

The NPS ERC first considered venting the containment passing through SGTS which has the capability of releasing gas containing radioactive substances into the atmosphere through filters. They, however, abandoned this idea because the relevant parts including the SGTS piping and filters were very likely to be damaged if the containment pressure was very high. They decided that a hardened vent (vent system by-passing SGTS), which was defined as an AM measure, was the only available option.[46]

(iii) The NPS ERC and the shift team had made preparations bearing in mind the necessity

[46] There are two different containment venting paths: One is the so called S/C venting line where the gases in the containment vessel are directly released via a path from the torus side to the main stack. The other is the so called D/W venting line where the gases in the containment vessel are directly released via a path from D/W side to the main stack. In the case of S/C venting system, over 99% of iodine is captured while passing through the water, because the gas inside the containment vessel is released through S/C pool to the stack. While in the case of D/W venting system the radioactive gases are directly exhausted into the atmosphere, resulting in a far greater amount of radioactive materials being released compared to S/C venting. Therefore a S/C venting system is preferable to a D/W venting system, if possible. The venting system that the Station Emergency Response Center (NPS ERC) intended to adopt, following site superintendent's direction made around 00:06 on March 12, was the S/C vent system.

of venting the containment after the total loss of AC power sources and no evidence was found that they hesitated to conduct the containment venting.

b. Site Superintendent Yoshida's direction to make preparations for the containment pressure venting

(i) From the time AC and DC power sources were totally lost until the night of March 11, it was impossible to measure the reactor water levels of Units 1 and 2 with the exception of the Unit 1 reactor water level from approximately 16:42 until 16:56 that day.

As for Unit 2, not only was the reactor water level unknown but the water injection into the reactor by the RCIC was also not confirmed. At approximately 21:02 that day, Site Superintendent Yoshida reported to the relevant authorities that the reactor water level would probably reach the TAF. At approximately 21:13 that day, they estimated it would reach TAF at approximately 21:40[47] and reported it to the relevant authorities.

At approximately 21:19 that day, the reactor water level gage recovered and showed that the water level for Unit 1 was 200 mm above the TAF and the team reported this reading to the NPS ERC.

Based on this report, Site Superintendent Yoshida presumed that the water level at Unit 1 had not yet reached the TAF and the IC still continued operating.

At that time, however, all the isolation valves of the IC at Unit 1 were thought to have been completely or almost completely closed for more than 5.5 hours from 15:37 that day. More than three hours had passed since 18:25 when the shift team closed the return line isolation valve (MO-3A).

Judging from the discussion above, the reliability of its readings was already likely to be reduced because the water level gage had been exposed to a high-temperature and high-pressure environment. It is logical to think that the core exposure and damage advanced considerably. We think Site Superintendent Yoshida misunderstood the operating condition of the IC.

At approximately 21:51 on March 11, the radiation level of the R/B at Unit 1

[47] The time when the RPV water level will reach TAF was estimated based on the worst case scenario assuming that RCIC was not functioning at all from the beginning.

increased, so that Site Superintendent Yoshida prohibited entry into the reactor building for the workers' safety.

The level of radiation was so high that access into the building was impossible though the reactor water level gage indicated that the water level had not yet reached the TAF. Primarily considering this fact, it would be logical to conclude that the water level of the Unit 1 reactor had already reached the TAF. They should have doubted about the accuracy of the gage and the operating condition of the IC.

Site Superintendent Yoshida immediately thought to ensure the safety of the workers when he was informed of the increase in the radiation level indoors. Nevertheless, he did not think about what had happened to the nuclear reactor and the IC based on the same information.

(ii) At approximately 22:00 on March 11, the shift team learned that the reactor water level gage of Unit 1 showed the level of 550mm above the TAF. At around that time, they also found that the gage of Unit 2 indicated the water level was 3,400mm above the TAF. The shift team reported these figures to the NPS ERC.

The IC at Unit 1 in particular was thought to have been out of service for many hours and no alternative water injection was implemented, so that the reliability of the reactor water level gage's readings was questionable at this point of time.

Learning that the water level of Unit 2 was still 3,400mm above the TAF, the NPS ERC estimated that it would take a long time for the water level to reach the TAF and reported their estimation to the relevant authorities at approximately 22:10 and 22:20 that day.

Because they knew the water level of Unit 2, the NPS ERC thought that the RCIC was probably operating. They changed their thought about the risk of the two reactors and came to believe that Unit 1 might be more dangerous than Unit 2.

At around that time, a member of the shift team arrived at the double doors of the R/B of Unit 1 but he felt he was in danger as his alarm pocket dosimeter (APD) indicated a total radiation dose of 0.8 mSv over about 10 seconds. The shift team member did not enter the R/B and returned to the Units 1 & 2 main control room. This information was communicated from the main control room to the NPS ERC.

As a result of the measurements around Unit 1, a radiation level of 1.2 mSv/h was detected in front of the north double doors of the T/B of Unit 1 and 0.5 mSv/h at the south double doors of the building. At approximately 23:40 that day, Site Superintendent Yoshida reported the increases in radiation levels to the relevant government offices and other organizations.

(iii) At approximately 23:25 on March 11, the recovery team was involved in restoring the measuring instruments in the Units 1 & 2 main control room. When they connected the cable reel of a small generator, which they had procured from a partner company for temporary lighting, to a D/W pressure gage terminal, the drywell (D/W) pressure gauge at Unit 2 indicated 0.141 MPa abs.

At approximately 23:50 that day, the recovery team measured the D/W pressure of Unit 1 in a similar way. The D/W pressure gage at Unit 1 showed 0.600 MPa abs, which was higher than the maximum allowable operating pressure of 0.528 MPa abs. The team reported the numerical value to the NPS ERC.

(iv) In the beginning, the NPS and TEPCO ERCs believed that the IC of Unit 1 was operating normally. After approximately 21:51 on March 11, however, as they received reports on many unusual events including the increase in radiation level and abnormal rising of the D/W pressure of the unit, they grew increasingly doubtful of the cooling capability of the IC.

At approximately 23:50 that day when Site Superintendent Yoshida received the report that the reading of the D/W pressure gage indicated 0.600 MPa abs. , he finally realized that the IC of Unit 1 was not operating properly so the temperature and pressure inside the Unit 1 reactor rose and, as a result, a large amount of steam generated inside the reactor vessel leaked from the containment and caused an abnormal rise in the D/W pressure.[48]

[48] At Unit 1 there are four SRVs through which RPV steam is released to S/C. The SRVs function as relief valves (pressure relief) near/at the RPV pressure of 7.3 MPa gage, and as safety valves (safety protection) near/at the RPV pressure of 7.7 MPa gage. In addition, there are three more SRVs through which the steam is released directly to the D/W. The latter three valves, however, function only as safety valves at 8.6 MPa gage without the function of relief valves. Accordingly it would be possible that a large amount of steam generated in the reactor was relieved directly from RPV to the D/W by actuation of these valves, which resulted in the pressure increase of D/W. Of course, the

At approximately 00:06 on March 12, Site Superintendent Yoshida thought of the possibility that the situation had already worsened and the D/W pressure of Unit 1 was by now higher than 0.600 MPa abs. He did not hesitate to direct the operation and the recovery teams to speed up the preparations for the containment venting of Unit 1.

Site Superintendent Yoshida presumed that if a large amount of steam was generated in the pressure vessel and leaked to the containment, then the reactor water level must have decreased considerably and the core was significantly damaged.

He also predicted that Unit 2 would face a situation similar to Unit 1 as they could not confirm the operation of the RCIC, so that he ordered his teams to make preparations for the containment venting of Unit 2.

The TEPCO ERC also learnt of the development in events via teleconference system at almost the same time as the NPS ERC. No one in the TEPCO ERC objected to or showed a sign of hesitation towards the preparations for the containment venting.

c. Preparations for the containment venting after Site Superintendent Yoshida's direction

(i) At approximately 00:49 on March 12, Site Superintendent Yoshida decided that a specific event (abnormal increase in the containment pressure) as defined in Paragraph 1, Article 15 of the NEPA had occurred because the D/W pressure of Unit 1 could have exceeded 0.600 MPa abs. and reported his decision to the relevant authorities at approximately 00:55 that day.

The TEPCO ERC thought that the containment venting at Units 1 and 2 would soon be implemented and had obtained the approval of TEPCO president Shimizu for the depressurizing operation by approximately 01:30 that day.

Moreover, the TEPCO ERC decided to obtain consent from the Japanese government since they had no precedent of the containment venting at all and the possible physical impact on local residents and the social ramifications on nearby communities could be huge. TEPCO Fellow Takekuro, who was stationed at the PMO, obtained the agreement

possibility that the steam leaked into the D/W from the damaged portions associated with the RPV or pipes or penetrations, at this time, cannot be ruled out.

of Prime Minister Kan, and Managing Director Komori went to the Ministry of Economy, Trade and Industry (METI) and obtained consent from Mr. Banri Kaieda, METI minister, and NISA.

Prime Minister Kan and METI Minister Kaieda had already understood that it was necessary to implement the containment venting in order to prevent the destruction of the containment as they had met and heard the opinions of TEPCO Fellow Takekuro, Chairman of NSC Madarame, Mr. Eiji Hiraoka, of NISA (hereinafter called "Vice Director-General Hiraoka") and other relevant parties in the Prime Minister's office on the 5th floor of the PMO.

The TEPCO ERC said to the NPS ERC via the teleconference system, "We certainly ask you to operate the MO and AO valves at any cost and vent the containments. At 3 a.m., METI Minister Kaieda and TEPCO will announce the venting. So, please start venting after the announcement."

(ii) From approximately 01:00 until around 02:00 on March 12, the shift team members equipped with self-contained air breathing sets (self-air-set), small flashlights and rubber boots went to the RCIC room on the first basement floor of the R/B of Unit 2 to inspect the operating condition of the RCIC system.

The RCIC room was flooded and the water level was just below the upper edge of their rubber boots. When they opened the door, water gushed out of the room and they could not go in. At that time, the shift team members heard a faint metallic noise from the RCIC room but could not confirm the operating sound of either the pump or the turbine rotor. They had no means of communication because their PHS did not work, so they returned to the Units 1 & 2 main control room and reported to the shift supervisor.

At approximately 02:10 that day, members of the shift team with the same outfits as the previous went to the RCIC room of the R/B at Unit 2. Though the level of water inside the room had risen, the shift team members went inside to check the operating condition of the RCIC system. They found that the needles of the pump inlet pressure gages on the instrument panel near the entrance to the room were shaking slightly and they heard a metallic noise similar to the operating sound. However, they could not find solid evidence to confirm the operation of the RCIC.

The shift team members thought that they would be able to see the operating condition of the cooling system by checking the reactor pressure and the RCIC pump discharge pressure of Unit 2 on the instrument racks located on the first and second floors of the R/B of Unit 2. First, they checked the RCIC pump discharge pressure on the RCIC instrument racks on the first floor and then went up to the second floor to check the reactor pressure on the reactor vessel system instrument racks.

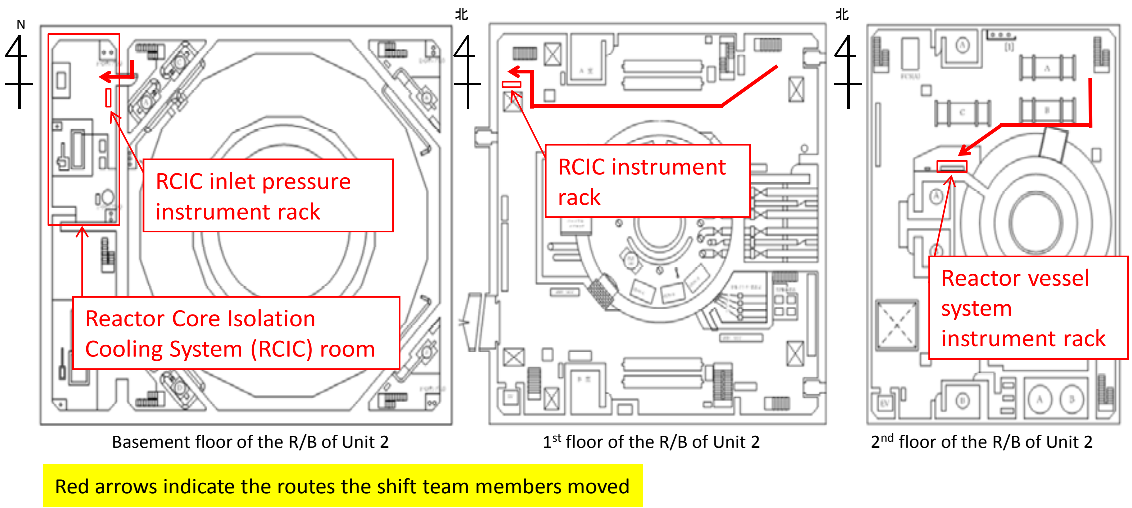

Fig. IV-2 Location of instrumentation racks and the routes the shift team members took to check the racks (based on materials from TEPCO)

During the inspection, they found that the RCIC pump discharge pressure was 6.0 MPa gage and the reactor pressure was 5.6 MPa gage. The RCIC pump discharge pressure was higher than the reactor pressure. The shift team members decided that the RCIC was operating and reported their conclusion to the Units 1 & 2 main control room.

At approximately 02:55 that day, the shift supervisor reported to the NPS ERC that the shift team believed the RCIC of Unit 2 was operating because their members had confirmed that the RCIC pump discharge pressure was higher than the reactor pressure. Upon receiving the report, Site Superintendent Yoshida decided to implement the containment venting at Unit 1 prior to Unit 2. He ordered his teams to give priority to the preparations for the depressurization of the No. 1 reactor containment and continue monitoring the parameters of the No. 2 reactor.

We presume that the shift team manually activated the RCIC at approximately 15:39 on March 11 right before the loss of power sources. Then it was unable to be controlled with its valves remaining open due to the loss of power sources, and the cooling system kept operating as its turbine continued rotating by the steam generated in the reactor.

(iii) At approximately 02:24 on March 12, NPS ERC investigated the working environment of the spot when starting the containment venting NPS ERC. As a result, it was proved that the workers could stay for about 17 minutes at most in an environment of up to 300 mSv/h referring to the radiation level limit (100 mSv/h) at emergency, and the self-air sets last about 20 minutes, but anyway workers have to take iodine tablets.

At approximately 02:30 that day, the recovery team of the NPS ERC measured the D/W pressure at Unit 1 using a small generator for temporary lighting and the D/W pressure gage of Unit 1 indicated 0.840 MPa abs. At approximately 02:47 that day, Site Superintendent Yoshida judged that the pressure of the containment increased abnormally and reported the measurement to the relevant authorities.

(iv) At approximately 03:06 on March 12, TEPCO Managing Director Komori, METI Minister Kaieda and, Director-General of NISA Terasaka held a joint press conference at METI to make the aforementioned announcement about the containment venting at Units 1 and 2.

Right before the press conference, Director-General of NISA Terasaka received the information that the RCIC at Unit 2 was operating. He therefore recognized that the containment venting at Unit 1 would be conducted prior to that of Unit 2.

On the contrary, TEPCO Managing Director Komori did not adequately receive or share this information with the NPS and TEPCO ERCs. He did not know that the RCIC of Unit 2 was running. What is more, TEPCO Managing Director Komori believed that the IC of Unit 1 was operating. Thus he thought that the containment venting of Unit 2 would be the first priority because it had not yet been confirmed that the RCIC of the No. 2 reactor was operating.

METI Minister Kaieda, Director-General of NISA Terasaka and TEPCO Managing Director Komori realized before the press conference that they had conflicting beliefs but did not have any solid evidence as to who was correct. Therefore they decided to announce the implementation of the containment venting, not specifying the Units .

During the news conference, however, Mr. Komori was questioned closely by news reporters in relation to which containment they would vent and he became confused when answering the questions.

(v) At approximately 03:45 on March 12, the engineering team of the NPS ERC did a trial calculation of radiation exposure evaluation in case the venting was implemented.[49] At approximately 04:01 that day, Site Superintendent Yoshida reported results to the relevant authorities.

At around that time, a person tried to go into the R/B at Unit 1 to the measure the radiation level. When he opened the double doors of the building, he saw white smokes inside the R/B. So, he shut the door and could not measure the radiation level. At approximately 04:00 that day, radiation level near the main gate of the Fukushima Dai-ichi NPS was monitored as 0.069 μSv/h. Subsequent monitoring at the same place at approximately 04:23 showed the increase in radiation level up to 0.59 μSv/h. Upon receiving these readings at approximately 04:55, Site Superintendent Yoshida reported monitored results to the relevant authorities.

At approximately 05:14 that day, Site Superintendent Yoshida judged that radioactive materials leaked from the containment taking into account the increase in the radiation level on the premises of the Fukushima Dai-ichi NPS and the downtrend in the D/W pressure. He reported to the relevant authorities that radioactive material was leaking.

(vi) By reviewing building plans and other materials, the operation team of the NPS ERC found that the small S/C vent valve (air-operated) which is necessary to open for the containment venting at the Unit 1 had a wheel handle for manual operation (by hand) and it would be possible to open the valve in the torus room. Based on the operation

[49] At this point of time there was not enough data at hand, the first trial calculation on the radiation exposure assessment was done, assuming that the so-called D/W vent was executed where a larger amount of radioactive materials are released to the atmosphere.

team's investigation, the recovery team of the NPS ERC established the specific sequences for implementing the venting of the containment when all power sources were lost. The team reported the findings of their review to the shift team in the Units 1 & 2 main control room.

(vii) After dawn on March 12, the shift team continued to check the operation of the valves necessary to configure the containment venting line at Unit 1, possible routes to the torus room where the small S/C vent valve (air-operated) that they had to open by hand was, and where this work would actually be undertaken, by reviewing documents and materials including the piping and instrumentation diagram (P&ID), the Emergency Operating Procedure for AM and valve drawings, and using acrylic boards in the Units 1 & 2 main control room.

From 00:00 until 04:30 on March 12 only, there were 21 aftershocks of intensity 1 to 3 at the Fukushima Dai-ichi NPS. At around 04:30 that day, Site Superintendent Yoshida considered the possibility of the aftershocks causing a tsunami and gave the main control rooms a previous notice of prohibiting on-site operation.

The shift team gathered fireproof suits, self-air-sets, APDs, survey meters, full-face masks and flashlights. This equipment, gear and tools had been stored on the first floor of the service building and had thus survived the tsunami. At approximately 04:45 that day, the NPS ERC delivered APDs preset at 100 mSv and full-face masks to protect against radiation exposure to the Units 1 & 2 main control room.

At approximately 04:50 that day, a worker who returned to the Seismic Isolation Building was contaminated, so the NPS ERC ordered all workers to use full-face masks and charcoal filters and to wear level B or C clothes or coveralls all the way from the entrance of the Seismic Isolation Building to their work sites (see Attachment IV-16).

At approximately 05:00 that day, the shift supervisor of the Units 1 & 2 main control room told his members to put on full-face masks and charcoal filters and level B outfits when they went to their work sites near or in the buildings of Units 1 and 2.

At around that time, the radiation level in the Units 1 & 2 main control room increased. The radiation level in the room rose as they got closer to Unit 1. Also the higher the measuring point, the higher the radiation level detected. Therefore almost all the members of the shift team moved to the Unit 2 block and crouched down on the floor.

(viii) The TEPCO ERC successively obtained such information about the on-going preparations for the implementation of the containment venting via the teleconference system. The TEPCO ERC reported every piece of such information to the Government ERC through a TEPCO liaison officer who was a member of the official communication team and was stationed in the emergency response center set up in the Ministry of Economy, Trade and Industry.

Though the people at the TEPCO ERC, the Government ERC and the PMO learned of such information, they did not fully comprehend just how difficult the preparations for the containment venting were in such an extremely serious environment as they had never actually experienced it themselves. Many of them were frustrated with the very slow preparations and some suggested that the NPS ERC was hesitant to conduct the venting of the containment.

At approximately 06:50 that day, METI Minister Kaieda issued an order to implement the containment venting under paragraph 3, Article 64 of the Law for the Regulations of Nuclear Source Material, Nuclear Fuel Material and Reactors (hereinafter called the "Reactor Regulation Act"). Though the NPS ERC was informed of the implementation order, the situation was extremely precarious such that the R/B of Unit 1 was dark with no lighting, the radiation level was very high and aftershocks were occurring frequently, so that they could not forward the preparations for the containment venting as scheduled.

(ix) In the early morning of March 12, while Site Superintendent Yoshida directed and supervised the on-site work of preparations for the containment venting at Unit 1 in the NPS ERC, he was suddenly notified by the TEPCO ERC via the teleconference system that Prime Minister Kan would visit the Fukushima Dai-ichi NPS. Site Superintendent Yoshida did not think that he had any executives available to attend to the prime minister and decided to meet the premier himself alone.

At approximately 07:11 that day, Prime Minister Kan came to the Fukushima Dai-ichi NPS by helicopter with an entourage including Chairman of NSC Madarame and met Site Superintendent Yoshida in a meeting room adjacent to the Emergency Response Office on the 2nd floor of the Seismic Isolation Building. At that time, Senior Vice Minister of METI, Motohisa Ikeda and TEPCO Executive Vice President Mutoh came from the Off-site Center to attend the meeting.

During the meeting, Site Superintendent Yoshida briefed Prime Minister Kan on the situation at the site and told him that the fieldwork was plagued with serious issues. Mr. Kan told the Site Supervisor Yoshida to quickly prepare for the venting of the containment at Unit 1. Site Superintendent Yoshida replied, "We are making preparations for the containment venting. We will start the venting by around 9 a.m." At approximately 08:04 that day, Prime Minister Kan left the Fukushima Dai-ichi NPS.

(5) Implementation of the containment pressure venting of Unit 1

a. Site Superintendent Yoshida's direction to implement the containment pressure venting

(i) At approximately 08:03 on March 12, Site Superintendent Yoshida saw Prime Minister Kan off at the doorway of the meeting room on the 2nd floor of the Seismic Isolation Building. He then returned to the Emergency Response Office in which the NPS ERC had been established and directed all related staffs to make preparations for the containment venting with the planned time of 09:00 that day.

To open the valves necessary for the containment venting, someone had to go into the R/B at Unit 1 where entry was prohibited due to the high radiation level. Site Superintendent Yoshida requested, through the operation team of the NPS ERC, that the shift team go to the building to manually open the valves though those who performed the task would be at risk of being exposed to a considerable radiation level. The shift team accepted his request.

(ii) All members of the shift team were wearing full-face masks and level C outfits at the closer side of Unit 2 block in the Units 1 & 2 main control room in an effort to reduce their level of exposure. Upon receiving the request from the NPS ERC, they decided to go to the R/B of Unit 1 to open the containment vent valve (MO valve) and the small S/C vent valve (air-operated) necessary for the implementation of the containment venting. The shift team decided to perform the task in three groups with each groups consisting of two persons taking into consideration that the task was too difficult for one worker to do alone because there was no lighting inside the R/B of Unit 1 as a result of the total loss of power sources, high levels of radiation were expected at the work sites in the building, and they would have to evacuate from the R/B due to aftershocks. All the task groups consisted of the shift supervisor and other senior members excluding younger people because it was expected that those who performed the task would be exposed to considerably high levels of radiation.

(iii) At approximately 05:44 on March 12, Prime Minister Kan issued instructions to residents within a 10-km radius of the Fukushima Dai-ichi NPS to evacuate, but communication and coordination with the related local governments and residents was delayed causing some confusion among them. At approximately 08:27 that day, the evacuation of some residents of Okuma Town was not yet complete and the NPS ERC obtained the information. At approximately 08:37 that day, the NPS ERC notified the Fukushima government that they were planning to start the containment pressure venting of Unit 1 at approximately 09:00. Upon the request of the Fukushima government, the two organizations negotiated and agreed to begin the containment pressure venting of Unit 1 after the evacuation of local residents was completed.

b. Implementation of the containment venting

(i) At approximately 09:02 on March 12, the NPS ERC deemed the evacuation of residents of Okuma Town completed as they had received confirmation from the Okuma city office by telephone and directed the shift supervisor of the Units 1 & 2 main control room to start the containment venting. However, the evacuation of the residents of Okuma Town was not in fact complete at that time. The NPS ERC did not communicate effectively with the Okuma city office and misunderstood the progress of the evacuation.

At approximately 09:04 that day, two members (the first task group) of the shift team equipped with the fireproof suits, self-air-sets, APDs and flashlights went into the R/B of Unit 1 to carry out the fieldwork for implementing the containment venting at Unit 1 (see Attachment IV-17 for details on the containment vent line at Unit 1). At that time, the shift team had already lost their means of communication including PHS. Since the task groups could not communicate remotely with the Units 1 & 2 main control room, they decided to send the three teams to the work site in turns. After one group returned to the main control room, the next one would leave for the R/B so that they could share detailed information on the progress of the work including its start and completion.

At approximately 09:05 that day, TEPCO issued a press release on the implementation of the containment pressure venting.

(ii) Task group 1 went to the installation site of the containment vent valve (MO valve) on the 2nd floor of the R/B at Unit 1 with only their flashlights to guide them. At approximately 09:15 on March 12, they manually opened the valve by 25 percent in accordance with the prescribed operation procedure and returned to the Units 1 & 2 main control room[50] (see Fig. IV-3).

At approximately 09:24 that day, task group 2 left for the torus room on the first basement floor of the R/B at Unit 1 to open the small S/C vent valve (air-operated). On the way to the torus room, however, the group realized it was possible that they could be exposed to a high radiation level exceeding the limit of 100 mSv. At approximately 09:30, they abandoned the task of opening the small S/C vent valve (air-operated) and returned to the main control room (see Fig. IV-4).

[50] The total radiation dose for a shift team member over the period of ten or more minutes was 25 mSv.

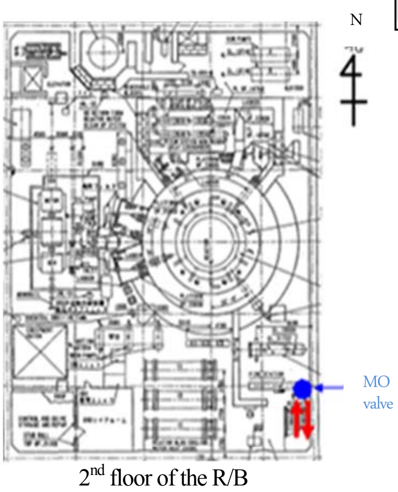

Fig. IV-3 Location of the MO valve

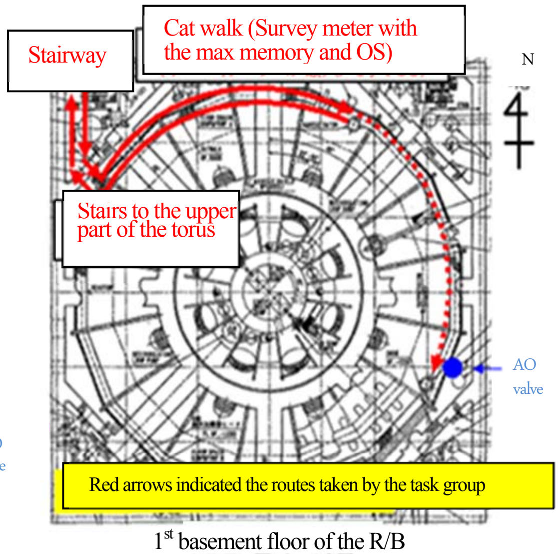

Fig. IV-4 Location of the AO vavle

Compiled from TEPCO's "Responses at the Fukushima Dai-ichi Nuclear Power Station in the Early Stages of the Tohoku District - off the Pacific Ocean Earthquake" (June 2011)

After receiving the report from task group 2, the shift supervisor decided that entry into the torus room was impossible because of the high levels of radiation and abandoned the operation by task group 3.

(iii) The NPS ERC decided to abandon the manual opening operation of the small S/C vent valve (air-operated) when they received the report that the shift team could not open the valve as access to the work site was interrupted by the high levels of radiation inside the R/B of Unit 1.

In addition to the small S/C vent valve (air-operated), there was a large S/C vent valve. To open the large valve, however, it was necessary to open an solenoid valve installed on the Instrument Air system (IA system) pipes to send compressed air for driving the large valve (see Attachment IV-18).

The existing large air compressor, which was used to generate and feed compressed air to drive the large S/C vent valve (air-operated), was not available due to the loss of power sources. Compressed air cylinders were placed near the IA system piping. However, the cylinders were not available either because they also required manual operation in the R/B of Unit 1.

The NPS ERC decided to perform the opening operation of the large S/C vent valve (air-operated) by using a small generator for temporary lighting in the Units 1 & 2 main control room so as to open the solenoid valve by energizing, and by connecting a portable compressor to the IA system piping to feed compressed air to the large valve.

However, the Fukushima Dai-ichi NPS did have neither a portable compressor to generate high-pressure air powerful enough to open the large S/C vent valve (air-operated) nor an adaptor to connect the equipment to the IA system piping as emergency equipment. The NPS ERC asked their partner companies to help and look for a portable compressor and a connection adaptor in their offices both inside and outside the premises of the NPS.

The recovery team of the NPS ERC took a leading role in reviewing a point available for connecting a portable compressor.

(iv) After approximately 10:17 on March 12, the shift team tried three times to open the small S/C vent valve (air-operated) in the Units 1 & 2 main control room based on the assumption that it was not completely impossible to open the small S/C vent valve (air-operated) using the compressed air remaining in the IA system pipes though they knew the existing air compressor could not be used due to the loss of power sources.

At approximately 10:40 that day, an increase in the levels of radiation were detected near the Fukushima Dai-ichi NPS's main gate and monitoring posts. At this point of time, the NPS ERC judged that a rupture disk had been burst by opening of the small S/C vent valve and radioactive materials had been released by the containment venting.

However, it was very likely that the increase in radiation level does not necessarily lead to the successful containment venting and if anything, the accidental radiation rise-up inside PCV caused to elevate the radiation level outside PCV. In fact, the radiation levels decreased at approximately 11:15 that day. The NPS ERC changed their assumption and thought that the containment venting was not working effectively.

The bursting pressure at the Unit 1 rupture disk was 0.448 MPa gage (= 0.549 MPa abs.). According to the S/C pressure gage, the S/C pressure was 0.740 MPa abs. at approximately 10:38 that day. Theoretically speaking, when the valves were opened and the pressure were applied to the rupture disk, the disk could burst as a matter of course.

Judging from the fact that the readings of the D/W and S/C pressure gages remained almost flat after that time, it was likely that the rupture disk was not burst. One possible cause of that situation was that the small S/C vent valve (air-operated) could not be kept open.

(v) At approximately 12:30 on March 12, the NPS ERC found a portable compressor in the office of a partner company on the premises of the Fukushima Dai-ichi NPS. In the partner company's office, they also found a jig, which could be used to connect the portable compressor to the IA system piping. An employee of the company altered it to create an opening for connection so that the jig could be used as an adaptor.

To make the installation, connection and refueling of the compressor easier, it was necessary to put the compressor in a location with a low radiation level. Moreover, the portable compressor should be installed as close to the large S/C vent valve (air-operated) as possible to achieve air pressure powerful enough to drive the valve. To this end, the recovery team of the NPS ERC reviewed the piping and instrumentation diagram and decided to install the portable compressor at the large equipment service entrance at the Unit 1 R/B.

The team also went to the large equipment service entrance of the Unit 1 R/B and took pictures of the place where the compressor would be installed and connected to the IA system. At that time, they found that the radiation level inside the large equipment service entrance at the Unit 1 R/B was higher than expected. So, the team decided to install the portable compressor outside the entrance and connect it to an IA system copper tube header in the instrument panel of a liquid nitrogen gas supply board outside the entrance.

After reviewing the specific procedures for installing the portable compressor and connecting the adaptor, the recovery team of the NPS ERC loaded the compressor and the adaptor onto a four-ton crane truck and drove it to the large equipment service entrance at the Unit 1 R/B. The recovery team placed the portable compressor near the large equipment service entrance at the Unit 1 R/B and connected it to the IA system copper tube header. At approximately 14:00, they started the compressor to feed air into the IA system pipes (see Fig. IV-5).

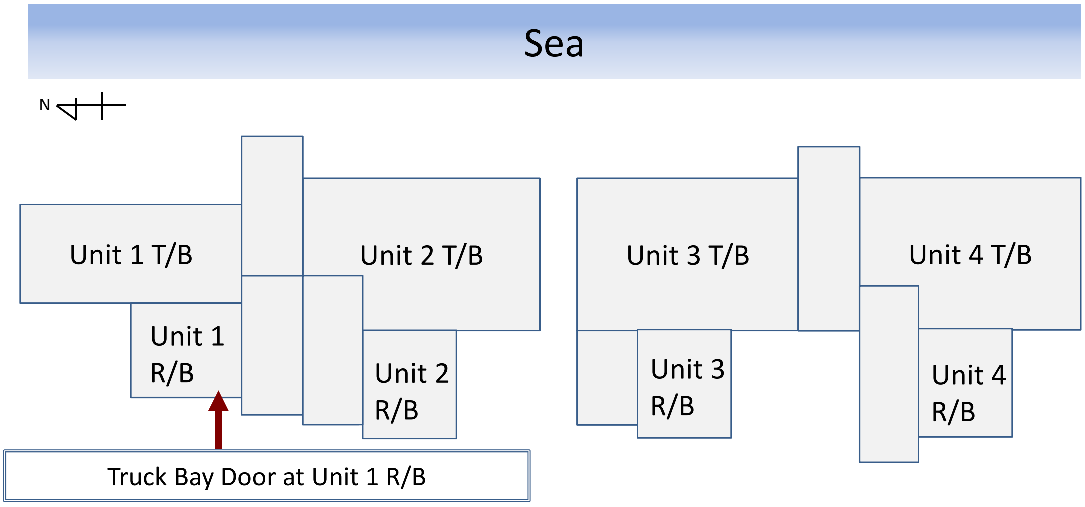

Fig. IV-5 Location of the truck bay doorsof the Unit 1 R/B (compiled from TEPCO's data)

Around that time, the recovery team of the NPS ERC energized the solenoid valve for the large S/C vent valve (air-operated) and opened the large vent valve in the Units 1 & 2 main control room.

(vi) The D/W pressure of Unit 1 was 0.75 MPa abs. at approximately 14:30 on March 12and dropped down to 0.58 MPa abs. and at approximately 14:50 NHK TV footage showed white smoke coming out from the stack of Unit 1. Site Superintendent Yoshida judged that radioactive material was being released by the containment venting at approximately 14:30 and reported it to the relevant authorities at around 15:18 that day.

The TEPCO ERC reported information concerning the abovementioned work and the CV venting implementation to the Government ERC through TEPCO's official communication team every time they obtained such information via the teleconference system.

(vii) At approximately 15:36 on March 12, the recovery team of the NPS ERC investigated the site after the explosion at the Unit 1 R/B and confirmed that the portable compressor placed outside the large equipment service entrance of the building had stopped. The recovery team checked that the cause of the stoppage was not because the device had run out of fuel so they tried restarting it but in vain.

After that, it became impossible to access the location where the portable machine was installed. Around March 20, 2011, the recovery team finally installed a new portable compressor.

c. Reasons why it took time to implement the containment venting

(i) Some pointed out that the reason for the delayed containment venting at Unit 1 was hesitations in decision-making and task implementation. As for the accident at Unit 1, we think it was caused by the NPS and TEPCO ERCs' incorrect understanding of the operating condition of the IC as mentioned in (3)d above. If it had not been for their misunderstanding, they would have started preparations for the containment venting along with an alternative method of water injection to the Unit 1 reactor earlier. Except for this point, however, we found no evidence that members of the NPS ERC hesitated to depressurize the containment at Unit 1 as mentioned below.

(ii) First of all, Unit 1 entirely lost its AC power sources at around 15:37 on March 11 and almost simultaneously it lost the DC power sources as well. Unit 1 was therefore in an extremely serious situation. It was around 00:06 on March 12 that Site Superintendent Yoshida directed his teams to make preparations for the containment venting at Unit 1. Considering this time lag only, the abovementioned allegation about the hesitation of the related parties may seem to be reasonable.

However, Site Superintendent Yoshida believed that the IC of Unit 1 was operating normally from late afternoon until the night of March 11. On the other hand, he suspected the RCIC at Unit 2 had failed. Based on his understandings Site Superintendent Yoshida thought that Unit 2 was in more dangerous situation compared to Unit1. Site Superintendent Yoshida, that is to say, did not feel an imminent necessity for the containment venting based on his misunderstanding of the operating condition of the IC of Unit 1. After all, he did not have any reason to hesitate the containment venting.

At approximately 22:00 that day, the reactor water level gage at Unit 2 read 3,400mm above the TAF, though the NPS ERC still could not confirm the operating condition of the RCIC. On the other hand, the radiation levels increased in the R/B at Unit 1 and at the monitoring posts after approximately 22:00 that day. At approximately 23:50, when they measured the D/W pressure at Unit 1, it was 0.600 MPa abs. We presume that Yoshida, Superintendent, had not directed his staff to measure the D/W pressure until that time because he did not see that the immediate implementation of the containment venting was necessary,.

At approximately 23:50 on March 11, Site Superintendent Yoshida learned that the D/W pressure of Unit 1 was 0.600 MPa abs. and came to feel an imminent necessity of implementing C/V venting. At approximately 00:06 on March 12, 16 minutes later, he ordered the start of preparations for the containment venting.

Judging from the discussion above, the reason for the delay of the containment venting was not of their hesitation but of their misunderstanding of the plant condition at Unit 1.

(iii) Before they received Site Superintendent Yoshida's direction to start preparations for the containment venting, the shift team and the operation team of the NPS ERC had already started to check the Emergency Operating Procedure for AM and the drawings showing the location and the structures of valves for the containment venting under the loss of all power sources.

However, it became impossible to open those valves necessary to implement the containment venting remotely from the control panel in the Units 1 & 2 main control room due to the total loss of AC and DC power sources so that they were forced to manually open them on-site. Since the existing Emergency Operating Procedure for AM prescribed the specific procedures on the premise that the plant can be controlled remotely from the control room, the operation team of the NPS ERC had to confirm many points one by one, including the identification of the valves to be opened, their locations and whether they could be manually operated.

After dawn on March 12, especially from approximately 04:00 until 05:00, the levels of radiation increased abnormally in the R/B at Unit 1 so that it became dangerous for the shift team to stay in the Unit 1 block of the main control room. It was still more dangerous to go into the reactor building and it is just like "doing something with their lives at risk." In addition, the frequent occurrences of aftershocks were another obstacle to their operation.

While evacuation areas were expanding without an effective means of communication, it was finally realized that the evacuation of residents from Okuma Town, Futaba County, Fukushima Prefecture, was not yet complete. TEPCO and the Fukushima prefectural government negotiated and agreed to postpone the containment venting until the completion of all the evacuation. At approximately 09:02 on March 12, the NPS ERC finally acknowledged that the evacuation of residents had finished (see b(i) above for details on the NPS ERC' misunderstanding about the completion of the evacuation).

At approximately 09:04 that day, the shift team, faced with a life-threatening situation, carried out preparations for the implementation of the containment venting.

When it was found that the manual opening operation of the small S/C vent valve (air-operated) was impossible on-site, the NPS ERC also put in their best effort to conduct the containment venting and they checked the installation, connection and procurement of a portable compressor.

Taking into consideration the development of the events mentioned above, we see no evidence that the shift team and the NPS ERC personnel hesitated to implement the containment pressure venting and consequently delayed the task of depressurization, though they totally lacked in preparedness against the total loss of AC and DC power sources (for example, no consideration was given to the location and water-tightness of emergency DGs and power panels and they did not have a spare portable compressor for emergency use) and the start of specific actions for the containment pressure venting was delayed as a result of their misunderstanding about the operating condition of the IC.

(6) Recovery of power sources

(i) From approximately 15:37 until 15:41 on March 11, all the AC power sources at Units 1, 2 and 3 were lost and, almost simultaneously, the 125 VDC power sources of Units 1 and

2 were also lost. After late afternoon that day, the recovery team of the NPS ERC confirmed each of these facts and inspected the damages of all power supply facilities. As a result of the investigation, they found that the circuit breakers and other devices of switchyard had fallen down on the ground and got unusable, and the quick recovery of external power sources was difficult. Except for an air-cooled DG in Unit 6, all other emergency DGs and/or their power panels were flooded and the team thought it impossible to repair them in a short time. All metal-clad switch gear for regular and emergency use in Units 1 to 5 were submerged and it would be impossible to feed power to electric devices without them even if external power sources or emergency DGs were recovered.

The NPS ERC decided that they would need truck-mounted generators. While investigating the damage at the Fukushima Dai-ichi NPS, the NPS ERC asked the TEPCO ERC via the teleconference system to procure truck-mounted generators as soon as possible.

At approximately 16:10 that day, TEPCO Head Office instructed all branches and power stations through the Power Distribution Department to secure high- and low-voltage power supply vehicles and confirmed the transport routes from their respective locations to the Fukushima Dai-ichi NPS.

At approximately 16:50 that day, high- and low-voltage truck-mounted generators left for Fukushima, but their trips were not smooth because of damaged roads and heavy traffic congestion on the way.

By approximately 17:50 that day, TEPCO reviewed the possibility of transporting high- and low-voltage truck-mounted generators by helicopter and asked the SDF to airlift the trucks. By approximately 20:50, however, they abandoned the plan because the trucks were too heavy to be transported by air.

At approximately 18:20 that day, TEPCO requested Tohoku Electric Power Co. to dispatch high-voltage truck-mounted generators to the Fukushima Dai-ichi NPS. In response to the request, Tohoku Electric Power Co., Inc. sent a fleet of high-voltage truck-mounted generators to Fukushima. By approximately 01:20 on March 12, a total of four trucks arrived at the NPS.

At approximately 21:28 on March 11, truck-mounted generators from the SDF reached the Fukushima Dai-ichi NPS. However, their cable connector specifications were different from those of TEPCO's connectors and thus the SDF vehicles were not used for power restoration at the nuclear power station.

(ii) After late afternoon on March 11, the recovery team of the NPS ERC investigated if it was possible to recover the power sources of the measuring instruments in the Units 1 & 2 main control room. As they were advised of the possibility of using automobile batteries to restore monitoring instruments, the recovery team asked partner companies to help them procure batteries.

With the cooperation of the private companies, the team removed two 12V batteries from buses and obtained four 6V batteries. By approximately 20:00 that day, they had brought the batteries that were available for recovering the power source of the measurement devices into the Units 1 & 2 main control room. They lined up the batteries with a total of 24V and connected them, and then linked them to a terminal for the reactor water level gage on the rear of the control panel. At that time, the recovery team of the NPS ERC had to check about 10,000 pages of wiring diagrams to find out target devices and identify those points at which circuits could be established because they could not use the desktop search system as there were no lights or PCs available in the main control room. In addition, the team looked for materials necessary for wiring work including cables, terminals and tape in the Units 1 & 2 main control room and instrument rooms as they could not find any of these in the NPS ERC.

At approximately 21:19 that day, the reactor water level gage of Unit 1 recovered. However, the water level was only 200mm above the TAF. So, they kept the batteries connected and put them in standby mode.

At approximately 22:00 that day, the reactor water level gage of Unit 2 also recovered and indicated that the water level was still about 3,400mm above the TAF. So, the team decided to keep connecting batteries to the meter The NPS ERC obtained small generators from partner companies on the premises of the Fukushima Dai-ichi NPS to restore the lighting of the Units 1 & 2 and 3 & 4 main control rooms. Temporary lighting was set up in the Units 1 & 2 main control room at approximately 20:49 and in the 3 & 4 main control room at approximately 21:58 that day.

The temporary lighting was not powerful enough to illuminate the entire rooms. It was only possible to spotlight small areas such as documents and measuring instruments to be monitored. They were small AC generators and later used as power sources of AC – powered instruments such as the D/W pressure gage and the S/C water temperature gage of Unit 2.

(iii) Incidentally, the high-voltage AC power supplies from off-site grid to the Fukushima Dai-ichi NPS were 275,000V and 66,000V. They were transformed at the power centers of the Units to three different voltages suitable for the respective electrical systems and delivered through system lines to electric facilities and equipment within the premises.

Specifically, there were three types of power distribution boards; the metal-clad switch gear (M/C) for internal high-voltage circuits (6,900V), the power center (P/C) for internal low-voltage circuits (480V), and the motor control center (MCC) for internal small-capacity low-voltage circuits (100V). The Fukushima Dai-ichi NPS's electrical systems of various sizes from large to small required three different voltages of 6,900V, 480V and 100V. Electric power supplied from off-site grid were transformed to the respective voltage requirements, connected to system lines of appropriate voltage ratings and delivered to electric facilities and equipment. Therefore, even if outside power sources were recovered, it was impossible to deliver electric power from those external sources to internal electrical systems as long as these power distribution boards were not available.

(iv) At approximately 16:39 on March 11, the recovery team of the NPS ERC started investigating the damage to external power sources and internal AC and DC power supply facilities caused by the earthquake and tsunami.

As for M/Cs and P/Cs installed on the first basement floors of the T/Bs of Units 1 and 2 (some of them were placed outside the buildings), the team was able to visually check whether or not they were submerged and/or damaged. By approximately 20:56 that day, they found that all the M/Cs and P/Cs for Unit 1 and all the M/Cs for Unit 2 were unusable but some P/Cs of Unit 2 were available. The NPS ERC received a report from the shift team in the Units 3 & 4 main control room stating that M/Cs and P/Cs installed on the first basement floor of the Unit 3 T/B were submerged and unusable.

The recovery team of the NPS ERC used available P/C power transformers[51] and power supply vehicles to search for recoverable electric systems. As a result of their investigation, they found that the SLC system of Unit 1 would be usable by temporarily connecting the C system (hereinafter called "2C system") of the Unit 2 P/C and the primary side of the Unit 1 MCC and then feeding a 480VAC current. They also confirmed that if they connected a high-voltage truck-mounted generator to the secondary side of the 2C system, the voltage could be step down to 480V by the P/C and so the SLC system and the control rod drive mechanism (CRD system) of Unit 2 would be available..

In contrast to the FP system's filtered water tank, the SLC and CRD systems had indoor tanks. Their capacities were not large but were hardly damaged by the earthquake and tsunami. Moreover, they had the advantage that water injection was possible even when the reactor pressure was high.

However, truck-mounted generators available at that time were of so-called high-voltage type (6,900V). It could not be directly connected to the P/C.

The recovery team of the NPS ERC had to secure a 480V power source necessary for the operation of SLC system equipment including pumps by temporarily connecting the high-voltage truck-mounted generators and the primary side of an available P/C (2C system), where the high voltage (6900V) current flowed.[52]

(v) Units 1, 2 and 3 all needed power source recovery.

From late afternoon until the night of March 11, the NPS ERC could not confirm the operation of the IC of Unit 1 or the RCIC of Unit 2 though they found that the RCIC of Unit 3 was running. The recovery team of the NPS ERC decided to give priority to recovering the power sources of Units 1 and 2 by any possible means including connecting a power supply vehicle and the 2C system with cabling.

Taking into consideration the distance to the 2C system and the ease of cabling, the recovery team planned to park a truck mounted generator on the south side of the Unit 2 T/B, lay high-voltage cables outside the building in a westerly direction, insert it into the

[51] This is a transformer where a primary voltage of 6900 V is stepped down to the secondary voltage of 480 V.

[52] According to the standards for vehicle-mounted power generators, 6900 V high voltage and 100 V low voltage generators are generally available, but 480 V generators are out of standard and unavailable in the market except for special orders.

building through an opening on its western side, lay more cables along a western hallway on the first floor of the building to the 2C system, which was located on the north side of the same floor, and then connect the truck-mounted generator and the 2C system with that high-voltage cable. They also decided to lay low-voltage cables from the 2C system to the primary side of the MCC, which was located to the northeast of the first basement floor of the control building (C/B) of Unit 1, and connect the two power centers with the low-voltage cables in order to recover a power source for the Unit (see Fig. IV-6).

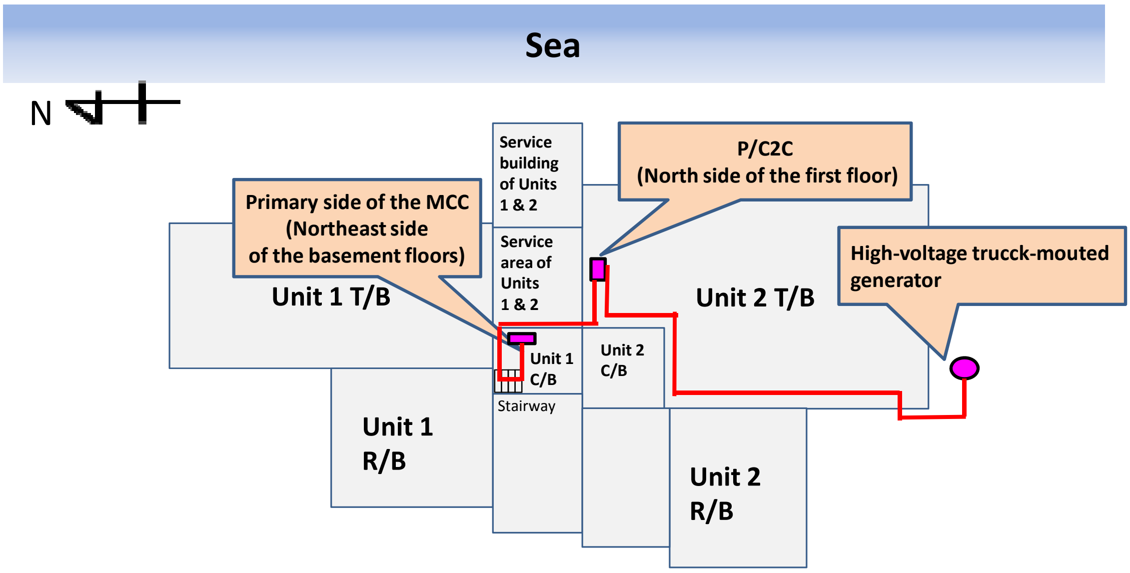

Fig. IV-6 Cabling route for Units 1 and 2 (schematic chart) (compiled from TEPCO data)

The cable mentioned above belonged to a partner company and was kept near Unit 4 for periodic inspection work at Unit 4. It had a diameter of more than 10mm. They cut the cable in lengths of about 200 meters. It weighed more than one ton.

After dawn on March 12, the recovery team of the NPS ERC transported the high-voltage cable by a four-ton crane truck to the large equipment service entrance of the Unit 2 T/B. Some 40 people from TEPCO and partner companies moved the cable to the first floor and laid it in the building. During the work, a warning for a major tsunami was issued and there were frequent aftershocks so that they often had to evacuate the building and suspend the task. The only tool available for communication between the site and the NPS ERC was wireless transceivers since the PHS was out of service. Thus the wire transceiver operator had to move to a place where he could make contact with the NPS ERC. It therefore took time to communicate with the command center. It eventually took several hours to lay the high-voltage cable in the T/B of Unit 2.

The terminal treatment of cable necessary for the connection with the 2C system was a special task as every three lines of the high-voltage cable had to be fixed to a metal plate. It took several hours for a few technicians to complete the work.

At the same time, about ten people from TEPCO and partner companies laid low-voltage cable from the 2C system on the north of the first floor of the Unit 2 T/B to the primary side of the MCC on the northeast of the first basement floor of the Unit 1 C/B. The recovery team treated the terminals of the cable in order to connect it to the primary side of the MCC.

From the night of March 11 until the morning of March 12, power supply vehicles started to arrive from the SDF and Tohoku Electric Power. Truck-mounted generators from TEPCO arrived at the Fukushima Dai-ichi NPS while the cable was being laid at the T/B of Unit 2. This TEPCO generator was chosen and parked to the south of the Unit 2 T/B to connect the high-voltage cable, which was inserted through an opening into the T/B, and the high-voltage truck-mounted generator.

(vi) At approximately 15:30 on March 12, they finished connecting the cable to the primary side of the 2C system and the high-voltage truck-mounted generator. They activated the generator and started measuring the insulation resistance.

The recovery team of the NPS ERC also placed a low-voltage truck-mounted generator inside the large equipment service entrance of the T/B of Unit 2 in order to recover a power source for the measurement of Unit 1. They used several cable reels to lay cable toward a cable bolt room, conducted the required terminal treatment and connected it to a power distribution panel for the measurement of Unit 1. At approximately 07:20 that day, they started feeding electric power.

At approximately 15:36 that day, there was an explosion in the R/B of Unit 1. Broken pieces and debris blown off in the explosion damaged the cable, which was connected to the power supply vehicle on the south of the T/B of Unit 2.

Since the R/B of Unit 1 was in danger of exploding again, all workers evacuated to the Seismic Isolation Building for a while. Since the operator also had to leave the site, he manually stopped the high-voltage power supply vehicle.

The low-voltage power supply vehicle was not damaged in the explosion as it was parked inside the large equipment service entrance of the T/B of Unit 2.

(7) Plant situation of Unit 3 and responses to it

(i) After approximately 16:03 on March 11, the RCIC of Unit 3 was operating using the condensate storage tank as its water source in accordance with the prescribed procedure.

The shift team cut off loads that were not immediately needed one by one so as to enable the RCIC of Unit 3 to operate as long as possible.

If the reactor water level increased and the RCIC automatically stopped, restarting the reactor core isolation cooling system would consume considerable capacity. Therefore the shift team operated the RCIC by controlling the flow rate to the reactor while they closely monitored the reactor water level by means of using the test line for periodical tests through which the fractional flow returns to CST (see Fig. IV-7).

Opening/closing of valves indicate state during operation

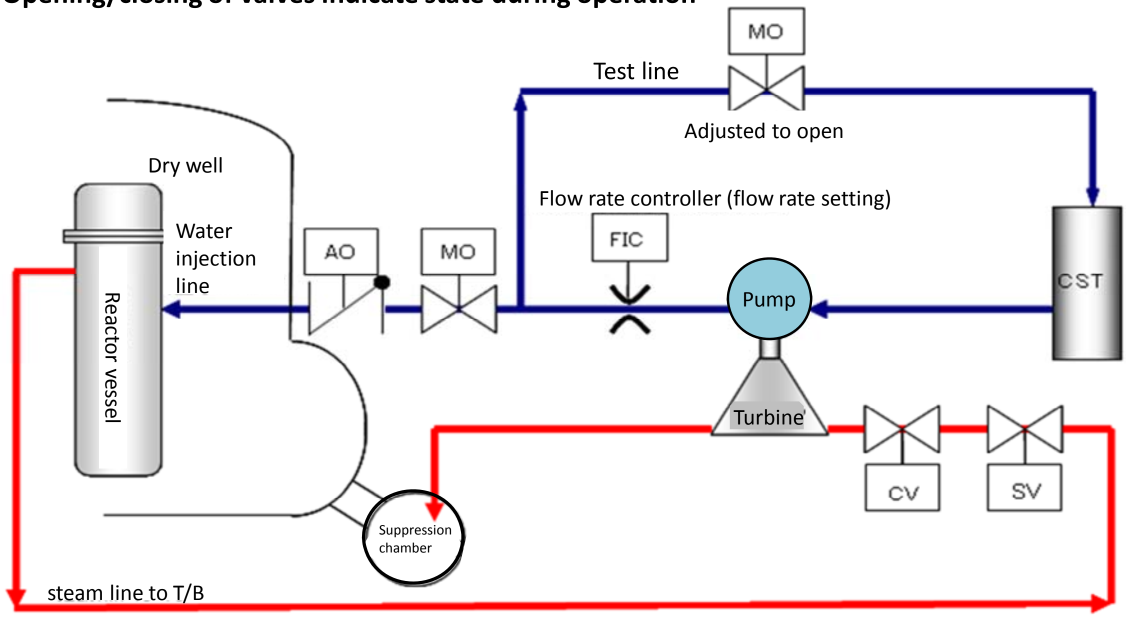

Fig. IV-7 Overview of the RCIC and HPCI water injection line (compiled from TEPCO data).

At approximately 11:36 that day, the RCIC of Unit 3 stopped. When the shift team went to the RCIC room on the first basement floor of the Unit 3 R/B to check the operation of the RCIC, they found drops of oily water on a latch of the RCIC and the latch was unfastened. The shift team fastened the latch and tried to restart the RCIC but it soon stopped again. They wiped the oil off and tried fastening the latch several times. Ultimately the RCIC did not work.

(ii) After that, the water level of the Unit 3 reactor dropped and the HPCI automatically started at approximately 12:35 on March 12.

In the Units 3 & 4 main control room, the shift team operated the HPCI by controlling the flow rate while they monitored the reactor water level gage and the HPCI flow rate controller ,using the test line as the RCIC.

At that time, Site Superintendent Yoshida judged that the water injection and the containment pressure venting of Unit 1 were the first priority, considering the general situation of the Units. He thought of using the HPCI to inject water into Unit 3 for the time being.

4. From the explosion at the Unit 1 R/B until the explosion at the Unit 3 R/B (from approximately 15:36 on March 12 until 11:01 on March 14)

(1) Seawater injection into Unit 1

a. Recovery after the explosion at the R/B of Unit 1

At approximately 15:36 on March 12, an explosion took place in the R/B of Unit 1 and its cause was thought to be hydrogen gas. Broken pieces were scattered, some workers were injured and everyone evacuated to the Seismic Isolation Building.

Right before the explosion, a high radiation level (1,015 μSv/h) exceeding 500 μSv/h was detected near monitoring post 4 at approximately 15:29 that day. Upon receiving the report, Site Superintendent Yoshida deemed that a specific event (abnormal increase in radiation levels at the site boundary) as defined in Paragraph 1, Article 15 of the NEPA had occurred and reported his assessment to the relevant authorities at approximately 16:27 that day right after the explosion.

Site Superintendent Yoshida first ordered the confirmation of the safety of workers and other personnel. After approximately 17:20 that day, while monitoring the ongoing status of affairs at the R/B of Unit 1, he ordered an investigation of the damages to the fire engines, buildings and other facilities and decided to resume the preparations necessary for seawater injection.

Along with a radiation safety staff, the in-house firefighting team and Nanmei workers went to the site near the R/B of Unit 1 and found radioactively contaminated iron plates and other debris scattered around from the Unit 1 R/B by the explosion and the surrounding radiation level was high. They also found the windows of the three fire engines connected which were laid out in series to inject seawater into the Unit 1 reactor were broken but the fire pumps were still intact.

However, the fire hoses were damaged by debris and had to be replaced with new ones. In a precarious environment as it was getting dark, the in-house firefighting team and Nanmei staff worked to recover the water injection line: they removed debris to secure space to configure a water injection line, collected new fire hoses from outdoor fire hydrants, and laid hoses over several hundred meters from the backwash valve pit in front of the T/B of Unit 3 to the embedded water discharge port of the T/B of Unit 1. As a result, it took time to resume the water injection. At approximately 19:04 that day, they were finally ready to inject seawater into the Unit 1 nuclear reactor (see Attachment IV-19).

b. Reponses by the TEPCO ERC and the Japanese government

(i) The TEPCO ERC understood the status of the seawater injection before and after the explosion of the Unit 1 R/B via the teleconference system. They believed that the seawater injection was urgent though they were aware of the harsh working environment at the Fukushima Dai-ichi NPS. Thus the TEPCO ERC did not object to Site Superintendent Yoshida's decision to resume the operation and reported the progress of the work to the Government ERC.

However, NISA officials who were stationed in the Government ERC and the PMO could obtain only the fragmentary information[53], so that they could not correctly appreciate the difficulty of the seawater injection operation.

(ii) At approximately 15:04 on March 12, right before the explosion of the Unit 1 R/B, METI Minister Kaieda said that he would issue an order of resuming injection operation to TEPCO if the interrupted situations continues. At approximately 17:55 that day, he verbally issued an order as stipulated in Section 3, Article 64 of the Reactor Regulation Act to TEPCO to fill the Unit 1 reactor with seawater and the minister also directed NISA to issue a statement of direction.[54]

By approximately 18:05 that day, the Tokyo and NPS ERC realized that the ministerial order had been issued.

(iii) No later than approximately 19:15 on March 12, the Government ERC received a report from TEPCO that the seawater injection had begun and they relayed the information by telephone to the officials participating in the PM’s Office Emergency Operations Team stationed in the basement of the PMO.

53 At this point of time, the nuclear safety inspectors at the Fukushima Dai-ichi NPS had already evacuated to the Off-site Center.

54 The instructive statement was prepared at around 20:05 on March 12 and formally issued later. Such a procedure is not unusual and not specific to this case, as verbal instructions are documented as ex-post records.

To share the information with other members, the officials of the PM's Office Emergency Operations Team announced at the meeting table that the seawater injection had begun. However, Prime Minister Kan, METI Minister Kaieda, Chairman of NSC Madarame and TEPCO Fellow Takekuro were on the 5th floor of the PMO and did not receive this information.

c. PMO's response and Site Superintendent Yoshida's decision to continue the seawater injection

(i) From late afternoon on March 12, Prime Minister Kan, Special Advisor to the Prime Minister Hosono, Chairman of NSC Madarame, a department chief of METI, Director-General of NISA Hiraoka and TEPCO Fellow Takekuro had a meeting in the Prime Minister's office on the 5th floor of the PMO about the seawater injection into the Unit 1 reactor and the expansion of the evacuation area. During the meeting, they also exchanged opinions on the continuation of the seawater injection. We have not grasped the details of the discussion yet because we have not yet held a hearing from Prime Minister Kan and some of the others present at the meeting. However, we interviewed some of the related parties who explained how the meeting progressed. The following is just the tentative results of our investigation and it is highly possible that we may revise the interim report depending on the future research.

Prime Minister Kan raised questions about the possible effects of the seawater injection to the reactor. Chairman of NSC Madarame and TEPCO Fellow Takekuro expressed their opinion, "We must give priority to water injection, even if we have to use seawater."

In addition, Mr. Kan questioned Mr. Madarame about the possible recriticality. Mr. Madarame answered, "We don't need to worry about the recriticality so much." The Prime Minister, however, was not fully convinced of the NSC chairman's opinion.

(ii) They then discussed the expansion of the evacuation area. Prime Minister Kan suggested expanding the existing evacuation area of a 10-km radius of the Fukushima Dai-ichi NPS and instructing those residents within a 20-km radius of the NPS to move further away. No one at the meeting objected to the plan.

Areas outside a 10-km radius of the Fukushima Dai-ichi NPS were deemed to be beyond the scope of evacuation and no emergency drills had ever been conducted. No practical preparations such as a means of communicating with local governments and communities, evacuation methods and sites, screening or the distribution of supplies had been made.

(iii) Some of those at the meeting raised questions about the seawater injection: "Are they ready for the seawater injection in the first place? When do we have to make a decision by?" TEPCO Fellow Takekuro had already been notified by the TEPCO ERC that the seawater injection hoses had been damaged in the explosion and it would take time to get prepared for resuming the operation. So, he answered, "We don't need to decide right away. They may take one or two hours."

They therefore decided to take a break and reconvene at approximately 19:30 that day.

(iv) The department chief of METI who was at the meeting was assigned the task of sorting the questions by Prime Minister Kan and directing them to TEPCO, NISA and the NSC. The three organizations would research their respective questions during the break and report their answers to Mr. Kan after the meeting resumed.

TEPCO Fellow Takekuro had to find answers to the following questions allocated to TEPCO.

(a) Do they have pumps for injecting seawater?

(b) Has the piping system for water injection been damaged?

(c) Will it be possible to control the reactor after the injection of seawater?

Since he did not have much time, TEPCO Fellow Takekuro called Site Superintendent Yoshida directly from the PMO. It was after 19:04 and the seawater injection had already resumed at the Fukushima Dai-ichi NPS but TEPCO Fellow Takekuro, who had been in the PMO, did not know this.

TEPCO Fellow Takekuro asked Site Superintendent Yoshida the aforementioned questions by phone. At that time, Site Superintendent Yoshida replied, "We've already started the seawater injection."

So TEPCO Fellow Takekuro requested Site Superintendent Yoshida to stop the seawater injection because discussions on the injection were still underway at the PMO. He decided to call the seawater injection that already been conducted “a test injection to check“ if seawater could be pumped into the reactor without any problems. In fact, however, Prime Minister Kan approved the seawater injection soon after the meeting reopened and TEPCO Fellow Takekuro did not have a chance to explain to Mr. Kan that the seawater had already been injected into the reactor as a test.

(v) Meanwhile, after his telephone conversation with TEPCO Fellow Takekuro, Site Superintendent Yoshida thought that since they were not sure when the seawater injection could be resume once it was suspended, the state of the reactor would steadily get worse. He therefore consulted with the TEPCO ERC and Executive Vice President Mutoh who was stationed at the Off-site Center via the teleconference system. The TEPCO ERC and Executive Vice President Mutoh answered that as long as the PMO 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.

Site Superintendent Yoshida, however, was concerned about the risk of suspending the seawater injection. He made the executive decision to continue the injection. Site Superintendent Yoshida called in the person in charge of the injection work and told him quietly so as to avoid being overheard by the teleconference system microphone or anyone around them, "I'm going to direct you to stop the seawater injection, but do not stop it." Soon after, Site Superintendent Yoshida ordered the suspension of the seawater injection in a voice that could be heard throughout the Emergency Response Office.

As a result, the injection of seawater into the Unit 1 nuclear reactor continued. Only Site Superintendent Yoshida, the person in charge of the task and a few other members knew this. Needless to say those at the TEPCO ERC and the Off-site Center, and most of the NPS ERC personnel believed that the seawater injection had stopped.

(vi) At approximately 19:27 on March 12, the Government ERC also received a report from the TEPCO ERC that the seawater injection had started but was now stopped and the Fukushima Dai-ichi NPS was waiting for further directions from Prime Minister Kan. The Government ERC communicated the content of the report to a liaison from NSC who was a member of the PM’s Office Emergency Operations Team stationed in the basement of the PMO and the team shared the information. However, this information was not provided to Prime Minister Kan and the other related parties on the 5th floor of the PMO.

After that, TEPCO Fellow Takekuro called the TEPCO ERC and said that he had obtained the Prime Minister's approval for the seawater injection. The information about the approval was communicated via the teleconference system to the NPS ERC.

Since most of the people at the TEPCO and NPS ERCs did not know the seawater injection had continued, Site Superintendent Yoshida issued a directive in the Emergency Response Office to resume the seawater injection at approximately 20:20 that day. He also reported this to the Government ERC, the TEPCO ERC and other related offices. They declared that full-scale seawater injection started at approximately 20:20 that day and that the seawater injection conducted prior to that time was a test run.

(vii) At approximately 20:45 on March 12, the NPS ERC decided to put boric acid from the NPS's stocks into the seawater of the backwash valve pit in front of the T/B of Unit 3 and inject seawater containing boric acid into the Unit 1 nuclear reactor in order to prevent the reactor from recriticality.

(2) Alternative method of water injection into Unit 3

a. Plant status of Unit 3 and response of the shift team

(i) The RCIC of Unit 3 of the Fukushima Dai-ichi NPS stopped for some reason at approximately 11:36 on March 12. The shift team went to the RCIC room on the first basement floor of the Unit 3 T/B to check the operation of the equipment. They also tried restarting the RCIC from the Units 3 & 4 main control room but failed. At approximately 12:06 that day when the RCIC of Unit 3 had already stopped, the shift team activated the D/DFP line and then the S/C spraying. In the meantime, the reactor water level of Unit 3 was dropping and the high-pressure coolant injection system (HPCI) automatically started at approximately 12:35 that day.

Since the flow rate of the HPCI system was high, the reactor water level would rise rapidly and the HPCI would soon stop if the flow rate were not adjusted. It requires a considerable amount of power (leading to batteries depletion) to restart the HPCI. In preparation for such a situation, the shift team had earlier opened a motor-driven valve on the test line of the HPCI to construct a line to inject water into the reactor and another line to return water to the condensate storage tank, which was the water source for the injecting. Thus the flow rate of the HPCI could be controlled (see Fig. IV-7).

After that time, the reactor pressure of Unit 3 decreased significantly due to the operation of the HPCI. According to the reactor pressure gage, the reactor pressure of Unit 3 was between 0.8 MPa gage and 1.0 MPa gage after 19:00 that day.

(ii) At approximately 20:36 on March 12, the shift team could no longer monitor the reactor water level because the 24-V DC power source for the reactor water level gage was depleted. The recovery team at the NPS ERC provided the Units 3 & 4 main control room with thirteen 2V batteries (including one spare battery) from the 50 batteries that the NPS ERC had obtained from the Hirono Thermal Power Station by dawn that day to recover the power source of the reactor water level gage of Unit 3. In the meantime, the shift team in the Units 3 & 4 main control room increased the setup value of the HPCI's flow rate to secure a sufficient amount of water to the reactor core because it was impossible to monitor the reactor water level in real time. They also closely monitored the reactor pressure and the discharge pressure of the HPCI to establish the operating status of the high-pressure coolant injection system.

The HPCI is a water injection system originally designed to inject a large volume of water into the reactor in a short space of time when the reactor was in a high pressure state of between 1.03 MPa gage and 7.75 MPa gage.[55]

The HPCI of Unit 3 was kept at a low rpm below its operating range defined in the operation procedure while the shift team was controlling the flow rate in a situation where the reactor pressure was fluctuating between 0.8 and 0.9 MPa gage. The discharge pressure of the HPCI was gradually dropping and getting closer to that of the reactor pressure.

Since the reactor water level was unknown, they were not certain whether a sufficient

[55] In "the application document for alteration in reactor establishment license" it is written that the HPCI at Unit 3 can inject the water into the reactor core at the rated flow rate in the pressure ranges of 10.5 kg/cm^2 to 79 kg/cm^2 gage. For reference, 1kg/cm2 in gage corresponds to approximately 0.09807 MPa gage.

amount of water had been injected into the reactor and there was a risk of the HPCI's breakdown as it was operating in an unusual fashion so the shift team began to feel anxious about the continuation of HPCI operation.

In addition, the shift team thought it was still possible to open the SRV by manual remote control from the control panel because the SRV status indicator on the control panel in the Units 3 & 4 main control room was green showing that the valve was completely closed (see Attachment IV-6).

The shift team thought that the discharge pressure of the D/DFP could be high enough to inject water into the reactor if they reduced the reactor pressure further, which was between 0.8 and 0.9 MPa gage at the time, by opening the SRV by manual remote control from the control panel and changed the D/DFP connection from the S/C spray line to the reactor water injection line.

The shift team decided to manually stop the HPCI at approximately 02:42 on March 13 as they thought that water injection by the D/DFP would be more stable than by the HPCI.

(iii) Before the manual shutdown of the HPCI of Unit 3, the shift team told some members of the operation team of the NPS ERC (including the shift supervisor of the Units 3 & 4 main control room who was on standby in the booth of the operation team in the Emergency Response Office) about their awareness of the issues concerning the operation of the HPCI. The shift team said that they wanted to manually stop the HPCI and use the D/DFP for the water injection after depressurizing the reactor with the SRV.

The members the shift team consulted discussed the problems related to the operation of the HPCI at Unit 3 and reviewed whether or not the HPCI should be manually stopped. As a result, they understood that the HPCI might break down if it was to continue running at an rpm below its acceptable operating range. They made a decision and told the shift team that stopping the HPCI was the only option if it really were possible to use the D/DFP for water injection by opening the SRV by manual remote control from the control panel.

The members of the operation team were so concerned with the on-site work that they did not pay much attention to the transmission of information. Consequently all the members of the operation team at the NPS ERC were not told of the shift team's awareness of issues concerning the operation of the HPCI or the information concerning the manual shutdown of the HPCI. The operation section chief did not get the information either. He only knew that the HPCI was running although its rpm had dropped due to the lowered pressure.

Consequently, Site Superintendent Yoshida and other members of the NPS and TEPCO ERCs did not know that the shift team of Unit 3 was going to manually stop the HPCI.

(iv) At approximately 02:42 on March 13, before the manual shutdown of the HPCI, the shift team went into the R/B of Unit 3 to check the operation of the D/DFP and switch from the S/C spray line to the reactor vessel water injection line. At that time, the working members of the shift team did not have any means by which to communicate with the Units 3 & 4 main control room. It was at approximately 03:05 that day when they returned from the R/B of Unit 3 to the main control room and the HPCI had already been manually stopped. Therefore, we are not certain which was conducted first, “the manual shutdown of the HPCI “or “the switching operation.” Anyhow those two operations must have been conducted within a very short space of time.

At approximately 02:42 that day, the shift team pressed the stop button on the control panel and completely closed the steam inlet valve of the turbine in the Units 3 & 4 main control room to manually shut down the HPCI. At approximately 02:45 and 02:55 that day, the shift team tried to open the SRV by manual remote control from the control panel in the Units 3 & 4 main control room. However, the SRV status indicator lamp on the control panel did not change from green, indicating it was completely closed, to red signaling it was fully open, in the two trials. The shift team decided that they were not able to open the SRV by manual remote control from the control panel and that they had failed to depressurize the reactor.

We assume that the reason why they failed to open the SRV although the status indicator lamp was illuminated was not because of actual trouble but because of low battery capacity.[56] It is clear from the fact that they succeeded in opening the valve at approximately 09:00 that day after the power source was restored.[57]In other words, the amount of battery needed to open the SRV was greater than that needed to illuminate the status indicator lamp. In some cases, therefore, we cannot say that manual remote control is always possible when the status indicator lamp on the control panel is on. Attention should be paid to this point when operating SRVs in the future.

(v) At approximately 02:45 and 02:55 on March 13, the shift team failed, twice in total, to open the SRV by manual remote control. The shift supervisor reported each of their failures to the operation team at the NPS ERC.

However, the members who received the reports or heard them, including the shift supervisor of the Units 3 & 4 main control room who was on standby in the Emergency Response Office, did not forward the information to the operation section chief. As a result, the NPS and TEPCO ERCs were unaware of not only the implemented manual shutdown of the HPCI but also the failure to open the SRV at that time.

According to the reactor pressure gage, the reactor pressure of Unit 3 dropped to 0.580 MPa gage at approximately 02:44 on March 13. However, it soon started to increase as it went up to 0.770 MPa gage at approximately 03:00 and 4.100 MPa gage at approximately 03:44 that day. In the meantime, the shift team attempted to inject water into the reactor by starting up the D/DFP of Unit 3. The discharge pressure of the

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[56] The flow controller (FIC) of HPCI lost its function of measuring the flow rate due to DC power loss at around 03:35 on March 13. In fact, there were some signs that DC power source was gradually depleting shortly after the HPCI trip.

[57] In general, the SRVs can be manually opened by remote control, if the RPV pressure is over 0.686MPa gage. According to the plant parameters released by TEPCO, the Unit 3 RPV pressure at around 02:44 on March 13 was 0.580MPa gage. Therefore the possibility that RPV pressure was below the required value at the time of the first opening operation at around 02:45 cannot be ruled out. On the contrary, taking into account a shift team operator's logbook saying that the RPV pressure was "0.8 MPa" at around 02:45 on the same day, it can be concluded that the lower pressure was not the real cause of the "fail to open." To return to TEPCO's plant parameters, the RPV pressure at Unit 3 around 03:00 on the same day elevated up to 0.770 MPa gage. If so, it is highly possible that the RPV pressure had reached the required pressure of 0.686 MPa gage at the time of the second opening operation at around 02:55 on the same day. Furthermore, judging from a shift operator's logbook saying that the RPV pressure at Unit 3 was "1.3 MPa" at around 02:55 on the same day, the RPV pressure supposedly satisfied the required value when the second opening action was taken.''

D/DFP reached 0.61 MPa gage by at approximately 03:05 that day[58] but did not exceed the reactor pressure of Unit 3. In short, it was physically impossible to inject water into the reactor.

Regarding this point, the operator's logbook at Unit 3 says in its column for 03:05 on March 13, "Thought a flowing sound could be heard around at the opening of 7% while pumping water into the reactor by D/DFP at MO-10-27B 15-percent ", suggesting the shift team had confirmed the injection of water into the reactor by the sound of water flowing. As we mentioned above, however, it was hard to think that the RPV pressure at around 03:05 that day fell to lower than 0.770 MPa gage, the reactor pressure value measured at approximately 03:00 that day, because the reactor pressure of Unit 3 was actually increasing and there was no particular reason suggesting the reactor pressure went from increasing to decreasing under the loss of its cooling water injection function. We therefore assume that the discharge pressure of the D/DFP at approximately 03:05 that day was not higher than the reactor pressure.[59]

If so, it cannot be concluded that the water injection by the D/DFP to Unit 3 nuclear reactor was implemented and we must say that the statement in the operator's logbook was the subjective personal opinion of the shift team members. In particular, the members who confirmed the activation of the D/DFP did not have any means of communication and firmly believed it was possible to inject water into the reactor by opening the SRV. It is therefore quite possible that they mistook the sound of air or water running through the surrounding pipes for the sound of water being injected into the reactor.

(vi) At approximately 03:35 on March 13, the recovery team tried restarting the HPCI

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58 According to a shift operator's logbook and the released plant parameters, at around 14:00 on March 12 the discharge and suction pressure of D/DFP were 0.35 MPa gage and 0.02 MPa gage, respectively. At around 01:45 on March 13 they were 0.42 MPa gage and 0.0 MPa gage, respectively. While the RPV pressures from the readings of the pressure gage at Unit 3 were 3.630MPa gage at around13:58 on March12, 3.560 MPa gage at around 14:25 on the same day, and 0.850 MPa gage at around 02:00 on March 13 and 0.580 MPa gage at around 02:44 on the same day. This evidence suggests that there was no period of time when RPV pressure was lower than the D/DFP discharge pressure. Accordingly it can be concluded that even if D/D FP had been ready for immediate use at this point of time and the water injection to the reactor had been switched from S/C spray line to FP line, the water injection operation could not have been successful.''

59 In the operator's logbook, there was a remark at around 02:55 on March 13 saying that SRVs failed to open and RPV pressure of 1.3 MPa (which is far above the discharge pressure of D/D FP).

from the Units 3 & 4 main control room, but failed. One possible reason was that the amount of capacity of the battery was not large enough to activate the HPCI, which required a large amount of power to restart.[60] What is more, the battery needed for this particular purpose could not be moved by people. If they had found a new battery that was suitable, it would have been practically impossible to carry it down to the R/B of Unit 3 and replace the old one.

At approximately 03:37 and 05:08 that day, the shift team went to the RCIC room via the HPCI room in the R/B of Unit 3 and inspected the mechanical parts of the RCIC in an effort to restart the RCIC but the reactor core isolation cooling system was not working.

The shift team also confirmed that the HPCI was stopped.

The HPCI room was not filled with steam or flooded and they did not find any evidence that the HPCI piping had been broken.

The shift team could not inject water through the FP system as they had failed to depressurize the reactor. They could not restart the RCIC or the HPCI. However, they reported those events and consulted with the operation team of the NPS ERC. Members of the operation team who received the reports from or had consulted with the shift team and those members of the local command center who heard the reports and/or consultation were so concerned with the seriousness of the situation on the site that none of them conveyed the content of the reports or consultation to the operation section chief. As a result, the NPS and TEPCO ERCs did not know about the manual shutdown of the HPCI or the response that the shift team carried out after the stoppage of the HPCI.

At approximately 03:55 that day, it occurred to those who were aware of the manual shutdown of the HPCI and the response of the shift team to report to the operation section chief. They informed their leader that the shift team had shut down the HPCI of Unit 3, had tried to inject water with the D/DFP but had failed, and the reactor pressure rose to approximately 4 MPa gage. From this report, Site Superintendent Yoshida and

[60] The required battery capacity for shutting down the HPCI is far smaller than that for restarting. Therefore it is not strange that the operator was unable to resume HPCI operation some time after successful shutdown.

other members of the NPS ERC finally learned of the shutdown of the HPCI of Unit 3. Until then, Site Superintendent Yoshida and other members of the NPS ERC had not received any report that the shift team of Unit 3 had planned to manually stop the HPCI or they had actually stopped the high pressure coolant injection system. They just assumed that the HPCI of Unit 3 was running.

At that time, the TEPCO ERC also learned this via the teleconference system and instructed the NPS ERC to verify whether the HPCI was stopped automatically or manually. The operation section chief asked his team members how the HPCI was stopped. In the noisy atmosphere of the Emergency Response Office, the operation section chief misheard the verbal report from his team. Although a team member replied, "*shudo teishi*" ("manually stopped"), the leader mistakenly heard, "*jido teishi*" ("automatically stopped") and announced "*jido teishi*" into a microphone at the main table. Since it was noisy inside the room, the person who had verbally replied did not notice his boss' mistake and thus did not correct him. Consequently, the NPS and TEPCO ERCs mistakenly believed that the HPCI of Unit 3 automatically stopped at approximately 02:42 on March 13.

b. Site Superintendent Yoshida's judgment on the water injection to Unit 3 reactor

(i) At approximately 03:55 on March 13, Site Superintendent Yoshida received the report from the operation section chief and realized that the HPCI of Unit 3 had stopped at approximately 02:42 that day. However, the NPS and TEPCO ERCs did not know that the shift team had manually stopped the RCIC system and believed it automatically stopped ,instead. At the same time, Site Superintendent Yoshida received another report that the shift team had tried opening the SRV to depressurize the reactor at Unit 3 for the D/DFP water injection, only to be in vain. He did not think it was a reliable option because the discharge pressure of the D/DFP was low; the quantity of water in the filtered water tank, which would be the source of the injection, might not be sufficient; and the outdoor piping connected to the FP line was probably damaged by the impact of the earthquake.

To enable water injection by the SLC, the restarting of the RCIC and the opening of the SRV, the recovery team of the NPS ERC had been reviewing the possibility of restarting the power source recovery work of Unit 3 and making relevant preparations since the evening of March 12. At approximately 03:55 on March 13, when the NPS ERC received the report on the shutdown of the HPCI from the shift team, the team had no idea when the power source would be recovered.

When he received the report on the shutdown of the HPCI of Unit 3, Site Superintendent Yoshida decided that they should secure water source as quickly as possible , giving more priority to Unit 3 and depressurize by the SRV for injecting water into the reactor using fire engines. He directed his teams to construct a water injection line to send water from the backwash valve pit in front of the T/B of Unit 3 to the No. 3 reactor and obtain the batteries necessary to open the SRV. The NPS ERC and TEPCO Executive Vice President Mutoh, who was stationed in the Off-site Center, did not question Site Superintendent Yoshida's decision.

(ii) At approximately 05:00 on March 13, the reactor pressure was 7.380 MPa gage. It remained in the 7-8 MPa gage range (as its current level of 7 MPa gage) until the start of depressurization.

At approximately 05:08 that day, the shift team started the S/C spraying by manually closing the RHR discharge valve to the core and opening the S/C spray valve in the torus room to suppress an increase in the containment pressure. At that time, the manual handle of the S/C spray valve was abnormally hot.

By approximately 05:08 that day, the shift team tried restarting the RCIC manually but failed. The shift team reported it to the NPS ERC at approximately 05:10 that day. Upon receiving the report, Site Superintendent Yoshida judged that a specific event (loss of reactor cooling function) as defined in Paragraph 1, Article 15 of the NEPA had occurred and reported it at approximately 05:58 that day to the relevant authorities.

(iii) Site Superintendent Yoshida judged that the reactor water level of Unit 3 had reached the TAF at approximately 04:15 on March 13 and he reported his judgment to the relevant authorities at approximately 06:19 that day.

c. Preparations for seawater injection after the shutdown of the HPCI

(i) Since dawn on March 13, the recovery team of the NPS ERC had connected a truck-mounted generator to the P/C of Unit 4 (hereinafter called "4D system"), and then the 4D system and the primary side of the D system to the Unit 3 MCC in order to supply power to the SLC system pump of Unit 3, which was capable of high pressure water injection (see Fig. IV-8).

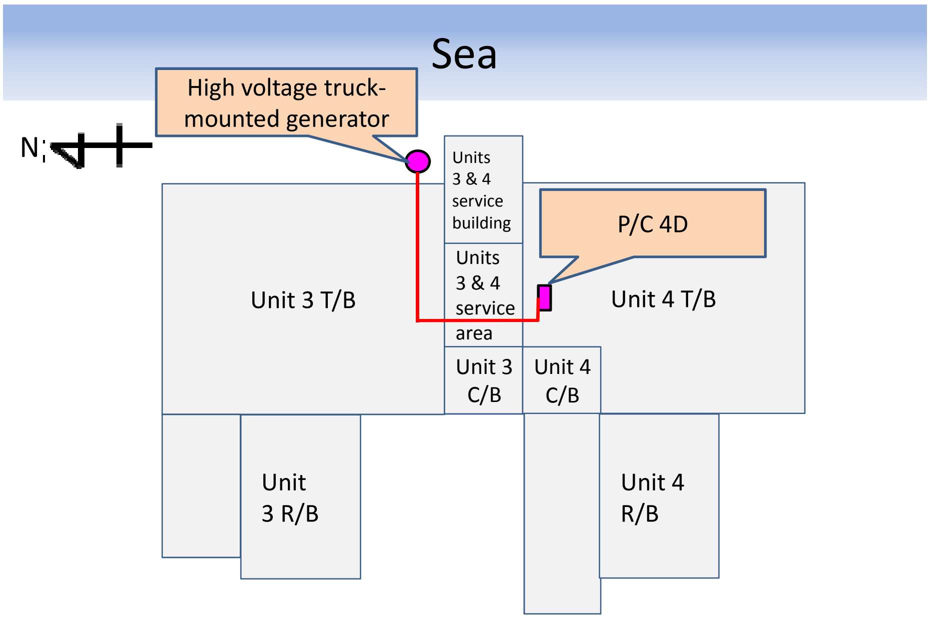

Fig. IV-8 Cabling route of Units 3 and 4 (schematic diagram) (compiled from TEPCO data)

However, cabling and connecting tasks require a great deal of time and labor and, moreover, an iron door to the passageway was warped and could not be opened. The recovery team had to ask a partner company to cut the door with a gas torch to secure the route for laying cable. They had to work under unfavorable conditions with broken pieces, rubble and debris strewn everywhere and some manholes without covers. Moreover, their work was often interrupted by frequent aftershocks and they had to evacuate from Units 3 and 4. Therefore the restoration of the power sources did not progress smoothly.

(ii) The traffic access between the area of Units 5 and 6 and the rest of the Fukushima

Dai-ichi NPS was restored by dawn on March 12 when the repair of the access road was complete. From approximately 06:00 until approximately 06:30 on March 13, the in-house firefighting team and Nanmei workers moved a fire engine that had been left near the reactors right after the earthquake to the seaside yard near Units 3 and 4 for the alternative means of water injection.[61]

Just as they had done for Unit 1, the in-house firefighting team and Nanmei workers made preparations, including laying the fire hoses and pumping the seawater up using fire engines from the backwash valve pit in front of the T/B of Unit 3 in order to inject water to the core at Unit 3 through the FP line from the embedded water discharge port of the No. 3 turbine building. A water injection line had been completed by approximately 07:00 that day (see Attachment IV-20).

(iii) Although the shift team failed to open the SRV twice after approximately 02:42 on March 13 when the HPCI stopped, they still had to open the SRVs and depressurize the reactor before implementing water injection through the FP system using fire engine. Thus, they needed to secure a power source for opening the SRVs. It required DC batteries totaling 120V to open the SRV. There were not enough batteries at the Fukushima Dai-ichi NPS.

By that time, almost 50 batteries, each of which weighing about 12.5kg, were sent from TEPCO branches and offices to the Fukushima Dai-ichi NPS and another 200 batteries had been delivered to the J village. However, they were all 2-volt batteries. To get the 120V necessary to open the SRV, they had to connect 60 batteries in series, which was not practical.

Hence the recovery team of the NPS ERC began looking for batteries within the premises of the Fukushima Dai-ichi NPS from approximately 06:00 that day. As they had acquired 12-volt batteries from the vehicles of partner companies to recover the power sources of measuring instruments at the Units 1 & 2 and Units 3 & 4 main

[61] At that point of time there were four fire engines available at Fukushima Dai-ichi NPS. Three of them (one from Fukushima Dai-ichi NPS and two from Self-Defense Force) were being used for sea water injection at Unit 1, but the remaining one (from Kashiwazaki-Kariwa NPS) was on standby. So, one free fire engine could be used for alternative water injection operation at Unit 3. An additional fire engine arrived at Fukushima Dai-ichi NPS from Kashiwazaki-Kariwa NPS during the period of around 06:00 - 06:30 on March 13.

control rooms, they decided to connect ten 12V batteries in series to secure the power source for the SRV. By approximately 07:44 that day, they had collected ten 12V batteries from the private cars of partner company employees.

The recovery team carried the sets of batteries to the Units 3 & 4 main control room and connected them to the SRV control panel to remotely open the SRV by operating the switch lever on the control panel. At that time, the radiation level in the Units 3 & 4 main control room was also very high, so that the recovery team members wore full-face masks and rubber gloves and performed wiring and connecting work under flashlights. In addition, they had to use substitute tools and jigs instead of special tools for cable end treatment and battery connecting jigs. Thus the work took longer than usual.

Since the SRV was air-operated, manual remote operation required compressed air to drive the air-operated valve mechanism in addition to the battery set to energize the solenoid valves of concerned SRVs (see Attachment IV-6). At that time, the NPS ERC thought that the residual pressure of the accumulator would be used for that purpose and so they did not prepare a portable compressor.

d. Shifting to freshwater injection and its implementation

(i) After dawn on March 13, METI Minister Kaieda, Director-General Hiraoka, Chairman of NSC Madarame and TEPCO Operation-Division-Director were reviewing and discussing the plant status of the Fukushima Dai-ichi NPS and the subsequent response to the accident in the Prime Minister's reception room on the 5th floor of Prime Minister’s reception room, making occasional telephone calls to Site Superintendent Yoshida to get relevant information.

At that time, they were informed that preparations were underway for seawater injection to the Unit 3 reactor. They expressed various opinions: "Seawater injection will lead to the decommissioning of the reactor", "If there is freshwater at the NPS, they should use it first.", "Is there any freshwater in the fire cisterns, filtered water tanks or demineralized water tanks at the NPS?", "Didn’t they build many fire cisterns at the NPS after the Chuetsu-oki Earthquake?".

Although they exchanged opinions with each other, they did not know whether or not the NPS ERC had decided on seawater injection after they confirmed there was no freshwater available at the Fukushima Dai-ichi NPS. The TEPCO division director who participated in the meeting was to call and ask Site Superintendent Yoshida about that.

Early in the morning that day, the TEPCO division director phoned Site Superintendent Yoshida and asked, "Is there any freshwater left in other fire cisterns or filtered water tanks? If there is any freshwater available, you should use it. That's the opinion here in the PMO."

(ii) The division director only informed Site Superintendent Yoshida of the views the participants expressed at their meeting in the Prime Minister's reception room. Site Superintendent Yoshida, however, took his words so seriously and thought it was the intention of the PMO, including Prime Minister Kan, so that the NPS ERC should inject all freshwater in filtered water tanks before injecting seawater. Site Superintendent Yoshida considered the possibility of using freshwater from the distant fire cisterns with the fire engines that had already come from the Kashiwazaki-Kariwa NPS via the TEPCO Fukushima Dai-ni Nuclear Power Station (hereinafter called "Fukushima Dai-ni NPS") at approximately 06:30 on March 13. He also thought it would be possible to get additional freshwater once the water supply trucks he had been asking for arrived at the NPS.

Site Superintendent Yoshida explained his idea to the TEPCO ERC and TEPCO Executive Vice President Mutoh in the Off-site Center via the teleconference system. He told them that he intended to implement freshwater injection. As no one objected, Site Superintendent Yoshida called in the person in charge of water injection and ordered him to tell the in-house firefighting team and Nanmei workers to stop the preparations for seawater injection and to switch the injection line from “sea water” to “fresh water”.

(iii) At that time, the workers had already completed the water injection line to pump the seawater collected in the reversing valve pit in front of the T/B of Unit 3 and feed it through the embedded water discharge port of the building and the FP line to Unit 3 reactor.

However, the in-house firefighting team and Nanmei workers complied with Site Superintendent Yoshida's directive and began searching for the water outlets of fire cisterns hidden by scattered debris to get additional freshwater sources amid high levels of radiation.

They planned to construct two water injection lines: one for sending freshwater pumped up from fire cisterns near the R/Bs of Units 3 and 4 to the fire cistern in the seaside yard in front of the T/B of Unit 3, and the other for feeding freshwater from the fire cistern in front of the T/B of Unit 3 to the embedded discharge port of the T/B of Unit 3 (see Attachment IV-21).

(iv) At approximately 09:08 on March 13, the recovery team of the NPS ERC connected the batteries totaling 120V to the SRV and energized its solenoid valve for SRV to open for the rapid depressurization of the Unit 3 nuclear reactor.

According to the readings of the reactor pressure gage, the reactor pressure of Unit 3 was 7.300 MPa gage at approximately 08:55 that day. After the start of depressurization, it went down to 0.460 MPa gage by approximately 09:10, dropping further to 0.350 MPa gage by approximately 09:25 that day. It was lower than the discharge pressure of the fire engine, thus water injection was possible. At approximately 09:25 that day, they started injecting freshwater into the No. 3 reactor using the fire engine.

Site Superintendent Yoshida was well aware that seawater injection was unavoidable because the quantity of available freshwater was limited.

He was also advised by Executive Vice President Mutoh at the Off-site Center to consider the implementation of seawater injection. At approximately 10:30 that day, Site Superintendent Yoshida directed his staff to get ready to quickly switch to seawater injection when the freshwater ran out.

(v) At approximately 12:20 on March 13, the Fukushima Dai-ichi NPS ran out of freshwater and there was no possibility of immediate replenishment from external sources.

The in-house firefighting team and Nanmei workers had already prepared to change the water source from the fire cistern to the backwash valve pit in front of the T/B of Unit 3 so that they would be able to quickly switch from freshwater to seawater injection. They started switching soon after the fire cistern ran dry but it was approximately 13:12 when the seawater injection to Unit 3 nuclear reactor began.

e. Problems identified (in the preparation and implementation of the alternative means of water injection into Unit 3)

(a) Start time of the preparation for and implementation of the alternative means of water injection into Unit 3

(i) If the HPCI stops, essentially reactor pressure and temperature will rise and reactor water level will lower. Therefore, it is a matter of course to prepare for an alternative method of water injection while the HPCI is still operating. In addition, when there is the need for reactor depressurization by opening the safety relief valve ("SRV"), Primary Containment Vessel ("PCV") venting may also need to be utilized on the assumption that the PCV could not withstand the high pressure released from the Reactor Pressure Vessel ("RPV").

In the case of Unit 3, the shift team not only operated the HPCI for many hours conserving battery power but also unlike with usual operation kept its rpm lower than its operating range with the flow rate controlled in a low reactor pressure state of below 1 MPa gage. Considering this fact, the Station Emergency Response Center ("NPS ERC") must have made thorough preparations for an alternative method of water injection as the next logical assumption was that they had to stop the HPCI in the early stages.

As the period from the evening of March 12 until dawn of March 13 was not long after the supposed hydrogen gas explosion at the Unit 1 R/B, the prevention of hydrogen gas explosions was a very urgent issue. Thus it was necessary to keep reactor water level high enough to prevent the mass generation of hydrogen gas as well.

It is presumed that the NPS ERC, TEPCO Emergency Response Center at the head office ("TEPCO ERC") and the shift team were, or could have been, aware of the importance of preparing the next alternative water injection while the Unit 3 HPCI was still running.

(ii) After around 20:36 on March 12, it became impossible to monitor Unit 3 reactor water level. At that time, the Unit 3 shift team was operating the HPCI below the normal rpm range with low reactor pressure of 1 MPa gage or less, and the difference between reactor pressure and HPCI discharge pressure was gradually becoming smaller. Accordingly the shift team thought it probable that the HPCI was not injecting enough water into the reactor and that continuing HPCI operation could lead to damage to the HPCI and result in steam leak. Therefore, they decided to manually stop the HPCI, perform depressurization using the SRV and utilize the D/DFP to inject water via the FP system into the reactor.

At that time, the shift team thought it possible to open the SRV with the operation switch on the control panel because the SRV status was indicated as fully closed on the control panel in the Units 3 & 4 main control room

In such a situation, it was not necessarily irrational that the shift team decided to change water injection method from the HPCI to the FP system.

On March 11, however, the shift team had already disconnected unnecessary loads from the 125V battery for operation and control of the RCIC and HPCI, and operated the RCIC and then the HPCI with that battery. Moreover, the same battery would be used to open the SRV and the shift team was aware of such fact. Therefore, the shift team could have expected that there might not have been left sufficient power with the 125V battery for opening the SRV because they had used it to operate the RCIC for about 20 hours and then the HPCI for more than 14 hours.

The shift team knew that it would require a great deal of battery power to restart the HPCI. They therefore could have recognized that once they had stopped the HPCI and used the battery to open the SRV, they would be unable to restart the HPCI even if they failed to open the valve.

Moreover, since the discharge pressure of the D/DFP indicated only 0.42 MPa gage at around 01:45 on March 13, it was not certain that reactor pressure could be lowered to such a level that water injection would be possible with the D/DFP. However, the shift team and the operation team of the NPS ERC did not address this issue. The shift team had only been trained for depressurization using SRVs with reactor pressure of around 7 MPa gage. They had not experienced similar depressurization training with reactor pressure of less than 1 MPa gage. Neither the shift team nor the NPS ERC operation team members, who had been consulted by the shift team about this issue, had any idea if the SRV could be opened successfully when reactor pressure was too low to push the SRV up.[62] Thus they should have taken into consideration the possibility that depressurization would fail even if it seemed possible to open the SRV from the control panel.

It seems that some members of the shift team headed for the D/DFP before the manual shutdown of the HPCI in order to switch the water injection line to the FP system line with the D/DFP. According to the shift operator's logbook, however, they stopped the HPCI at around 02:42 that day and then the injection line switching was reported at around 03:05 that day. Therefore it is determined that they confirmed the switching of the water injection line after the manual shutdown of the HPCI. However, if they had failed to change the water injection line, then water injection with the D/DFP would have been impossible. Thus they should have confirmed the line change before the manual shutdown of the HPCI as the correct order of operation.

Furthermore, the shift team should have conducted depressurization with the SRV upon completion of water injection line change preparation not after but before the manual shutdown of the HPCI. If they had conducted operations in the sequence mentioned above, they could have avoided the situation in which they lost all means of water injection as water injection with the D/DFP was impossible and the HPCI was already stopped.

(iii) The shift supervisor reported to and consulted with the operation team of the NPS ERC before his team shut down the HPCI at around 02:42 on March 13. He also reported to the operation team on the failure of depressurization with the SRV after HPCI shutdown and discussed subsequent responses with them. However, only a

[62] The SRV, functionally, can be opened manually above the RPV pressure of 0.686MPa gage and remain in an open position down to 0.344MPa gage after the first actuation. Under this limiting pressure, however, the valve is to be fully closed because valve disk weight exceeds the lifting force. The SRV is, anyhow, less likely to be opened in the lower pressure ranges.

limited number of members of the operation team shared this information and the operation team chief did not received timely reports. It was at around 03:55 that day when the operation team chief received the report and the NPS and TEPCO ERCs finally shared the information. At that time, the reactor pressure had already exceeded 4 MPa gage, and the report was obviously too late.

As stipulated in the Accident Management Operating Procedures ("AM"), the shift supervisor of the main control room basically makes decisions necessary for plant operation. If the impact of operation on the plant behavior or other important factors is great, however, the shift supervisor shall ask his support organization for advice or direction. As the manual shutdown of the HPCI had the potential to impact the subsequent plant response, it is considered to correspond to such cases.

When the operation team received such an important report or piece of information from the shift team, they should have had to convey it to their section chief without omission so that the entire NPS ERC could have shared the information.

The shift team thought they could open the SRV by themselves and depressurize the reactor after they stopped the HPCI. In fact, however, they failed to open it. The team encountered a situation that they had not initially expected. Since it was highly possible that the shift team may be unable to handle the situation by themselves, the operation team should have immediately reported to their section chief when they received a report on such a serious problem. If they had, the NPS and TEPCO ERCs could have shared the information and implemented the next best way including the procurement of new batteries. The delayed report forced the NPS ERC to fall behind in responding to the situation. As a result, the plant status and the work environment deteriorated further and reactor depressurization and subsequent alternative method of water injection became more difficult.

When the operation team chief asked his team members in the noisy atmosphere of the Emergency Response Office whether the HPCI had been stopped automatically or manually, he misheard what his team member said. Though the member had replied "*shudo teishi*" ("manually stop"), the chief mistakenly thought he had said "*jido teishi*" ("automatically stop") and he announced at the main table that the HPCI was automatically stopped. No correction was made and the NPS and TEPCO ERCs continued to believe the incorrect information.

Although the operation team received such an important report from the shift team, they were slow in reporting it to their section chief, and thus he did not receive accurate information. One of the immediate causes was that the member who received the report from the shift team and other members who heard the report were too concerned about the on-site work and did not realize how important it was that the entire NPS ERC shared the information.

Those members were shift supervisors and others in positions of responsibility for Unit 3 operation at the Units 3 & 4 main control room. At that time, they were next shift team members on standby at the NPS ERC. The question of whether or not the shift team should have stopped the Unit 3 HPCI and implemented an alternative means of water injection and the fact that they failed in depressurization were very important issues for the standby shift team members considering the responsibilities they would subsequently assume in the Units 3 & 4 main control room. Therefore they were so concerned with those issues that they were careless in reporting to the operation team chief.

They were shift operators skillful in controlling the plant but were not experienced in conveying information in an emergency situation. If it had not been for the loss of power, the NPS and TEPCO ERCs would have been able to immediately acquire important plant information through the Safety Parameter Display System ("SPDS"). The staff of the NPS and TEPCO ERCs had therefore not been trained to manage information in a situation without the SPDS. The operation team of the NPS ERC had to take responsibility for the transmission of information in place of the SPDS although they had not been trained at all. Consequently it is assumed that when the operation team encountered such serious events like the manual shutdown of the HPCI and the failure to open the SRV, they were so concerned about the on-site response that they did not pay enough attention to sharing the information with the NPS ERC or efficiently transmit the information.

(iv) The HPCI is an emergency cooling system to temporarily feed water in emergency cases and is not designed for long-term use. Therefore, the NPS ERC must have accurately realized the operating condition of the HPCI after the evening of March 12 and implemented an appropriate alternative method of water injection before they stopped the HPCI system.

The following are the alternative methods of water injection available to the NPC ERC at that time.

(a) SLC system water injection

(b) FP system water injection using the D/DFP

(c) FP system water injection using fire engines

(v) It seems that the NPS ERC considered the possibility of power source recovery work at Unit 3 in order to restart its RCIC and open the SRV after the evening of March 12 and actually started the work in the early morning of March 13.

Many staff members of the NPS ERC regarded the depressurization with the SRV as a last resort because plant conditions could lead to the worst case scenario that reactor water level would drop with no water injection available if they could not lower reactor pressure to a level where water could be injected. Hence some thought that the SLC system water injection should come first if it was restorable since it was originally designed for high pressure water injection.

In fact, the shift team operated the Unit 3 HPCI for many hours conserving the battery. Moreover, they controlled flow rate and kept the rpm lower than the usual operating range. Accurately taking into account the actual operating condition of the HPCI, they should have reviewed and determined which option would be available in a few hours as an alternative method of water injection. Therefore it is considered not appropriate to persist with any alternative water injection plan that could not even be predictable when it would become available.

In view of this point, the power source recovery work of Unit 3 had not yet been completed when supposed hydrogen gas explosion occurred in the Unit 3 R/B at around 11:01 on March 14. It is therefore obvious that until around 02:42 on March 13 when the shift team manually stopped the HPCI more than 30 hours before the explosion, the NPS ERC had no definite idea when SLC system water injection would be implemented. In addition, the NPS ERC could have expected that it would take a considerable amount of time to recover the power source of Unit 3 taking into consideration the fact that they had spent many hours restoring the power sources of Units 1 and 2 after dawn on March 12.

Even if they could restore and use the Unit 3 SLC system, the capacity of its water source tank was only 15.5 m^3. According to 2-2-1 of the Severe Accident Operating Procedures of Unit 3, if the RPV was not damaged, water injection into the reactor requires 25 m^3 per hour even after more than 20 hours had passed since reactor scram. As for Unit 1, they used up 80m^3 of freshwater on March 12 and still continued injecting seawater. It is therefore evident that the SLC system water injection would not be able to put Unit 3 into cold shutdown and hence another alternative method of water injection was needed.

Accordingly SLC system water injection was not an appropriate option as an alternative method of water injection after HPCI injection because the NPS ERC did not have a definite idea when it would become available and the capacity of its water source was small.

(vi) As for FP system water injection using the D/DFP, the second option, the NPS and TEPCO ERCs were aware that the low discharge pressure of the D/DFP would require reactor depressurization before water injection and that the earthquake caused outdoor piping rupture (of seismic design Class C) and water leaks from the filtered water tank. Therefore they could not expect this to be an effective water injection option.

Accordingly, the FP system water injection using the D/DFP was not reliable as the next alternative method of water injection. If they had had to implement FP system water injection using the D/DFP, they should have collected batteries from automobiles within the premises of the NPS to secure power necessary to open the SRV before HPCI manual shutdown. However, the NPS ERC did not take action to secure the power source while the Unit 3 HPCI was running.

(vii) The third and last option was FP system water injection using fire engines. Site Superintendent Yoshida had already thought in the evening of March 12 that FP system water injection using fire engines would be the only possible option since he could not predict when the power source of Unit 3 would be recovered and the SLC system water injection was not reliable.

However, the recovery and operation teams of the NPS ERC did not make any preparations because the third option was not defined as an measure in the AM and they did not think it was their responsibility. As of the evening of March 12, the in-house firefighting team had not started preparing for FP system water injection using fire engines as an alternative method of water injection into Unit 3 either.

Some people connected with TEPCO hinted that they did not trust FP system water injection using fire engines at that time because it did not use the power plant's permanent water injection facilities unlike SLC system water injection or water injection using the D/DFP. However, SLC system water injection also used temporary cabling to connect a truck-mounted generator to the Power Center (“P/C”). Although it was not electricity but water, SLC system water injection was not very different from FP system water injection in that both used temporary facilities.

We also found some people connected with TEPCO who said that they did not trust water injection with fire engines because there had been no significant change in reactor water level according to parameters while continuous water injection using fire engines was conducted for Unit 1. Considering the Unit 1 plant behavior (increase in radiation levels, abnormal drop in reactor pressure, abnormal increase in D/W pressure, mass generation of hydrogen gas, etc.) from March 11 until March 12, its reactor water level indication could definitely not be trusted. If they had decided that FP system water injection using fire engines was not reliable because the reactor water level indication had not shown any change, their decision was completely irrational.

Therefore no evidence was found to justify the exclusion of FP system water injection using fire engines from the list of alternative water injection options because of its reliability.

(viii) According to the Unit 3 reactor pressure gage, reactor pressure indicated 0.820 MPa gage at around 19:42 on March 12, indicated less than 1 MPa gage until HPCI manual shutdown, And indicated 0.580 MPa gage immediately after HPCI shutdown at around 02:44 that day. The NPS and TEPCO ERCs consecutively received such information. Meanwhile, the discharge pressure of the fire pump (A2 type) that TEPCO generally used is 0.85 MPa gage, much higher than the discharge pressure (approximately 0.4 MPa gage) of the Unit 3 D/DFP. The NPS and TEPCO ERCs were generally aware of those basic values.

Judging from the changes in reactor pressure as of the evening of March 12, it could have been possible to use the FP system and fire engines to inject water into the reactor without depressurization with the SRV if conditions permitted. The NPS ERC therefore should not have excluded FP system water injection using fire engines from their options, but should have started preparations for FP system water injection with fire engines at early stages as Site Superintendent Yoshida had then had in mind. After HPCI manual shutdown, reactor pressure decreased to 0.5800 MPa gage at around 02:44 on March 13. Accordingly, if they had made preparations at early stages, they could have been ready to inject water without waiting for depressurization with the SRV.

(ix) Discussions follow concerning the situation relating to the fire engines within the premises of the Fukushima Dai-ichi NPS during the period from the evening of March 12 until dawn on March 13 since preparations for FP system water injection would not be possible without fire engines.

In addition to the three fire engines (one belonging to the Fukushima Dai-ichi NPS and the other two coming from the Self-Defense Force ("SDF")), which were used for seawater injection into the Unit 1 reactor, there was one from the Kashiwazaki-Kariwa NPS (which was already being used to inject freshwater into the Unit 1 reactor) and another Fukushima Dai-ichi NPS fire engine which was parked near Units 5 and 6 and became available when the access road was repaired by dawn on March 12. The NPS and TEPCO ERCs clearly understood the locations of those fire engines.

As such, it could have been possible to use the fire engine near Units 5 and 6 or the one from the Kashiwazaki-Kariwa NPS to prepare for injecting seawater from the backwash valve pit in front of the Unit 3 T/B to the Unit 3 nuclear reactor.[63]

(x) In addition, discussions follow concerning whether or not it was possible to have batteries prepared for depressurization with the SRV while the Unit 3 HPCI was still running.

In fact, the recovery team of the NPS ERC began searching for batteries necessary for the depressurization at around 06:00 on March 13. By around 07:44 that day, the recovery team had collected ten 12V batteries from private cars parked in front of the Seismic Isolation Building. Therefore it is believed that it would also have been possible to secure those batteries in the evening of March 12.Meanwhile, the NPS ERC had already employed a method of using car batteries to recover power on March 11. Thus they could have thought of acquiring batteries in the same way in the evening of March 12.

The members of the NPS ERC toured the mass retailers of auto parts in the city of Iwaki and finally procured eight 12V batteries during the day of March 13. On March 11, they had already learned that 2V batteries were not suitable for recovering power because their capacity was too small. Therefore they must have been aware of the high possibility that they would need 12V batteries.[64] If so, then naturally the members of the NPS ERC, other TEPCO branches/offices and/or power stations would have visited to mass retailers of auto parts and other relevant stores to procure batteries on March 12. In fact, however, the Fukushima Dai-ichi NPS did not send their members to procure batteries nor did it ask the Off-site Center or the Fukushima Dai-ni NPS to procure batteries.

According to these, it can be decided that the NPS ERC were unable to procure

63 The helicopter started Kashiwazaki-Kariwa NPS at around 18:15 on March 12, carrying 300 APDs, 100 protective clothes (level C) , 20 protective masks and many charcoal filters and it had already arrived at Fukushima Dai-ichi NPS around 21:20 by way of Fukushima Dai-ni NPS. Taking into consideration the additional protective equipment or outfits which were in stock at Fukushima Dai-ichi NPS, there is no reason why shift teams could not start preparing for the water injection operation in the field, just because of the protective goods shortage.

64 During the period from mid-night of March 11 to the morning of March 12, TEPCO ordered 1000 (a thousand) 12-Volt batteries (with 1000 additionally ordered later) for cars from Toshiba and a thousand batteries were delivered at TEPCO's Onahama coal center around mid-night on March 14. The 320 batteries of them were transported to the Fukushima Dai-ichi NPS during the time from 20:00 to 21:00 on March 14. As of the report date, there was no evidence that TEPCO had ordered batteries from companies other than Toshiba.

batteries necessary for opening the SRV while the Unit 3 HPCI was still operating.

(xi) In short, it was very risky to expect so much of the SLC system, as long as it had a small capacity with no idea when power would recover. Therefore, preparations should and could have been completed for FP system water injection using fire engines in order to feed water into the reactor without interruption while the reactor was being substantially depressurized by the HPCI.

Such measures could have been taken without procuring new equipment or materials, considering the situation of the Fukushima Dai-ichi NPS at that time. In addition, the continuous seawater injection became possible for Unit 1 and the Unit 2 RCIC was operating during the period from the evening of March 12 until the dawn of March 13, so there should have been time to deal with Unit 3 as well as other units.

In reality, however, the NPS ERC started constructing a water injection line with fire engines after they reported HPCI manual shutdown at around 03:55 on March 13. It took time moving the fire engine parked near Units 5 and 6 at around 06:00 that day, collecting batteries necessary for opening the SRV, carrying them into the Units 3 & 4 main control room and connecting them to a terminal at the back of the control panel with cable after around 07:00 that day. Consequently it was at around 09:20 that day when water injection started after depressurization with the SRV.

A hasty conclusion should be avoided about whether or not the damage of Unit 3 could have been prevented or mitigated by depressurization and/or earlier alternative water injection because there were many uncertain factors including the possibility of an earlier alternative method of water injection and the conditions of the reactor core at the time. It could be presumed that, however, if depressurization of Unit 3 had been performed much earlier than it actually had and the alternative method of water injection using fire engines had been conducted smoothly, the progress of core damage might have been slower, radiation dose in the RPV would have been less and subsequent work might have been easier.

(b) Shifting the alternative water injection line of Unit 3

After completion of a seawater injection line from the backwash valve pit in front of the Unit 3 T/B, Site Superintendent Yoshida changed his directive to inject freshwater from fire cisterns even at a distance upon suggestion from TEPCO division manager at the PMO.

It is probably correct to say that the change to freshwater in the water injection line did not delay the start of water injection because it took time to collect the batteries necessary for PCV venting and reactor depressurization even after the change in the water injection line had been completed.

It was, however, at around 09:25 on March 13 when the freshwater injection into the Unit 3 reactor started and the available freshwater dried up at around 12:20 that day. As it was impossible to immediately obtain additional freshwater using water tank trucks, they had to change the water injection line to the seawater injection line previously constructed.[65]

Eventually, it was at around 13:12 on March 13 when seawater injection started. Consequently, for some 52 minutes after running out of freshwater, adequate water injection was not available and workers were forced to reconstruct the seawater injection line at the area of high radiation levels.

(3) Preparations for the alternative method of water injection into Unit 2 and response to secure water sources

a. Preparations for alternative water injection into Unit 2

(i) It was confirmed with Unit 2 at around 04:00 on March 12 that water level showed a decrease for the condensate storage tank, the water source for the RCIC. Accordingly, the shift team decided to change the water source for the RCIC from the condensate storage tank to the S/C in order to maintain the water level of the condensate storage tank and control increase in S/C water level.

From around 04:20 to around 05:00 that day, some shift team members wearing the

65 While switching to the initially planned sea water injection line, the fresh water injection into the core was not completely interrupted, because D/DFP was operated successively at Unit 3. However, as Site Superintendent Yoshida predicted, it may not be appropriate to think that the alternative injection (fresh water) system was functioning satisfactorily, considering the state of things where D/DFP discharge pressure was lowering, the water quantity in the filtrate water tank was reducing and some breaks possibly occurred in the pipe laid outside the buildings.

level C outfits and full-face masks went to the RCIC room on the first basement of the Unit 2 R/B. The RCIC room was flooded and the depth of water was up to about the upper edge of the rubber boots the team members were wearing and the temperature and humidity were high. The shift team members divided the work among them, and monitoring pump inlet pressure at the RCIC inlet instrument rack and using flashlights for lighting, manually operated three motor-operated valves in order to change the water source of the RCIC from the condensate storage tank to the S/C.

Consequently, circulating steam would not be cooled effectively and pool temperature and pressure of the S/C would rise once they activated the Unit 2 RCIC using the S/C as its water source. Though the shift team must have been able to foresee such a situation, they did not monitor pool temperature and pressure of the S/C until 04:30 on March 14.

(ii) Right after 12:00 on March 13, Site Superintendent Yoshida ordered preparations for seawater injection into the Unit 2 reactor be made so that they could swiftly shift to seawater injection if the Unit 2 RCIC stopped. Since all freshwater available on the premises of the Fukushima Dai-ichi NPS was to be used for Unit 3, Site Superintendent Yoshida decided that seawater injection was the only option for Unit 2.

At that time, the recovery team of the NPS ERC thought that opening the SRV would be necessary for water injection using fire engines as with Unit 3. They carried in ten 12V batteries that they had removed from automobiles in the morning of the day to the Units 1 & 2 main control room, and connected them in series to the SRV control panel. By around 13:10 that day, they had already completed preparations for manually opening the SRV via the operation switch at the SRV control panel.

The in-house firefighting team and Nanmei workers were making preparations to construct a seawater injection line so as to change the water source for Unit 3 from freshwater in the fire cisterns to seawater in the backwash valve pit in front of the Unit 3 T/B. Thus they had to put off the construction of an outdoor alternative water injection line for Unit 2.

(iii) After seawater injection to Unit 3 started, the in-house firefighting team and Nanmei workers placed fire engines and connected hoses in order to enable seawater injection into Unit 2 from the backwash valve pit in front of the Unit 3 T/B . By the late afternoon of March 13, they completed a seawater injection line to Unit 2 (see Attachment IV-22).

Since there was no seawater source except for the backwash valve pit in front of the Unit 3 T/B and the amount of seawater in the pit was limited, the NPS ERC decided to perform water injection to Units 1 and 3 before Unit 2 because Unit 3 had no alternative water injection other than seawater and Unit 2 RCIC was considered operating. Therefore, they kept the pumps of fire engines on standby, while they completed preparation for the FP system water injection line with fire engines and depressurization with the SRV.

The TEPCO ERC was also aware of the situation regarding water injection via the teleconference system, and did not object to the decision of the NPS ERC since the TEPCO ERC knew that the amount of seawater in the backwash valve pit in front of the Unit 3 T/B was limited and it was unavoidable to conduct water injection only into Unit 3 and put that for Unit 2 on standby.

b. Considerations in securing water sources

(i) In the afternoon of March 13, the NPS ERC performed water injection to Units 1 and 3 using the seawater that had collected in the backwash valve pit in front of the Unit 3 T/B, while the seawater in the pit was gradually decreasing.

Consequently, the NPS ERC thought that the water source would soon dry up if they injected seawater from the backwash valve pit into the Unit 2 reactor as well as Units 1 and 3. The NPS ERC thus gave the highest priority to securing water, regardless of whether it was seawater or freshwater, and requested the TEPCO ERC to arrange for water procurement from outside sources.

(ii) The in-house firefighting team and Nanmei workers searched for points from where they could pump seawater or freshwater within the vicinity of the T/Bs and R/Bs.

For instance, they tried to pump seawater through the water intakes located between the seaside yard near the Unit 4 T/B and the south shallow draft quay but they could not access them because there was a cave-in on the approach slope down to the intakes. They also procured a diesel engine and a submerged pump and connected them to pump seawater up through a maintenance hatch in the water discharge channel but without success.

Moreover, they considered pumping seawater up directly from the sea using a fire engine. The vertical distance between the fire engine and the sea surface was approximately 20 meters and the suction pressure of the fire pump was too weak to pump up seawater.

Around that time, seawater was found to have collected on the first basement of the Unit 4 T/B. At that time, they thought it possible that two shift team members, who were missing after the tsunami hit the Fukushima Dai-ichi NPS, might be in the basement of the No. 4 T/B. Site Superintendent Yoshida wanted to confirm their safety as soon as possible and ordered a fire engine be moved into the Unit 4 T/B through its truck bay door and pump seawater that had collected in the basement. The in-house firefighting team and Nanmei workers used a backhoe to open the entrance shutter of the truck bay door, moved a fire engine into the building and tried to pump the seawater up. However, the seawater level was too low for pumping up by the fire pump.

They also opened a fire hydrant to feed water into the backwash valve pit in front of the Unit 3 T/B but no water came out from the fire hydrant.

They continued searching for water to feed into the backwash valve pit but failed.[66]

(iii) From 01:10 on March 14, the seawater level in the backwash valve pit in front of the T/B of Unit 3 appeared decreasing and the fire engine used for the water injection into Unit 3 could no longer pump seawater up from the pit.

The site workers searched for water sources to feed water into the backwash valve pit but had no success.

When they checked the backwash valve pit again, however, they found that the overall level of water in the pit did not decline and that debris and rubble in the pit had resulted in providing some places in the pit with sufficient depth for water pumping up.

Therefore, the workers moved the fire engine used for water injection into Unit 3

[66] A 1.9-ton water tank truck (full to the brim) arrived at Fukushima Dai-ichi NPS, dispatched from TEPCO branch office in Chiba Prefecture at around 15:00 on March 13.
The truck was, however, on standby without being incorporated into the immediate injection operation, because 1.9 tons of water was thought to not be enough for effective water injection.

closer to the backwash valve pit and laid and anchored a fire hose to pump up water from such pools in the pit. From around 03:20 that day, they successfully resumed water injection into Unit 3.

Because the amount of remaining water in the pit was limited, water injection to Units 1 and 2 were kept suspended.

c. Construction of a new seawater injection line

(i) After 05:00 on March 14, four fire engines (with a total of 11 emergency personnel) arrived successively at the Fukushima Dai-ichi NPS from TEPCO's Minami-Yokohama and Chiba Thermal Power Stations ("TPS") and other places.

The NPS ERC thought it would be possible to pump seawater at the north shallow draft quay to refill the backwash valve pit in front of the Unit 3 T/B. The NPS ERC thus ordered its staff to construct a water refill line using fire engines for that purpose.

It was decided to station the fire engine from the Chiba TPS at the north shallow draft quay to pump seawater. The vertical distance between the fire engine and the sea, however, was approximately ten meters so it was impossible for just one fire engine to draw up and feed seawater into the backwash valve pit in front of the Unit 3 T/B.

They positioned another fire engine, which had come from the Minami-Yokohama TPS and was capable of high-pressure water spraying, near the north P/P gate, lined it up and connected it to the fire engine from the Chiba TPS to construct a water refill line from the north shallow draft quay to the backwash valve pit.

(ii) At that time, while reconfiguration of a PCV vent line for Unit 3 was being tried it was found difficult to keep open the large and small S/C vent valves (air-operated). According to the readings on the D/W pressure gage, D/W pressure appeared to be increasing as it indicated 0.3650 MPa abs at around 05:00, 0.3900 MPa abs at around 05:30, 0.4100 MPa abs at around 05:40, 0.4250 MPa abs at around 06:00 and 0.4700 MPa abs at around 06:20 on March 14.

In addition, Unit 3 reactor water level indicated 1,800 mm below the Top of Active Fuel ("TAF") at around 05:40 and 2,350mm below the TAF at around 06:00, and it went out of scale at around 06:20 that day.

Site Superintendent Yoshida paid attention to the increasing D/W pressure indication particularly to the increase by 0.045 MPa abs in only 20 minutes from around 06:00 to 06:20 that day and to the reactor water level indication having gone out of scale after sudden decrease at around 06:20. Site Superintendent Yoshida became worried that Unit 3 might be in a dangerous state and by around 07:00 that day D/W pressure could go beyond 0.5 MPa abs or the D/W design pressure.[67]

Around that time, Site Superintendent Yoshida was more afraid of a hydrogen gas explosion rather than destruction of the Unit 3 PCV because his teams had confirmed signs similar to those discovered at Unit 1, such as an increase in radiation levels near the north double door and the south side of the Unit 3 R/B, white haze inside the double door, possible uncovered core, and D/W pressure indicating above 0.500 but below 0.6 MPa abs. He thought that if a large amount of hydrogen gas were generated from the possible uncovered core, it would continue to leak from the RPV to the PCV and then from the PCV to the Unit 3 R/B. When the gas reached a certain level of concentration and was exposed to a spark or static electricity, a hydrogen gas explosion would occur. Site Superintendent Yoshida voiced his fears via the teleconference system to TEPCO Managing Director Komori who was at the TEPCO ERC.

A number of people were working near the Unit 3 R/B injecting water into the reactor and recovering power sources for the Unit. Thus Site Superintendent Yoshida decided that he had no alternative but to stop all work on the site in order to protect the many workers from an explosion in the Unit 3 R/B. Site Superintendent Yoshida suggested temporarily evacuating his workers via the teleconference system to the TEPCO ERC and Executive Vice President Mutoh at the Off-site Center

The TEPCO ERC and Executive Vice President Mutoh understood Site Superintendent Yoshida's sense of risk and approved the temporary evacuation of workers to the Seismic Isolation Building. From around 06:30 until 06:45 that day, Site Superintendent Yoshida issued an evacuation order to all workers.

(iii) According to the readings of the D/W pressure gage, Unit 3 D/W pressure reached

[67] In fact, the pressure gage installed at Unit 3 indicated that the D/W pressure was 0.5200MPa abs. at around 07:00 on March 14.

0.5200 MPa abs at around 07:00 on March 14 and then dropped slightly to 0.5000 MPa abs at around 07:20 that day. After that, it remained around 0.5 MPa abs.

On one hand, Site Superintendent Yoshida was still worried about a hydrogen gas explosion in the Unit 3 R/B, but on the other, he knew that it was urgent that a seawater feed line to the backwash valve pit in front of the Unit 3 T/B be constructed. He discussed the matter with the TEPCO ERC via the teleconference system. Considering that D/W pressure indicated stable although it remained in the high range, Site Superintendent Yoshida decided to resume all on-site work and withdrew the evacuation order at around 07:30 that day.

The in-house firefighting team and Nanmei workers resumed the construction of a seawater feed line to the backwash valve pit in front of the Unit 3 T/B. By around 09:00, they had completed the work and the backwash valve pit could be refilled with seawater.[68]

In addition to the seawater feed line from the north shallow draft quay through the Minami-Yokohama TPS fire engine to the backwash valve pit in front of the Unit 3 T/B, the in-house firefighting team and Nanmei workers constructed an another line to the embedded water discharge port of the Unit 2 T/B from the same fire engine.

At that time, however, the line from the fire engine to Unit 2 was put on standby and only the line to the backwash valve pit in front of the Unit 3 T/B was activated to feed water (see Attachment IV-23).

At around 10:00 on March 14, seven water supply vehicles from the Self-Defense Force of Japan brought about 35 tons of water to the Fukushima Dai-ichi NPS. The trucks were parked on the premises for a while and six SDF personnel inspected the backwash valve pit in front of the Unit 3 T/B in preparation for water feed work. Two of the seven water supply vehicles started heading toward the backwash valve pit.

(iv) At around 11:01 on March 14, four TEPCO employees and three Nanmei workers were injured in the explosion in the Unit 3 R/B. In the interest of safety, all workers

[68] At around 09:00 on March 13 1.9 tons of water was replenished to the backwash valve pit in front of the Unit 3 T/B from the water tank truck which came from a TEPCO Chiba branch office and had been on standby at Fukushima Dai-ichi NPS since the previous day.

engaged in water injection and power recovery immediately stopped working and evacuated to the Seismic Isolation Building.

At the same time, four SDF personnel were injured while they were preparing for the water refilling using the SDF water supply vehicles near the backwash valve pit. The two water supply vehicles stalled on the way to the backwash valve pit and the other five water supply vehicles did not provide water to the pit but left the Fukushima Dai-ichi NPS with the injured SDF personnel on board.

d. Response by the Nuclear and Industrial Safety Agency (NISA)

(i) At around dawn on March 14, the Nuclear and Industrial Safety Agency (NISA) asked TEPCO when FP system water injection of Unit 2 would be possible from the viewpoint that FP system water injection should be implemented while the RCIC was still running.

At that time, the NPS ERC decided that FP system water injection should first be implemented at Unit 3, followed by Unit 1 and then Unit 2 because the water injection time of Unit 3 was shorter than that of Unit 1 and the Unit 2 RCIC was still operating.

The NPS ERC also intended to implement the FP system water injection to Unit 2 while its RCIC was functioning. However, the amount of seawater in the backwash valve pit in front of the Unit 3 T/B was limited and FP system water injection to Unit 2 was impossible without securing a new water source.

The NPS ERC told NISA via the TEPCO ERC about conditions concerning FP system water injection of Unit 2:

(a) as the backwash valve pit was running out of seawater, it became necessary to secure a new water source;

(b) a powerful compressor was needed for PCV venting; and

(c) as soon as power for the reactor pressure gage and other measuring instruments of Unit 2 was restored, they would reconstruct a PCV vent line, depressurize the reactor, and then immediately start FP system water injection.

NISA had assumed that seawater was being pumped up directly from the sea until they received the above answer. They did not think that the water sources of the Fukushima

Dai-ichi NPS were limited. Hence NISA blamed the TEPCO ERC for not providing accurate information.

(ii) After around 07:00 on March 13, NISA planned to station a Nuclear Safety Inspector at the Fukushima Dai-ichi NPS to check the water injection work in compliance with METI Minister Kaieda's order.

At that time, the Nuclear Safety Inspector was on the second floor of the Seismic Isolation Building but he did not stay in the Emergency Response Office. He occasionally went into the Emergency Response Office to check what was written on the whiteboards. In most cases, he was in another room and just received the plant information provided by the NPS ERC.

Therefore the Nuclear Safety Inspector could not attain or report any information about the water sources of water injection lines to the Off-site Center and the Government ERC although he was in a position to obtain information about the plant conditions and the details of accident responses in a timely and appropriate manner and was instructed to confirm the water injection work. The officials in the Off-site Center and the Government ERC could also have instructed the Nuclear Safety Inspector and obtain information about the water injection in a timely and appropriate manner. They should have shared such information within NISA because it was very important information related to the abovementioned order of METI Minister Kaieda.

Notwithstanding, the collection of information by the Nuclear Safety Inspector and communication of information within NISA were not effective and thus the NISA failed to adequately share the important information.

(4) Preparations for PCV venting of Units 2 and 3

(i) At around 17:30 on March 12, the Unit 2 RCIC and the Unit 3 HPCI were operating.

Having learned from construction of the Unit 1 PCV vent line that such work took time, Site Superintendent Yoshida directed his teams to complete PCV vent lines of Units 2 and 3 before radiation levels in the R/Bs increased.

(ii) When the operation team of the NPS ERC prepared the Unit 1 PCV vent line, they also reviewed the possible procedures for constructing PCV vent lines of Units 2 and 3 based on various materials and documents including the Operating Procedures for AM, valve drawings, and piping and instrumentation diagrams.

Upon receiving the abovementioned direction from Site Superintendent Yoshida, the operation team confirmed the structures, locations, operating methods and operating procedures of the valves they had to open for PCV venting of Units 2 and 3 based on piping and instrumentation diagrams, the Operating Procedures for AM, valve check lists and the procedures for PCV venting of Unit 1.

As a result, they found that for both Units 2 and 3 they could manually open the PCV vent valves (motor-operated) but could not manually operate the S/C vent valves (air-operated) by hand.

The operation team of the NPS ERC prepared the procedures for PCV venting of Units 2 and 3 based on the results and findings of their review and investigation and informed the shift teams of the Units 1 & 2 and Units 3 & 4 main control rooms of the procedures (see Attachments IV-24 and IV-25 for details on the PCV vent lines of Units 2 and 3 respectively).

On the other hand, the shift teams of the Units 1 & 2 and Units 3 & 4 main control rooms were reviewing the PCV venting procedures for their respective reactors.

(iii) In the late afternoon of March 12, radiation levels inside the Unit 2 R/B indicated relatively low. Upon receiving Site Superintendent Yoshida's directive, the shift team decided to manually open the PCV vent valve (motor-operated) before radiation levels started increasing and actually went into the Unit 2 R/B and manually opened the valve by 25 percent.

At around 19:10 that day, however, the operation team of the NPS ERC instructed the shift team to close the PCV vent valve (motor-operated) that they had just opened. The operation team was worried that if they opened all valves except for the rupture disk to construct a PCV vent line, the piping would be filled with hydrogen gas and cause a hydrogen gas explosion in the event of rupture disk burst.

(iv) To open the large S/C vent valves (air-operate) on the PCV vent lines of Units 2 and 3, they had to energize the solenoid on the air supply valves on the IA system line to supply compressed air .

They had two options for feeding compressed air to the large S/C vent valves: compressed air cylinders[69] or compressors.

However, the permanently installed compressors were not available because of loss of power. As of late afternoon on March 12, there was only one portable compressor, which was being used for Unit 1.

The recovery team of the NPS ERC located compressed air cylinders on drawings. They decided to open compressed air cylinders installed for the IA system line inside the R/Bs of Units 2 and 3 and feed compressed air to the large S/C vent valves (air-operated) via the IA system line.

(5) Implementation of PCV venting of Unit 3

(i) The NPS ERC decided on the procedures for PCV venting of Unit 3: they would first open the large S/C vent valve (air-operated) and then manually open the PCV vent valve (motor-operated).

In the evening of March 12, in order to open the large S/C vent valve (air-operated) of the PCV vent line from the Unit 3 S/C to the stack, the recovery team of the NPS ERC used a small generator for temporary lighting as a power source in the Units 3 & 4 main control room and completed the cabling work necessary to energize the solenoid on the air supply valve on the IA system line. The shift team received from the recovery team information about the location of terminals for cabling in order to energize the solenoid valve. At around 04:50 on March 13, they completed the connection work and energized the solenoid valve.

Then the shift team went to the torus room on the first basement of the Unit 3 R/B and found that the large S/C vent valve (air-operated) indicated as fully closed. They also confirmed that the fill pressure for the compressed air cylinder for driving the large S/C vent valve (air-operated) indicated zero.

The shift team had been in the torus room several times. There was no lighting, there was the sound of steam blowing from the SRV, the temperature of the torus room was so

[69] In case of Unit 1, radiation levels were already so high inside R/B at the time of constructing a containment vent line that there was no choice but to give up on the idea of using air cylinders installed inside the R/B.

high due to high temperature in the S/C that part of a rubber boot of a shift team member melted when he put his foot on the upper part of the torus.

At around 05:23 that day, the recovery team of the NPS ERC entered the Unit 3 R/B. On the first floor of the R/B, they took one of the three compressed air cylinders for calibration of D/W oxygen concentration meters and replaced with it the failed compressed air cylinder for the large S/C vent valve (air-operated). Then they checked for leakage and air pressure and confirmed that the IA system line had no problems before finally supplying compressed air into the IA system line.

After that, the recovery team of the NPS ERC tried to go further into the torus room on the first basement of the Unit 3 R/B to see if the large S/C vent valve (air-operated) was open or closed but could not go near the room because of high radiation levels. At around 08:00, they returned to the Units 3 & 4 main control room.

(ii) At around 05:50 on March 13, TEPCO issued a press release about the implementation of PCV venting of Unit 3.

According to the Unit 3 reactor water level gage, reactor water level read 2,000 mm below the TAF at around 05:00, 2,300 mm below the TAF at around 05:10, 2,400 mm below the TAF at around 05:25 and 2,600 mm below the TAF at around 06:00. Based on these readings, Site Superintendent Yoshida judged Unit 3 reactor water level reached the TAF at around 04:15 and reported it to the relevant authorities.

Unit 3 water level continued to drop and indicated 3,000 mm below the TAF at around 07:35 that day according to the reactor water level gage.

According to the D/W pressure readings, Unit 3 D/W pressure indicated 0.3450 MPa abs at around 05:10 that day, and thereafter showed a rising trend to reach 0.3900 MPa abs at around 06:00, 0.4500 MPa abs at around 07:05 and 0.4600 MPa abs at around 07:30 that day.

At around 07:35 that day, Site Superintendent Yoshida reported to the relevant authorities the results of radiation exposure evaluation for the case of Unit 3 PCV venting.

At around 07:39, the shift team, according to the direction from the NPS ERC and operated the relevant valves and started D/W spray in order to sufficiently decrease Unit 3 D/W pressure before depressurization. At around 07:56 that day, Site Superintendent

Yoshida reported the team's operation to that effect to the relevant authorities.

Right after 08:00 that day, however, the TEPCO ERC ordered the NPS ERC via the teleconference system to stop D/W spray because the TEPCO ERC, the PMO and NISA were estimating when PCV venting would be performed based on the pressure trend in the PCV. The NPS ERC told the shift team the direction and accordingly the team stopped D/W spray of Unit 3. From around 08:40 until around 09:10, the shift team manually opened the RHR discharge valve and manually closed the D/W spray valve in order to reconfigure the reactor water injection line.

(iii) At around 08:35 on March 13, the shift team went to the second floor of the Unit 3 R/B and manually opened the PCV vent valve (motor-operated) by 15 percent.[70] At around 08:41 that day, they completed construction of the Unit 3 PCV vent line except for the rupture disk.[71] At around 08:46 that day, Site Superintendent Yoshida reported to that effect to the relevant authorities.

At around 08:56 that day, a high level of radiation (882 μSv/h) exceeding 500 μSv/h was detected at the monitoring post and Site Superintendent Yoshida judged that a specific event (abnormal increase in radiation levels at the site boundary) as defined in Paragraph 1, Article 15 of the NEPA had occurred and reported his judgment to the relevant authorities at around 09:01 that day.

At around 09:08, the recovery team of the NPS ERC conducted rapid depressurization of Unit 3 reactor using the SRV.

At around 09:20, Site Superintendent Yoshida reported to the relevant authorities that they would start FP system line water injection to the Unit 3 reactor.

At around 09:25 that day, the NPS ERC started injecting freshwater into the Unit 3 reactor through the FP system line with fire engines.

According to the D/W pressure readings, Unit 3 D/W pressure indicated 0.6370 MPa abs at around 09:10 and 0.5400 MPa abs at around 09:24 that day. Consequently the NPS

[70] The shift team operators in the Units 3 and 4 main control room had some concerns about the CV buckling problem under negative pressure, while considering the operational sequences of CV venting for Unit 3. So the valve opening of 25% determined in discussions was finally changed to 15%.

[71] In fact, the shift team operators tried opening the large S/C vent valve using a pressurized air source, but the open status of the valve could not be finally confirmed because of inaccessibility to the torus due to high radiation level around.

ERC judged that Unit 3 PCV venting had been performed at around 09:20 and Site Superintendent Yoshida reported it to the relevant authorities at around 09:36 that day.

According to the D/W pressure readings, Unit 3 D/W pressure indicated 0.5400 MPa abs at around 09:24 and thereafter appeared to decrease to 0.4000 MPa abs at around 09:49 and 0.2700 MPa abs at around 10:55 that day. Namely the Unit 3 D/W pressure indication exceeded the rupture disk bursting pressure (0.427 MPa gage = approximately 0.528 MPa abs) once and then significantly declined. It is therefore highly probable that gases containing radioactive substances were released from the stack through the PCV vent line (S/C side).

(iv) At around 09:28 on March 13, Unit 3 D/W pressure briefly showed a rising trend. The possible cause of the pressure increase was that the air pressure was not sufficient of the compressed air cylinder installed for the large S/C vent valve (air-operated).

Therefore, the recovery team of the NPS ERC went to the first floor of the Unit 3 R/B to check the compressed air cylinder for the large S/C vent valve (air-operated), and they found that there was air leak resulted from incomplete connection of the cylinder to the valve. Consequently they temporarily repaired the leak by taping up the joint. At that time, the recovery team checked and found that sufficient air remained in the cylinder. Therefore they did not replace it with a new one. Instead, they took another cylinder for the D/W oxygen concentration meter calibration located on the first floor of the Unit 3 R/B and placed it near the compressed air cylinder for the large S/C vent valve (air-operated) to make future replacement work easier. Since white haze filled the first floor of the Unit 3 R/B and their APDs showed high readings at that time, they evacuated from the building.

In case the newly prepared compressed air cylinder for future replacement would not fit to the large S/C vent valve (air-operated), the recovery team of the NPS ERC, with the help of partner companies, looked for proper compressed air cylinder connectors in the warehouses of those companies and managed to obtain some.

As the Unit 3 D/W pressure indication started rising again at around 11:17 that day, the NPS ERC judged that air from the cylinder was insufficient to keep open the large S/C vent valve (air-operated).

Accordingly the recovery team of the NPS ERC and the shift team went into the Unit 3

R/B and replaced the compressed air cylinder for the large S/C vent valve (air-operated) with the one that the recovery team had previously prepared. The temperature and humidity on the third floor of the R/B had been considerably high last time the recovery team exchanged compressed air cylinders, so this time the team members used self-contained air breathing sets ("self-air-sets") and took two-shift with 15-minute work per shift because of high radiation levels.

At around 12:30 that day, it was confirmed that the large S/C vent valve (air-operated) of Unit 3 was at the open position.

According to the readings of Unit 3 D/W pressure, D/W pressure indicated a rise to 0.4800 MPa abs at around 12:40, and then started decreasing, reaching 0.3000 MPa abs at around 13:00 and then 0.2300 MPa abs at around 14:30 that day.

As there was still a risk that the large S/C vent valve (air-operated) could not be kept open even with a new compressed air cylinder, the recovery team planned to use jigs to permanently lock the valve open and they headed for the torus room on the first basement of the Unit 3 R/B.

However, this was not successful and they returned to the Seismic Isolation Building because in the torus room temperature was quite high and the vibration from SRV operation was so strong.

(v) At around 14:15 on March 13, as the monitoring post indicated radiation level of 905 μSv/h, Site Superintendent Yoshida judged that a specific event (abnormal increase in radiation levels at the site boundary) as defined in Paragraph 1, Article 15 of the NEPA had occurred and reported his decision to the relevant authorities.

At around 14:31 that day, a high radiation level of more than 300 mSv/h was detected north of the double door of the Unit 3 R/B, white haze was observed inside the double door and a level of 100 mSv/h was detected south of the double door. These events were reported to the NPS ERC.

Upon receiving the report, Site Superintendent Yoshida was afraid that the Unit 3 core had been considerably damaged, resulting in large amount of steam generation and hydrogen gas leak from the PCV into the R/B and a hydrogen gas explosion, like at Unit 1, could occur in the R/B. The NPS and TEPCO ERCs had already checked several options for removing hydrogen gas from the R/B. However, they could not take any practical action because of high radiation levels inside the R/B and a concern that a spark and/or static electricity could cause a hydrogen gas explosion.

At around 15:28 that day, as radiation levels indicated 12 mSv/h in the Unit 3 side of the Units 3 & 4 main control room, the shift supervisor instructed his team members to move to the Unit 4 side of the room.

In addition, according to the Unit 3 D/W pressure readings, D/W pressure showed a rising trend again, indicating 0.2300 MPa abs at around 14:30, 0.2600 MPa abs at around 15:00 and 0.3100 MPa abs at around 15:30 that day.

The compressed air cylinders were not effective enough to keep the large S/C vent valve (air-operated) open while the Unit 3 D/W pressure indication was increasing and entry into the Unit 3 R/B was very difficult due to high radiation levels. The NPS ERC therefore decided to connect a portable compressor to the IA system line and send compressed air to the valve at around 15:53 that day.

Since the portable compressor had not been prepared beforehand, the NPS ERC procured one from a partner company although its capacity was small.

At around 17:52 that day, the recovery team transported the portable compressor with a crane truck to the truck bay door of the Unit 3 T/B where radiation level was relatively low. They placed the portable compressor near the IA compressed air storage tank inside the truck bay door on the first floor of the Unit 3 T/B. They connected the portable compressor to the IA system line and activated it at around 19:00 that day (see Fig. IV-9).

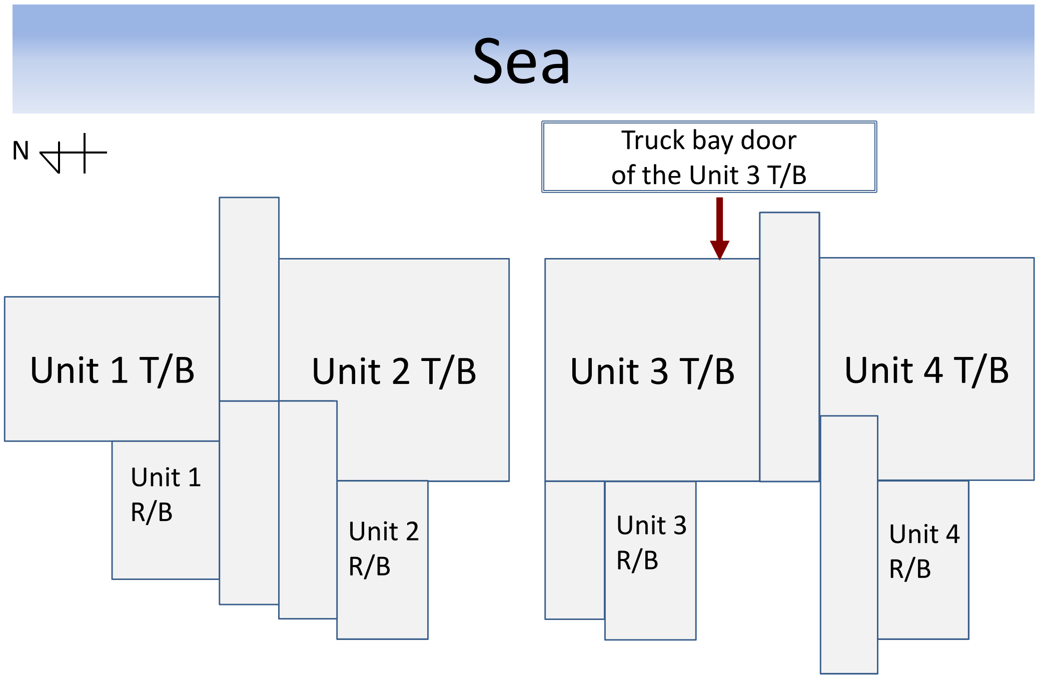

Fig. IV-9 Location of the truck bay door of Unit 3 T/B (compiled from TEPCO data)

The recovery team of the NPS ERC refueled the portable compressor every few hours to keep it running.

According to the Unit 3 D/W pressure readings, however, D/W pressure indicated still 0.425 MPa abs at around 20:30 that day and did not show clearly decreasing. Therefore, the large S/C vent valve (air-operated) might not yet have been open at that time. One possible reason was that because of the small capacity of the portable compressor it took time to pressurize the entire IA system line to feed air to the valve.

According to the Unit 3 D/W pressure readings, D/W pressure indicated finally 0.4100 MPa abs at around 20:45, and started decreasing, falling to 0.3200 MPa abs at around 21:45, 0.2850 MPa abs at around 22:30 that day and 0.2400 MPa abs at around 00:00 on March 14. Therefore at around that time, the large S/C vent valve (air-operated) of Unit 3 might have been kept open.

In the meantime, the NPS ERC was asking other NPSs via the teleconference system for more powerful portable compressors and searching for portable compressors in the offices of partner companies.

(vi) After that, the Unit 3 D/W pressure indication started increasing again, rising to 0.2450 MPa abs at around 01:00 on March 14, 0.2650 MPa abs at around 02:00 and 0.3150 MPa abs at around 03:00 that day.

The NPS ERC decided that the Unit 3 large S/C vent valve (air-operated), which was open once, was now closed and the PCV vent line was not properly functioning. Accordingly, at around 03:40 that day, the recovery team used a small generator for temporary lighting in the Units 3 & 4 main control room to energize the solenoid of the valve on the IA system line for the large S/C vent valve (air-operated).

According to the D/W pressure readings, however, Unit 3 D/W pressure indicated, still increasing, 0.3400 MPa abs at around 04:00 and 0.3650 MPa abs at around 05:00 that day. It is therefore presumed that the Unit 3 large S/C vent valve (air-operated) could not be kept open because the solenoid had not been kept energized on the valve on the IA system line.

The recovery team of the NPS ERC thought that the capacity of the portable compressor was too small to keep supplying a sufficient amount of compressed air. From around 03:00 until 05:00, they procured a new portable compressor from the Fukushima Dai-ni NPS, and replaced with it the one that had been running near the truck bay door of the Unit 3 T/B.

Just in case they could not keep open the large S/C vent valve (air-operated), the recovery team of the NPS ERC decided to open the small S/C vent valve (air-operated) as well.

At around 05:20 that day, the recovery team energized the solenoid valve on the IA system line for the small S/C vent valve (air-operated), using the small generator for temporary lighting in the Units 3 & 4 main control room. They continued opening operation until around 06:10 that day.

At that time, they had already delivered compressed air to the large S/C vent valve (air-operated) through the IA system line. Thus energizing the solenoid valve on the IA system line should open the small S/C vent valve (air-operated).

According to the Unit 3 D/W pressure readings, however, D/W pressure indicated 0.4250 MPa abs at around 06:00 and 0.5200 MPa abs at around 07:00 that day. Therefore it is presumed that they could not have kept open the small S/C vent valve (air-operated).

After all, they tried several times to open the large and small S/C vent valves (air-operated) of the Unit 3 PCV vent line even after the explosion at the Unit 3 R/B. It was quite difficult, however, to maintain the air pressure necessary for the air-operated valves and to keep energized the solenoid valves on the IA system line, resulting in the large and small S/C vent valves (air-operated) not kept open.

(6) Construction of the Unit 2 PCV vent line

(i) At around 17:30 on March 12, Site Superintendent Yoshida directed his teams to make preparations, like those for Unit 3, for PCV venting for Unit 2.

At around 08:10 on March 13, the shift team of the Units 1 & 2 main control room went into the Unit 2 R/B with the necessary equipment including self-air-sets and flashlights to manually open the PCV vent valve (motor-operated), and opened the motor-operated valve by 25 percent according to the prescribed procedure.

At around 10:15 that day, Site Superintendent Yoshida ordered completion of the Unit 2 PCV vent line except for the rupture disk.

Accordingly, the recovery team of the NPS ERC went to the first floor of the Unit 2 R/B to feed compressed air from an existing air cylinder to the large S/C vent valve (air-operated), and they opened the compressed air cylinder located near the IA system line.

Furthermore, the recovery team energized the solenoid valve on the IA system line using a small generator for temporary lighting in the Units 1 & 2 main control room, resulting in opening operation of the S/C vent valve (air-operated).

By around 11:00 that day, they completed the Unit 2 PCV vent line except for the rupture disk.

According to the Unit 2 D/W pressure readings, however, D/W pressure indicated 0.380 MPa abs at around 11:35 that day and stayed above 0.400 but below 0.5 MPa abs in the morning though increasing. Thus, according to the Unit 2 D/W pressure readings, the D/W pressure indication did not exceed the rupture disk bursting pressure (0.427 MPa gage = approximately 0.528 MPa abs) nor showed a significant decrease. Therefore it is hard to say whether the rupture disk burst and PCV venting was completed.

At that time, Site Superintendent Yoshida did not think that the rupture disk would soon burst and PCV venting would be completed. That was why he directed the NPS ERC teams to complete the PCV vent line except for the rupture disk in order to enable quick depressurization of the Unit 2 PCV when need. Thus Site Superintendent Yoshida instructed the recovery team of the NPS ERC and the shift team to keep open the large S/C vent valve (air-operated) and monitor Unit 2 D/W pressure.

At around 15:18 that day, Site Superintendent Yoshida reported to the relevant authorities the results of the radiation exposure evaluation of the areas near the Fukushima Dai-ichi NPS in case of Unit 2 PCV venting.

(ii) The NPS ERC decided that, like for Units 1 and 3, it would be effective to install and connect a portable compressor in addition to compressed air cylinders in order to keep open the Unit 2 large S/C vent valve (air-operated). The NPS ERC twice asked other NPSs via the teleconference system to send portable compressors to the Fukushima Dai-ichi NPS at around 18:20 and 22:10 on March 13.

By around 01:50 on March 14, a portable compressor from the Fukushima Dai-ni NPS arrived at the Fukushima Dai-ichi NPS. Though this portable compressor had a small capacity like the one used for Unit 3, there was no chance of acquiring other compressors.

Therefore the recovery team of the NPS ERC placed the portable compressor near the IA system compressed air storage tank inside the truck bay door on the first floor of the Unit 2 T/B where radiation levels indicated relatively low, as they had for Unit 3. They connected the compressor to the IA system line and turned it on (see Fig. IV-10).

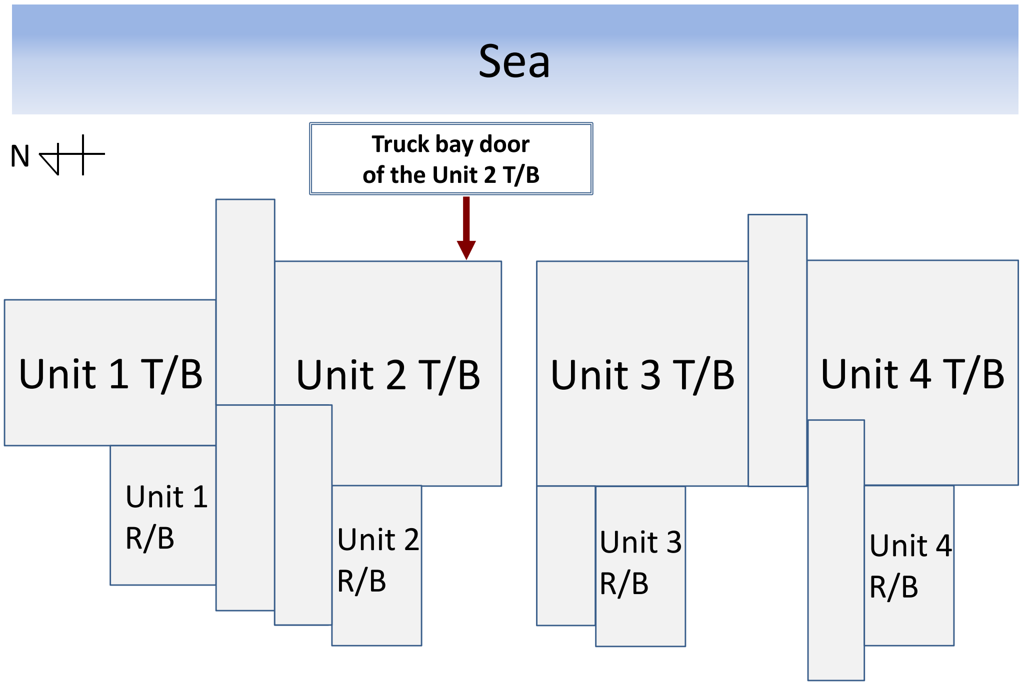

Fig. IV-10 Locations of the truck bay door of Unit 2 T/B

(compiled from TEPCO data)

The recovery team of the NPS ERC refueled the running portable compressor every few hours to keep open the Unit 2 large S/C vent valve (air-operated).

(7) Recovery of power sources

(i) After the supposed hydrogen gas explosion in the Unit 1 R/B, the recovery team of the NPS ERC investigated Units 3 and 4 for available power source facilities in the late afternoon of March 12, and confirmed that the D system (hereinafter called "4D system") of the P/C was available in the electrical room on the first floor of the Unit 4 T/B . At around 20:05 that day, the recovery team reported this to the NPS ERC.

Then the recovery team of the NPS ERC checked if there was any power source that could be fixed using the 4D system. As a result, they decided to try to restore the SLC system, the PCV vent valves and the charger panels of DC facilities by connecting a temporary cable to the D system of the MCC in the Unit 3 R/B and feeding 480V power to it.

Consequently the recovery team cleared obstacles flooded up by the tsunami from access roads in order to deploy a high-voltage truck-mounted generator. They also cut the warped fire doors on the access way of the C/B of Units 3 and 4 by gas torch and broke the entrance shutter of the truck bay door of the Unit 3 T/B to secure routes for temporary cabling. Moreover, they mobilized some 40 TEPCO members to lay newly procured cables and process their terminals. At around 14:45 on March 13, when some members opened the double door of the Unit 3 R/B for cabling, they found that radiation levels indicated high and there was white haze inside the R/B (radiation level inside the building was estimated approximately 300 mSv/h based on the readings of their APDs). Since the situation in the Unit 3 R/B appeared very similar to that in the Unit 1 R/B just before explosion, all the workers evacuated to the Seismic Isolation Building and the work and preparations for the Unit 3 R/B were suspended for more than two hours.

At around 04:08 on March 14, the Containment Atmospheric Monitoring System (CAMS) of Unit 3 and the Spent Fuel Pool ("SFP") water temperature gage were finally restored for power.

(ii) Meanwhile at around 08:30 on March 13, the recovery team attempted to restart the high-voltage truck-mounted generator that was connected to the 2C system in order to restore power for the SLC and other systems of Units 1 and 2. However, power could not be supplied because an over current relay operated due to cable damage. Therefore the recovery team replaced the damaged cable with new cable, reconnected it to the truck-mounted generator, and resumed power recovery work.

In addition at around 22:00 on March 12, the recovery team of the NPS ERC connected the low voltage truck-mounted generator parked inside the truck bay door of the Unit 2 T/B to the Unit 2 instrumentation power distribution panel in order to restore power for the Unit 1 instrumentation systems. However, water collected in a cabling route from a cable reel caused an earth leakage breaker to trip. It occurred repeatedly, forcing the team to replace the cable reel every time the breaker tripped.

The recovery team also replaced the small generator, which was damaged by the impact of the explosion in the Unit 1 R/B, with a new one and started supplying power to restore the temporary lighting of the Units 1 & 2 main control room.

(iii) Until around 11:01 on March 14 when a supposed hydrogen gas explosion in the Unit 3 R/B occurred, the team had been conducting the recovery work mentioned in (i) and (ii) above. The seawater injection using fire engines had already started for Unit 3 and the recovery team never activated the SLC system pump to implement SLC system water injection.

Due to reasons, including the impact of the explosion in the Unit 3 R/B, neither the SLC system nor the CRD system was used for Units 1 to 3.

(8) Considerations regarding measures against hydrogen gas explosion

a. Prior recognition of the possibility of a hydrogen gas explosion

After around 21:51 on March 11, the NPS ERC, the TEPCO ERC and the shift team of the Units 1 & 2 main control room clearly recognized the risk of a hydrogen gas explosion in the PCV when indications increased for radiation levels near the Unit 1 R/B and D/W pressure, as might have resulted from the hydrogen gas generated in the PCV from accelerated fuel cladding – water reaction with the uncovered core due to low reactor water level, migrated and built up in the PCV. It was believed that a hydrogen gas explosion could be prevented by injecting nitrogen into the PCV and controlled by releasing hydrogen gas through PCV venting.

Until the explosion in the Unit 1 R/B, however, no one at the NPS ERC, TEPCO ERC or the Unit 1 shift team had thought of the possibility that hydrogen gas built up within the PCV would escape to the R/B and result in an explosion there by a spark, static electricity or other cause.

b. Ex-post recognition about the hydrogen gas explosion

When the explosion in the Unit 1 R/B occurred, people in the Seismic Isolation Building where the NPS ERC was located felt a sudden violent motion from below but did not immediately comprehend what had happened.

At first, Site Superintendent Yoshida thought another earthquake had struck. However, he received a report that only pillars could be seen around the top of the Unit 1 R/B. He ordered someone be sent to the Unit 1 R/B to see what had occurred.

The person sent to the field returned and reported to Site Superintendent Yoshida that he saw sparks from the Unit 1 T/B. Site Superintendent Yoshida thought that the generator in the Unit 1 T/B contained hydrogen and that hydrogen might have exploded.

However, another report came in that no damage was found in the Unit 1 T/B. Site Superintendent Yoshida concluded that hydrogen in the generator was not the cause of the explosion.

At around 15:40 that day, members of the NPS ERC watched the explosion in the Unit 1R/B, which was broadcast on TV. In addition at around 15:57 that day, Unit 1 reactor water level indicated 1,700 mm below the TAF, which was the same reading as before the explosion. Consequently it was understood that the RPV did not blow up or get damaged. Therefore the NPS and TEPCO ERCs thought it highly probable that a hydrogen gas explosion had taken place in the upper part of the Unit 1 R/B.

Because there was a spent fuel pool (“SFP”) in the upper part of the Unit 1 R/B, the NPS ERC thought of the possibility that SFP water level had dropped due to decay heat and thus the spent fuel was uncovered to generate hydrogen gas. They tried to confirm SFP water level but were unable to because no monitoring instrumentation was available. In the first place, considering the relationship between decay heat and the amount of water in the SFP, it was too quick for the SFP water level to have dropped to a level low enough to uncover the spent fuel. Thus the NPS ERC decided it was unlikely that the SFP was the cause of the hydrogen gas explosion. However, their consideration of the SFP at that time provided a good opportunity for the NPS and TEPCO ERCs to launch a full-scale review for SFP cooling.

According to the Unit 1 reactor pressure gage (channel B), which recovered at around 20:08 on March 12, Unit 1 reactor pressure indicated 0.370 MPa gage, and thereafter remained at approximately 0.3 MPa gage, which was four times higher than the atmospheric pressure. Therefore the NPS and TEPCO ERCs firmly believed that the Unit 1 RPV did not explode or get damaged.

The NPS and TEPCO ERCs discussed possible causes of the explosion in the Unit 1 R/B, judging from the footage broadcast on TV and other materials, and determined that hydrogen gas was the only possible cause. The probable sequence causing hydrogen gas to build up in the Unit 1 R/B was that a large amount of hydrogen generated in the Unit 1 reactor leaked from the RPV to the PCV and escaped from the PCV into the R/B, filling the upper part of the R/B. By the end of March 12, the two ERCs concluded that it was highly likely that hydrogen leaked from the RPV, exploded in the R/B with a spark or static electricity.

By at around 13:37 on March 13, Unit 1 D/W and S/C pressures were restored and indicated 0.595 MPa abs for D/W and 0.590 MPa abs for S/C, respectively. Judging from these values, it was identified that PCV pressure had been maintained at an appropriate level.

c. Consideration regarding measures against a hydrogen gas explosion

Early in the morning of March 13, the NPS and TEPCO ERCs had already discussed various options for preventing a hydrogen gas explosion considering the risk of another explosion in other units.

First, the Fukushima Dai-ichi NPS had the Standby Gas Treatment Systems ("SGTS") to remove and release hydrogen gas built up in the R/Bs into the atmosphere. However, these systems did not work because of loss of power and they had no idea when power would be recovered.

They also considered the option of drilling holes in the roofs and/or walls of the R/Bs. If a spark or static electricity occurred while drilling, however, it would possibly cause a hydrogen gas explosion. Therefore they abandoned this idea.

The R/Bs at the Fukushima Dai-ichi NPS had blow-out panels which were designed to automatically move when the pressure inside the buildings increased from a buildup of steam. They checked if they could remove the panels. Having learned that the blow-out panels of the R/Bs at the Kashiwazaki-Kariwa NPS had moved easily at the Chuetsu-oki earthquake, the panels at the Fukushima Dai-ichi NPS were securely installed to avoid easy removal. Therefore, workers had to go into the R/Bs to remove the panels. Moreover, sparks and static electricity could inevitably be generated. Thus this option was determined not feasible.

The NPS and TEPCO ERCs therefore concluded that the best practical method was to use water jet technology, which did not generate sparks or static electricity, to drill holes in the building walls so as to prevent hydrogen from building up inside the R/Bs. Accordingly the NPS ERC actually started procuring water jet systems.

At around 11:01 on March 14, however, a supposed hydrogen gas explosion in the Unit 3 R/B occurred, causing extensive damage to the roof and walls of the Unit 3 R/B.

Around that time, it was confirmed that the blow-out panels of the Unit 2 R/B had moved, while it was possible that the blow-out panels of the Unit 2 R/B had already moved with the impact of the explosion in the Unit 1 R/B.

Between around 06:00 and around 06:10 on March 15, an explosion occurred in the Unit 4 R/B, damaging its roof and walls.

In short, before water jet systems could be procured, the explosions in the R/Bs of Units 1, 3 and 4 damaged the roofs and walls of the buildings and moved the blow-out panels. Therefore it was not necessary to use the water jet system to drill holes in the walls of those buildings.

Soon after the explosion in the Unit 1 R/B, the NPS and TEPCO ERCs learned there was a risk that a considerable amount of hydrogen gas could leak to the R/B from the RPV and/or PCV and cause an explosion even if the integrity of the RPV and/or PCV had not been compromised. However, they could not take any effective measures to prevent a hydrogen gas explosion, did not have the means or tools to measure the concentration of built up hydrogen inside the buildings, and had no idea when a hydrogen gas explosion could occur, yet they had to deal with various problems throughout the NPS with the fear of more explosions.

(9) Considerations regarding cooling of the SFP

(i) Early in the morning of March 13, white smoke was seen coming out of the Unit 1 R/B after the explosion.

The NPS and TEPCO ERCs were worried that Unit 1 SFP water level had probably dropped from evaporation due to the high temperature and impact of the explosion. Therefore if they left the situation as was, the spent fuel in the SFP would be uncovered and radioactive substances would be released into the air through the damaged parts of the building.

As the tsunami triggered by the Tohoku District - off the Pacific Ocean Earthquake had flooded coastal areas and reached certain elevations, all AC power sources except for the Unit 6 emergency diesel generator (6B) were lost and all seawater pumps were damaged and malfunctioned. As a result, the SFPs of all six units and the common pool lost their cooling and water supply functions. The NPS and TEPCO ERCs were afraid that if SFP water temperature increased due to the decay heat of spent fuel, SFP water level of not only Unit 1 but also other units would decrease, then the uncovered spent fuel would cause hydrogen and radioactive substances to build up in the R/Bs.

At that time, 292 spent fuel assemblies and 100 new fuel assemblies were stored in the Unit 1 SFP and decay heat was estimated to be 0.18 MW as of March 11. There were 587 spent fuel assemblies and 28 new fuel assemblies stored in the Unit 2 SFP and decay heat was estimated to be 0.62 MW as of March 11. There were 514 spent fuel assemblies and 52 new fuel assemblies stored in the Unit 3 SFP and decay heat was estimated to be 0.54 MW as of March 11. There were 1,331 spent fuel assemblies and 204 new fuel assemblies stored in the Unit 4 SFP and decay heat was estimated to be 2.26 MW as of March 11. There were 946 spent fuel assemblies and 48 new fuel assemblies stored in the Unit 5 SFP and decay heat was estimated to be 1.01 MW as of March 11. There were 876 spent fuel assemblies and 64 new fuel assemblies stored in the Unit 6 SFP and decay heat was estimated to be 0.87 MW as of March 11.

(ii) The NPS ERC thought that the Unit 4 SFP probably generated the highest decay heat of the six units and its water temperature might be considerably higher because all the fuel assemblies had been taken out from the Unit 4 reactor and moved to the SFP shortly before the earthquake. At around 11:50 on March 13, Unit 4 SFP water temperature indicated 78°C.

(iii) From March 13, the NPS and TEPCO ERCs reviewed SFPs cooling.

As the Unit 4 SFP was undergoing a periodic inspection, the reactor well and dryer-separator pit (“DS pit”) were filled with water.

Since the reactor well and SFP were separated from each other by a pool gate, they considered placing a temporary engine pump on the operating floor of the Unit 4 R/B to transfer water from the reactor well and DS pit to the SFP (see Attachment IV-26 for the structure of the Unit 4 SFP and its peripheral facilities). However, radiation levels in the Unit 4 R/B indicated already high so that they could not implement this plan.

As for Unit 1, the roof of the Unit 1 R/B fell into the SFP allowing water to flow from outside the building into the pool. Therefore they considered spraying water from a large ladder truck parked near the Unit 1 R/B. However, rubble and debris was scattered around the Unit 1 R/B by the tsunami and explosion, and radiation levels in the vicinity indicated also high. As such, they decided it was risky to prepare and make the site available for the use of a large ladder truck, and implement water spray and refill work in such a situation.

The NPS and TEPCO ERCs also considered sprinkling water and dropping ice into the Unit 1 SFP from a helicopter. In fact, the TEPCO ERC procured 3.5 tons of ice and transported it to the Fukushima Dai-ni NPS by air. However, radiation levels were expected high even in the airspace above the Unit 1 R/B and at that time Unit 3 plant conditions were unpredictable. Thus some people said dropping ice from above could be unsafe. It was also pointed out that the sporadic dropping of 3.5 tons of ice would not effectively cool the water in the Unit 1 SFP (its capacity was 990 m^3 = 990 tons). Ultimately, dropping of ice and sprinkling of water by helicopter were never implemented.

Furthermore, the NPS and TEPCO ERCs checked to see if it was possible to connect fire hoses to the MUWC system and/or the Fuel Pool Cooling and Cleanup (“FPC”) system line to inject water into the SFPs for cooling. To this end, however, they had to go into the R/B of high radiation levels in order to make preparations. Hence they abandoned this plan as well.

(iv) From March 13, the NPS and TEPCO ERCs continued examining and discussing protective/preventive measures and options concerning possible uncovered spent fuel with an increase in SFP water temperature and a decrease in water level. While they could not find an effective option, there was a supposed hydrogen gas explosion in the Unit 3 R/B at around 11:01 on March 14, and it was confirmed that the outer walls above the operating floor were damaged, resulted in releasing a great amount of steam. Following the explosion at Unit 3 between around 06:00 and 06:10 on March 15, there was another supposed hydrogen gas explosion in the Unit 4 R/B, damaging its walls and other parts above the operating floor.

5. From the explosion in the Unit 3 R/B until the pressure drop of Unit 2 S/C and the explosion in the Unit 4 R/B (from around 11:01 on March 14 until 06:10 on March 15)

(1) Alternative method of water injection into the reactors of Units 1, 2 and 3

a. Damage to the alternative water injection lines after the explosion in the Unit 3 R/B

(i), Rubble and debris of high radiation levels was scattered in and around the backwash valve pit in front of the Unit 3 T/B by the explosion in the Unit 3 R/B.

In addition, as for the water injection lines of Units 1, 2 and 3 which were already in use or were ready for use, the fire engine pumps stopped and fire hoses were damaged and rendered unusable except for the two vehicles which came from the Minami-Yokohama and Chiba TPSs and were parked away from the building.

(ii) Right after the explosion in the Unit 3 R/B, it was possible to measure the Unit 3 plant parameters. According to these measurements, reactor pressure (channel A) indicated 0.291 MPa gage, reactor pressure (channel B) 0.285 MPa gage, D/W pressure 0.4800 MPa abs and S/C pressure 0.4700 MPa abs at around 11:02 on March 14. Judging from these values, it was identified that RPV and PCV pressures were maintained at appropriate levels.

Therefore Site Superintendent Yoshida decided that the explosion in the Unit 3 R/B did not occur inside the RPV or PCV but was caused by hydrogen gas which had leaked from the RPV and PCV and built up in the R/B as was the case with the explosion in the Unit 1 R/B.

b. Plant condition of Unit 2

According to the Unit 2 reactor water level readings, reactor water level clearly indicated a decrease after around 12:00 on March 14.

The pool water temperature gage and pressure gage of the Unit 2 S/C indicated high readings of 149.3 °C and 0.486 MPa abs at around 12:30 that day. The shift team noticed the decrease in water level of the condensate storage tank, which was the water source for the Unit 2 RCIC, and switched to the S/C to prevent the water source from drying up at around 04:00 on March 12. Additionally, the RHR was not functioning due to the failure of the seawater pump. Thus water temperature and pressure of the S/C steadily increased.

According to the Unit 2 reactor water level gage, reactor water level clearly decreased after around 12:00 on March 14, and Site Superintendent Yoshida judged that the Unit 2 RCIC stopped at around 13:25 that day.

c. Restoration of the alternative water injection lines of Units 2 and 3

(i) Around noon on March 14, Site Superintendent Yoshida directed his teams to quickly secure an alternative method of water injection for Units 1, 2 and 3 because he assumed the plant conditions of the three units would inevitably deteriorate if the current situation continued because the fire engines had stopped, fire hoses had been damaged and the alternative method of water injection into the three units had not been implemented at all. At that time, he believed that water injection was urgently needed for Unit 2, where reactor water level had started indicating a downward trend, and also for Unit 3, where an explosion had occurred one hour earlier.

(ii) From around 13:00 on March 14, the in-house firefighting team and Nanmei workers checked the areas around the reactor buildings while a radiation safety staff was monitoring radiation levels around them. They confirmed that most of the fire engines used for water spray/injection had stopped operating and fire hoses had sustained extensive damage and were unusable.

In addition, as there were so much rubble and debris scattered in and around the backwash valve pit in front of the Unit 3 T/B it deemed impossible to reconstruct a water injection line with fire engines and hoses similar to what had been placed there.

Therefore they decided to construct alternative water injection lines that morning to pump seawater using the fire engine from the Chiba TPS that was parked near the north shallow draft quay and directly feed the seawater into the embedded water discharge ports of the T/Bs of Units 2 and 3 using a fire engine from the Minami-Yokohama TPS, bypassing the backwash valve pit in front of the Unit 3 T/B (see Attachment IV-27).

(iii) Though the alternative water injection line to the Unit 2 reactor had been completed at around 14:43 on March 14, it was around 16:30 when they started the fire engines because continuous aftershocks forced the workers to stop work and evacuate.[72]

As for power sources for depressurization by the SRV necessary for implementing FP system water injection at Unit 2, the recovery team of the NPS ERC had already secured its power source at around 13:10 on March 13 by connecting ten 12V batteries in series to the SRV control panel in the Units 1 & 2 main control room. After the water injection line with fire engines was completed at around 16:30 on March 14, however, it took time to open the SRV and they failed to notice that the fire pump for alternative water injection stopped due to running out of fuel. It was around 19:57 when continuous water injection became available.

As for Unit 3, the FP system water injection line with fire engines was completed at around 16:30 that day and the fire engines started to inject water into the reactor.

d. The responses of the Fukushima Dai-ichi NPS, TEPCO Head Office and the PMO to the alternative method of water injection for Unit 2

(i) According to the Unit 2 reactor water level gage, reactor water level indicated clearly decreasing after around 12:00 on March 14, which identified that the RCIC had definitely failed, and therefore FP system water injection using fire engines was urgently needed.

To enable FP system water injection using fire engines, reactor pressure had to be lower than the discharge pressure of the fire pump. Thus it was necessary to open the SRV to depressurize the reactor.

Unit 2 S/C pool temperature and pressure, however, indicated very high because the RCIC had been operating for many hours using the S/C as its water source. In addition, the RHR had already stopped and thus the depressurization and cooling of the S/C were difficult. Therefore, if they opened the SRV to depressurize the reactor, the S/C would probably not be able to cool and condense the steam that would come from the RPV. If the steam would not completely condense, it would stay in the S/C to cause further

[72] At around 15:28 on March 14 while water injection operation was on standby due to an aftershock, Site Superintendent Yoshida reported to the authorities concerned the estimated time when the water level of RPV at Unit 2 would reach TAF at around 16:30 on the same day.

increase in its pressure and temperature, resulting in possible damage of the S/C.

Site Superintendent Yoshida thought it necessary to construct PCV vent line (S/C side) for Unit 2 to secure an escape route for the S/C pressure. Accordingly he directed his people to complete the PCV vent line before depressurizing the reactor and injecting seawater into it.

The TEPCO ERC learned via the teleconference system about the process by which the NPS ERC reached the decision to prepare for Unit 2 PCV venting. None of the TEPCO ERC staff opposed the NPS ERC's plan to implement the preparations for Unit 2 PCV venting before depressurization and water injection of the Unit 2 reactor.

(ii) At that time, Special Advisor to the Prime Minister, Goshi Hosono, Chairman of NSC Madarame, TEPCO Fellow Takekuro, a division manager of TEPCO, NISA members and engineers from Toshiba were trying to form an accurate picture of the plant status of Unit 2 and were discussing subsequent responses to possible future events in the Prime Minister's reception room on the 5th floor of the PMO. At that time, they discussed depressurization of and water injection into the Unit 2 reactor, and agreed, considering the plant status of Unit 2, that depressurization and water injection should be given first priority in order to prevent the fuel from damage. Some of them called and advised the TEPCO ERC and Site Superintendent Yoshida. Chairman of NSC Madarame told Site Superintendent Yoshida that he believed they should depressurize the reactor and inject water into it earlier without waiting for completion of the PCV vent line (see Attachment IV-28).

(iii) Although his opinion differed, Site Superintendent Yoshida took the NSC chairman's comment seriously. Site Superintendent Yoshida conveyed what Mr. Madarame had told him to the TEPCO ERC via the teleconference system and discussed which to come first, preparations for PCV venting or depressurization and water injection of the reactor.

As a result of their discussion via the teleconference system, the NPS and TEPCO ERCs agreed that they should quickly construct the PCV vent line first although it was in opposition to Mr. Madarame's opinion because high pressure and temperature of the Unit 2 S/C could limit the effect of reactor depressurization and further increase in S/C pressure could lead to S/C destruction risk.

(iv) The PCV vent line (except for the rupture disk) of Unit 2 was completed once on March 13. At around 11:01 on March 14, there was a supposed hydrogen gas explosion in the Unit 3 R/B. The impact of the explosion displaced the circuit to energize the solenoid valve on the IA system line for the large S/C vent valve (air-operated), resulting in the air-operated valve in the closed position.

At around 16:00 that day, the recovery team of the NPS ERC recovered the circuit for the solenoid valve and tried to open the large S/C vent valve (air-operated) using a portable compressor procured from outside the Fukushima Dai-ichi NPS. However, they could not immediately open it as air pressure was too low (see 5(2) below for details on the preparations for Unit 2 PCV venting).

Sometime between around 16:00 and 16:30 that day, the recovery team reported to the NPS ERC that the large S/C vent valve (air-operated) was not easy to open and they would need time to complete the work. The TEPCO ERC also shared this information via the teleconference system. The NPS and TEPCO ERCs reviewed the procedures for PCV venting, depressurization and alternative water injection again.

Finally, President Shimizu decided that they could not postpone depressurization and water injection of the Unit 2 reactor until completion of the PCV vent line, considering the process of the discussion between the two ERCs and the situation at the Fukushima Dai-ichi NPS. President Shimizu directed Site Superintendent Yoshida not to wait for completion of the PCV vent line but to implement depressurization and water injection according to the opinion of Chairman of NSC Madarame.

Site Superintendent Yoshida accepted the president's directive and told his site members in charge to start depressurization and water injection of the Unit 2 reactor and concurrently continue preparations for PCV venting.

At around 16:30 that day, the in-house firefighting team and Nanmei workers started the fire engines and injected water through the seawater injection line that they had earlier completed. This enabled the water injection line to start injecting any time once the Unit 2 reactor was depressurized.

(v) At around16:34 on March 14, the recovery team of the NPS ERC connected ten 12V batteries in series to the control panel in the Units 1 & 2 main control room[73] From the control panel, they energized the solenoid valve for the SRV to start depressurization. However, they could not open the SRV right away.

The recovery team made efforts to continue to depressurize the Unit 2 reactor by changing SRV control circuit connections, trying to open other SRVs simultaneously, and disconnecting and reconnecting all 10 batteries.

According to the reactor pressure gage, Unit 2 reactor pressure indicated 6.998 MPa gage at around 16:34 that day. It indicated still 6.075 MPa gage at around 18:03, more than one hour after they had started depressurizing.

They continued trying to open the SRV to depressurize the reactor. However, they had trouble in keeping the SRV open and the steam from the RPV barely condensed in the S/C because of high temperature and pressure in the S/C. Consequently, it took time to depressurize the RPV to the sufficient extent.

The reactor pressure was finally lowered to a level where water injection was possible at around 19:03 that day, when the reactor pressure gage indicated 0.630 MPa gage.

Until that time, according to the Unit 2 reactor water level gage, reactor water level indicated 3,700 mm below the TAF at around 18:22 before it went out of scale and immeasurable at around 18:50 that day. Accordingly the NPS and TEPCO ERCs confirmed with each other via the teleconference system that all fuel rods of Unit 2 could be uncovered as of around 18:22 that day.

The PMO and the Government ERC periodically received reports on the plant status of Unit 2.

At that time, the in-house firefighting team members took turns checking the condition of the fire engines that were used for water injection into Unit 2 because of high radiation levels, and found that the fire engines of the Chiba and Minami-Yokohama TPSs had run out of fuel and stopped operating at around 19:20, soon after the start of water injection into the Unit 2 reactor.

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[73] After around 10:00 on March 13 the NPS ERC recovery team members removed ten 12-Volt batteries from TEPCO employees' private cars and brought them to the Unit1/Unit 2 main control room. They connected these batteries in series and had already finished preparing for controlling SRVs remotely from the control panel.

Accordingly the in-house firefighting team carried fuel from a tanker parked on the premises of the Fukushima Dai-ichi NPS to refuel the fire trucks.

They restarted the two fire engines at around 19:54 and 19:57 respectively, and resumed continuous water injection into the Unit 2 reactor at around 19:57. Therefore it is assumed that water injection into the Unit 2 reactor stopped completely for at least 37 minutes from the time the in-house firefighting team found that the fire engines had stopped.

After that, staff members at the NPS ERC set up a roster for checking and refueling the fire trucks every few hours.

The destination of the seawater injection line from the north shallow draft quay was changed several times afterwards. For instance, they closed the valve of the fire engine from the Minami-Yokohama TPS for water injection into the Unit 3 reactor so as to increase the discharge pressure of the seawater injection line to the Unit 2 reactor. To secure a sufficient amount of water for both units, they sent seawater from the north shallow draft quay to the backwash valve pit in front of the Unit 3 T/B and used the SDF fire engine to inject seawater from the backwash valve pit into the Unit 2 reactor through the embedded water discharge ports of the Unit 2 T/B (see Attachment IV-29).

(vi) As to Unit 2, reactor pressure rises repeatedly interrupted water injection even after starting continuous seawater injection into the Unit 2 reactor at around 19:57 on March 14.

According to the reactor pressure gage, Unit 2 reactor pressure indicated higher than 1 MPa gage from around 20:54 until 21:18 that day (it indicated 1.463 MPa gage at around 21:18) and then it decreased due to depressurization. It again exceeded 1 MPa gage from around 22:50 until 23:40 that day (it indicated 3.150 MPa gage from around 23:20 until 23:25 that day) and then decreased again as a result of further depressurization. From around 00:16 until 01:11 on March 15, it again rose to over 1 MPa gage (it indicated 2.520 MPa at around 01:02 that day). At least during those periods of high values, Unit 2 reactor pressure seemed higher than the discharge pressure of the fire pumps and therefore it was highly likely that water had not been injected into the reactor.

Though they assumed that all the fuel of the Unit 2 reactor was uncovered, they could not smoothly implement depressurization or inject a substantial amount of water into the reactor. Site Superintendent Yoshida was afraid that if they could not improve the situation, the nuclear fuel in the core would melt, and penetrate into the bottom of the RPV and PCV, leading to release of radioactive materials outside through these pierced openings; it was the worst-case scenario similar to the so-called "China syndrome." Moreover, Site Superintendent Yoshida was worried that if such a serious incident occurred at Unit 2, they would be unable to continue water injection and other work necessary at Units 1 and 3 and a similar situation would develop at the two reactors.

Site Superintendent Yoshida resolved to prevent such a serious situation at any cost, including to his own life. However, there were many TEPCO clerical employees and other members of partner companies in the Seismic Isolation Building of the Fukushima Dai-ichi NPS and Site Superintendent Yoshida knew he was responsible for protecting their lives. Site Superintendent Yoshida consulted with the TEPCO ERC and decided to have the minimum number of members necessary for controlling the reactors stay at the Fukushima Dai-ichi NPS and evacuate all other members from the NPS depending on the Unit 2 plant conditions.

To avoid causing unnecessary concern, Site Superintendent Yoshida told a few selected members of the general affairs team to arrange for buses for evacuation. so that a quick evacuation was possible if required.

From around 01:00 on March 15, Unit 2 reactor pressure indicated steadily staying above 0.600 but below 0.7 MPa gage and continuous water injection into the reactor became possible. Thus Site Superintendent Yoshida did not issue an evacuation order and neither did the TEPCO ERC advise him to do so until there was the sound of an explosion and the Unit 2 S/C pressure indication fell to zero.

As a result of this Committee's investigation, we could not identify anyone at the NPS or TEPCO ERCs who had thought of evacuating everyone from the Fukushima Dai-ichi NPS in the process responding to the accident.

e. Implementation of the alternative method of water injection into Unit 1

The resumption of the water injection into Unit 1 was required because it had stopped since around 01:10 on March 14 when it became impossible to pump seawater up from the backwash valve pit in front of the Unit 3 T/B.

The in-house firefighting team and Nanmei workers began constructing a water injection line to Unit 1 from late afternoon on March 14 by moving a fire engine from TEPCO's Sodegaura TPS to the north shallow draft quay to pump seawater and connecting a fire hose directly to the embedded water discharge port of the Unit 1 T/B. At around 20:30 that day, they resumed injecting water into the Unit 1 reactor (see Attachment IV-30).

f. Problems identified (in the preparation and implementation of the alternative method of water injection into Unit 2)

(i) Until around 13:25 on March 14, the NPS ERC believed that the Unit 2 RCIC was operating. However, they could not implement an alternative method of water injection using fire engines while they thought the RCIC was running. At around 19:57 that day, the alternative method of water injection finally became possible. Discussions follow concerning the problems in preparation for and implementation of the alternative method of water injection into the Unit 2 reactor.

(ii) The Unit 2 RCIC kept operating after the total loss of all power on March 11 but it was unable to be controlled due to the loss of power.

At around 04:00 on March 12, the shift team discovered that the water level of the condensate storage tank, which had been the water source of the Unit 2 RCIC, was dropping and switched the water source to the S/C in an effort to prevent the tank from drying up. For this reason, the shift team activated the Unit 2 RCIC with the S/C as a water source though the RHR was not operating. If the RCIC had operated for a long period of time, it would have been obvious that temperature and pressure in the S/C would rise due to increasing temperature of the steam, which would be circulating between the RPV and S/C. In other words, the Unit 2 RCIC was operating although its cooling function was degraded. As reactor pressure rose, the difference between the discharge pressure of the RCIC pump and the reactor pressure would fall thus the injection capability of the RCIC would also gradually decline.[74]

At that time, if the Unit 2 RCIC failed to function, the only alternative method of water injection was FP system water injection with fire engines, which was a low pressure system. Therefore this alternative method of water injection required the reactor to be depressurized using the SRV. It meant that steam would escape from the RPV into the S/C. Thus if water temperature or pressure in the S/C were too high, depressurization with the SRV would be difficult and the integrity of the S/C would be compromised.

Thus in the case of Unit 2, the operating RCIC did not guarantee the safety of the reactor. To avoid such a situation, it was necessary to monitor S/C pressure and temperature from the early stages after switching the water source to the S/C.[75] In addition, they should have constructed a water injection line from the FP system to the reactor using fire engines. If the status of the S/C required, they should have switched water injection line to the FP system, depressurizing the reactor, without waiting for RCIC shutdown.

(iii) Regarding this point, Site Superintendent Yoshida ordered preparations be made immediately for water injection and PCV venting of Unit 2 shortly after the explosion in

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[74] According to the plant parameters released by TEPCO, the RPV pressure at Unit 2 turned upwards after around 09:00 on March 14. The pressure rose up to 6.188 MPa gage at around 12:30 and to 7.065 MPa gage at around 13:00 on the same day. While the pump discharge pressure of RCIC was confirmed to be about 6.0 MPa gage by a shift team operator during the period of around 02:00 to 02:55 on March 12. Afterwards, any factor causing a drastic increase of the pump discharge pressure of RCIC is not to be found. (On the contrary, in TEPCO's internal documents there is a remark saying that pump discharge pressure was presumably 5.3 MPa gage about 21:30.) At around 13:25 on March 14, the Station Emergency Response Center (NPS ERC) reported to the government the occurrence of an event (as function loss of RCIC) falling under Article 15, paragraph 1 of the Nuclear Emergency Preparedness Act on grounds that the RPV water level showed a sign of consistent decline. However, depending on the parameters above the RPV pressure turned to rise after around 09:00 and the RCIC was gradually losing its function. (In fact, the RPV water level was trending downward at this time). After all it is highly possible that water injection was completely interrupted at around 12:30 to 13:00 on March 14 due to the higher RPV pressure exceeding the RCIC pump discharge pressure.

[75] The existing supply power for the S/C pressure gage is of AC 120V, but if 24 volt DC power is available, the real pressure can be obtained by conversion of the voltage measured directly by a tester into the corresponding pressure. The fifty 2-volt batteries were delivered from Hirono Thermal Power Station around the dawn of March 12, so the S/C pressure could have been monitored (at least, intermittently) with 24 volt DC power by connecting twelve 2-volt batteries in series. The S/C pool temperature can also be measured, if AC power of 120 volts is at hand, which is prepared by connecting the cable reel ends of a small generator used for temporary lighting to the S/C pool temperature gage terminals.

the Unit 1 R/B although he did not have detailed information about the operating condition of the Unit 2 RCIC. On March 13 when the Unit 2 RCIC was still running, the water injection line from the backwash valve pit in front of the Unit 3 T/B to the Unit 2 reactor had already been completed and the ten 12V batteries were connected to the SRV control panel in the Units 1 & 2 main control room in preparation for opening operation of the SRV. However, since water injection into the Unit 3 reactor was given priority due to limited amount of water in the backwash valve pit, water injection into the Unit 2 reactor could not be started.

On the other hand, Site Superintendent Yoshida and the shift team were not aware of any problems with the operating condition of the RCIC and the necessity of close monitoring. Therefore, any attention was not given at all to monitoring pressure and pool temperature of the Unit 2 S/C until around 04:30 on March 14.

It was around 04:30 that day when the pressure of the Unit 2 S/C finally started to be measured.[76] At that time, the S/C pressure gage indicated 0.467 MPa abs, increasing thereafter to 0.486 MPa abs at around 12:30 that day. Additionally, it was around 07:00 that day when the pool temperature of the Unit 2 S/C finally started to be measured.[77] At that time, the S/C water temperature gage indicated 146 °C, increasing thereafter to 149.3 °C at around 12:30 that day.

While power recovery had been a higher priority for lighting and instrumentation, the pressure and pool temperature of the Unit 2 S/C could have been monitored, though intermittently, by utilizing the small generator for temporary lighting or batteries for instrumentation that had already been used for power recovery. If the NPS ERC had closely monitored the Unit 2 S/C pressure and pool temperature and determined appropriate responses, they would not have been so optimistic about the plant conditions of Unit 2.[78] In other words, since reactor depressurization had been required because

[76] The pressure of S/C was decided by converting the output voltage measured by a tester into the corresponding pressure. Now the power source for the pressure sensor was prepared by connecting two 12-volt batteries in series.

[77] As for the S/C pool temperature, the shift team operators confirmed the readings of temperature indicators by connecting a cable reel of a small generator to the measuring instrument terminals.

[78] The suppression pool temperature exceeding 100℃ corresponds to a specific event (loss of pressure suppression function) falling under Article 15, Paragraph 1 of the Nuclear Emergency Preparedness Act. Therefore it is absolutely essential to keep a consistent watch on suppression pool temperature. In fact, at the Fukushima Dai-ni

high pressure water injection could not be expected as an alternative method after RCIC shutdown, rise in pressure and/or temperature of the S/C would have inevitably resulted in difficulty in reactor depressurization.

In fact, however, the NPS ERC and the shift team did not start monitoring of the pressure or temperature of the Unit 2 S/C until around 04:30 that day. Though they started monitoring thereafter, they did not pay attention to the increasing trends of both S/C pressure and pool temperature so that they could not earlier perform reactor depressurization and alternative water injection. Therefore it is assumed that the NPS ERC and the shift team were optimistic about the Unit 2 plant conditions without noticing any problems with the operating RCIC and were not aware of the necessity for appropriate evaluation based on close monitoring of pool temperature and pressure of the S/C.

(iv) By dawn on March 14, due to the decreasing amount of water in the backwash valve pit in front of the Unit 3 T/B water injection into the Unit 3 reactor became the priority, therefore water injection to the Unit 2 reactor was not implemented though the injection line had been completed.

By around 05:00 that day, four fire engines arrived from the Minami-Yokohama and Chiba TPSs and other locations. The in-house firefighting team and Nanmei workers completed the seawater supply line shortly after 09:00 that day by constructing a line to supply seawater directly from the north shallow draft quay to the backwash valve pit in front of the Unit 3 T/B. At that time, the water injection line from the backwash valve pit to the Unit 2 reactor had already been prepared.

In addition, another water injection line directly to the Unit 2 reactor was completed before the explosion in the Unit 3 R/B by connecting fire hoses of the fire engines from the Minami-Yokohama TPS to the embedded water discharge ports at the Unit 2 T/B bypassing the backwash valve pit.

NPS, the suppression pool temperatures at Unit 1 and Unit 2 exceeded 100℃ at around 05:22 and at around 05:32 on March 12, respectively, because the RHR system lost its function due to sea water pump damages and the power failure. The Site Superintendent at the Fukushima Dai-ni NPS reported to the concerned authorities on the occurrence of events (at Unit 1 and Unit 2) falling under the Article 15, Paragraph 1 of the Nuclear Emergency Preparedness Act at around 05:48 on March 12. The suppression pool temperature at Unit 3 also exceeded 100℃ a little later. So the Site Superintendent made an additional declaration for Unit 3 at around 06:18.

Since either of the lines could, to some extent, have solved the problem of the water sources running out of water for water injection to the reactors of Units 1, 2 and 3, it provided the NPS ERC with an opportunity to think of starting water injection into Unit 2. Actually they did not start, however, alternative water injection to Unit 2, keeping it on standby.

While the Unit 2 PCV vent line had been completed on March 13, a portable compressor was transferred from the Fukushima Dai-ni NPS to the Fukushima Dai-ichi NPS at around 01:52 on March 14, placed outside the truck bay door of the Unit 2 T/B and connected to the S/C control panel on the morning of March 14, contributing to keeping open the Unit 2 large S/C vent valve (air-operated). Thus all equipment and materials necessary for Unit 2 PCV venting were assumed in place.

Therefore, it is presumed that they could have performed Unit 2 PCV venting and reactor depressurization as needed and water injection into the Unit 2 reactor using the fire engines and the FP system line before the explosion in the Unit 3 R/B occurred.

(2) Implementation of Unit 2 PCV venting

(i) At around 11:01 on March 14, there was a supposed hydrogen gas explosion in the Unit 3 R/B and all workers except for the shift team in the main control room evacuated to the Seismic Isolation Building. All work was suspended for a while to confirm safety of workers and field conditions.

At around 12:50 that day, it was confirmed that the circuit for energizing the solenoid valve for the Unit 2 large S/C vent valve (air-operated), in the Units 1 & 2 main control room had been displaced by the impact of the explosion, resulting in the air-operated valve in the closed position.

Therefore it was necessary to reconstruct the PCV vent line by energizing the solenoid valve for the large S/C vent valve (air-operated)

The portable compressor, which had been set up inside the truck bay door of the Unit 2 T/B for the large S/C vent valve (air-operated), had been inspected and found to be operational without damages from the explosion.

(ii) Since Unit 2 reactor water level showed a decreasing trend after that, Site Superintendent

Yoshida decided that the RCIC had stopped at around 13:25 on March 14 and ordered an alternative method of water injection be quickly secured.

The in-house firefighting team and Nanmei workers started constructing a water injection line from the north shallow draft quay to Units 2 and 3 using two fire engines because the previously available water injection line had been damaged in the explosion in the Unit 3 R/B.

Site Superintendent Yoshida believed that if they opened the SRV to start depressurization before they secured a PCV vent line (S/C side), steam would not condense enough in the S/C and reactor pressure would not be sufficiently lowered, and further increase in pressure could lead to S/C destruction. Accordingly he deemed it necessary to implement PCV venting before depressurization and water injection and pressed his teams to make preparations for Unit 2 PCV venting.

From around 16:00 that day, the recovery team started operation to open the large S/C vent valve (air-operated). They used the small generator to energize the solenoid valve on the IA system line in the Units 1 & 2 main control room. However, they could not keep the valve open because the amount of compressed air was not sufficient from the portable compressor placed inside the truck bay door of the Unit 2 T/B.

(iii) As mentioned in Section (1) d (iv) above, at around 16:30 on March 14, Site Superintendent Yoshida simultaneously ordered that Unit 2 depressurization and water injection be implemented and preparations for PCV venting be made. The recovery team of the NPS ERC increased the amount of compressed air and continued their effort to open the large S/C vent valve (air-operated).

Thereafter, however, the recovery team of the NPS ERC continued sending compressed air through the IA system line and energizing the solenoid valve with no sign of a decrease in Unit 2 D/W pressure. The recovery team therefore assumed that the degraded solenoid valve caused the large S/C vent valve (air-operated) not kept open. At around 18:35 that day, accordingly the team decided to try to open the small S/C vent valve (air-operated) in addition to the large S/C vent valve (air-operated).

At around 21:00 that day, the recovery team continued the valve opening task and managed to temporarily open the Unit 2 small S/C vent valve (air-operated). Thus they at least constructed a PCV vent line except for the rupture disk, though a temporary one. At around 21:03 that day, however, the Unit 2 D/W pressure gage indicated 0.419 MPa abs, lower than the rupture disk bursting pressure (0.427 MPa gage = approximately 0.528 MPa abs) and did not show a noticeable decreasing trend so the NPS ERC determined that PCV venting had not successfully been performed yet. Thus the NPS ERC decided to keep open the small S/C vent valve (air-operated) and continuously monitor Unit 2 D/W pressure.

(iv) According to the Unit 2 D/W pressure gage, D/W pressure indicated 0.482 MPa abs at around 22:40 and 0.540 MPa abs at around 22:50 that day, exceeding the maximum allowable operating pressure of the D/W (0.427 MPa gage = approximately 0.528 MPa abs). Accordingly, Site Superintendent Yoshida judged that a specific event (abnormal increase in the containment pressure) as defined in Paragraph 1, Article 15 of the NEPA had occurred and reported to that effect to the relevant authorities.

As to the Unit 2, D/W pressure indicated abnormal increase even though the PCV vent line (S/C side) was constructed. Accordingly the NPS ERC presumed that the small S/C vent valve (air-operated) could not be kept open because of supposed degradation of the solenoid valve or insufficient compressed air from the portable compressor.

Accordingly the recovery team of the NPS ERC considered the use of compressed air cylinders in addition to the portable compressor. To this end, some members of the team had to go into the Unit 2 R/B, repair the connection between the IA line and compressed air cylinders installed near the IA line, and replace the compressed air cylinders. However, radiation levels inside the Unit 2 R/B indicated so high that access there was impractical. The recovery team therefore abandoned the idea of using compressed air cylinders.

Thereafter, the Unit 2 D/W pressure gage indicated a rising trend of 0.580 MPa abs at around 23:00, 0.620 MPa abs at around 2310, 0.700 MPa abs at around 23:25, and 0.740 MPa abs at around 23:35, indication remaining above 0.700 but below 0.8 MPa abs in the early morning of March 15.

On the other hand, the Unit 2 S/C pressure gage showed 0.380 MPa abs at around 22:50, 0.360 MPa abs at around 23:00, 0.350 MPa abs at around 23:10, and 0.300 MPa abs at around 23:35, indicating a rather decreasing trend. The difference between the two pressures was growing larger and the S/C pressure indication was fluctuating above 0.300 but below 0.4 MPa abs by around 05:45 on March 15, which value corresponded to about 30 percent of the D/W pressure indication.

At that time, some staff members of the NPS and TEPCO ERCs reasoned that the big difference between the D/W and S/C pressure indications was due to condensing steam from the RPV to the S/C through the SRV, causing increased water level in the S/C to flood the vacuum breaker connecting the D/W and the S/C. However, it cannot be denied that the pressure gages failed and could not give accurate indications. The cause of the pressure difference was not known at the time of preparation of this report.

(v) At that time, Site Superintendent Yoshida thought that the increasing D/W pressure could destroy the Unit 2 PCV if they did not construct a PCV vent line on the D/W side because while the S/C pressure indicated lower than the rupture disk bursting pressure (0.427 MPa gage = approximately 0.528 MPa abs) the D/W pressure showed an increasing trend according to D/W and S/C pressure indications. However, it was also possible that even if the S/C pressure had been actually higher than that indicated by the S/C pressure indication, the rupture disk would not have burst because the S/C vent valves (air-operated valves) on the PCV vent line (S/C side) could not be kept open.

At around 23:35 on March 14, Site Superintendent Yoshida consulted with the TEPCO ERC via the teleconference system and decided to open the Unit 2 small D/W vent valve (air-operated) for Unit 2 D/W venting.

The PCV vent line had two separate outgoing lines on the D/W and S/C sides. However, the two lines joined in one and extended outside to the stack through the line where the PCV vent valve (motor-operated) was installed (see Attachment IV-24). Therefore in order to construct a PCV vent line on the D/W side, it was needed to open either of the large or small D/W vent valves (air-operated) because the PCV vent valve (motor-operated) had already been in the open position at that time.

Unlike S/C venting, D/W venting would release gases containing radioactive materials into the atmosphere without passing through the suppression pool. Thus S/C venting was the first priority. Site Superintendent Yoshida, however, thought that further increase in D/W pressure could destroy the PCV and decided that Unit 2 D/W venting was an inevitable response.

The TEPCO ERC shared Site Superintendent Yoshida's assessment and no one objected his plan.

(vi) At just past 00:00 on March 15, in the Units 1 & 2 main control room the recovery team of the NPS ERC energized the solenoid valve for the small D/W vent valve (air-operated), using compressed air from the portable compressor placed inside the truck bay door of the Unit 2 T/B, and constructed a PCV vent line (D/W side) except for the rupture disk. However, within a few minutes they discovered that the small D/W vent valve (air-operated) was in the closed position.

Therefore the recovery team tried to open the small D/W vent valve (air-operated) but the D/W pressure gage indicated still 0.730 MPa abs at around 07:20, and the D/W pressure indication stayed above 0.700 but below 0.8 MPa abs without showing a clear decrease. Therefore it is presumed that the small D/W vent valve (air-operated) was not kept open.

(vii) In conclusion, it is considered that as to the Unit 2 PCV venting was not successfully achieved despite various efforts made for S/C or D/W venting.

The bursting pressure of the rupture disk on the PCV vent line of Unit 2 was set to the same value (0.427 MPa gage) as that of Unit 3. It was lower than that of Unit 1 (0.448 MPa gage). Therefore, it is not the cause for the delay in PCV venting that the Unit 2 rupture disk bursting pressure was too high.

The reliability of the D/W and S/C pressure gages was questionable. It is, however, clear that the NPS ERC tried to perform PCV venting according to the readings of these indicators while the pressure gages were still indicating values between 0.4 and 0.5 MPa abs before reaching the PCV pressure of 0.853 MPa gage (approximately 0.954 MPa abs) defined as a "condition requiring venting operation" in the "Severe Accident Operating Procedures". Therefore, it is not the cause for the delay in PCV venting either that the TEPCO-defined PCV pressure was too high as a "condition requiring venting operation" in the "Severe Accident Operating Procedures".

Judging from the on-site responses in PCV venting, the preparations were delayed by the impact of the explosion at Unit 3. In addition, insufficient amount of compressed air for operating the air-operated valves as well as incomplete energizing of the solenoid valve on the IA system line required many hours in constructing a PCV vent line. As a result, it is considered that PCV venting was not successfully achieved because the PCV vent line was not completed (so that the rupture disk did not burst).

(3) Unit 2 S/C pressure decrease, the explosion in the Unit 4 R/B and subsequent responses

(i) At around 06:00 on March 15, in order to take over duty at the Units 3 & 4 main control room a new shift team (hereinafter called "incoming shift team") left the Seismic Isolation Building for the Units 3 & 4 Service Building by car. The Units 3 & 4 main control room was located on the second floor of the Units 3 & 4 Service Building.

The incoming shift team got out of the car near the Units 3 & 4 Service Building and entered the building.

They did not see much rubble or debris that could obstruct traffic on the way to or near the Units 3 & 4 Service Building.

After they entered the building and went to the first floor at around 06:10 that day, the incoming shift team heard a big boom, audible even through their full-face masks. After that, the incoming shift team went into the Units 3 & 4 main control room and knew the then on-duty shift team (hereinafter called "outgoing shift team") also heard the sound.

Soon after, the operation team of the NPS ERC ordered the outgoing and incoming shift teams to evacuate to the Seismic Isolation Building, and the two shift teams left the building. The area around the building had changed drastically from what the incoming shift team had seen shortly before, with rubble, debris and many other obstacles scattered or piled up in places.

The two shift teams first planned to go back to the Seismic Isolation Building in the incoming team's car. At that time they found that the upper part of the Unit 4 R/B had been damaged and the road nearby was covered with pieces of concrete and other obstacles so that travelling by car was impossible. Therefore the teams got out of the car and left for the Seismic Isolation Building on foot. At around 08:11 that day, they arrived at the building and reported to the NPS ERC that the 5th floor of the Unit 4 R/B was damaged.

It is identified that according to those pulses observed at the seismic monitoring points within the premises of the Fukushima Dai-ichi NPS from around 06:00 until 06:10 the waves of the vibration propagated in concentric circles assuming that the epicenter was at the Unit 4 but they showed irregular patterns if Unit 2 was the assumed epicenter.

According to the shift teams' report and the observed results at the seismic monitoring points, it is presumed that the big boom sound was caused by the explosion in the Unit 4 R/B.

(ii) On the other hand, according to the S/C pressure gage Unit 2 S/C pressure indicated 0 MPa abs at around 06:10 on March 15.

The value of the S/C pressure indication was in absolute pressure. So, if it were converted to gage pressure with the atmospheric pressure set at zero, the value would be minus (-) 0.101 MPa gage. Therefore, it could not be logically explained that S/C rupture caused the S/C pressure to equal the atmospheric pressure. In addition, a pressure value far below the atmospheric pressure could not be explained theoretically.

In this context, the Unit 2 pressure gages indicated events that could not easily be explained: the D/W pressure indicated increase while S/C pressure indicated decrease after around 22:00 on March 14, and the former stayed above 0.700 but below 0.8 MPa abs and the latter above 0.300 but below 0.4 MPa abs. Judging from this fact, the reliability of the pressure indications is questionable.

It is probably a logical conclusion that there was a leak somewhere in the Unit 2 PCV considering the subsequent fact that water contaminated with very high concentration of radioactive materials collected in the Unit 2 T/B. However, it is difficult to determine when such a leak was created.

(iii) Site Superintendent Yoshida thought that some kind of explosion had taken place in the Unit 2 PCV based on the information that a big boom sound had been heard between 06:00 and 06:10 on March 15 and that Unit 2 S/C pressure indicated zero in absolute pressure. Since the members of the outgoing and incoming shift teams who confirmed the damage to Unit 4 evacuated on foot because the road on the mountain side of the Unit 4 R/B had been blocked by rubble and debris and travel by car was impossible, it took time to return to the Seismic Isolation Building. Therefore, Site Superintendent Yoshida did not get the information about the damage to the Unit 4 R/B until around 08:11 that day.

At that time, Site Superintendent Yoshida judged that Unit 2 S/C pressure indicated 0 MPa abs because some kind of explosion had occurred in the Unit 2 PCV. He directed all members except the leading staff, including himself, and those members necessary for monitoring the plant and conducting emergency recovery work to temporarily evacuate from the Fukushima Dai-ichi NPS. The members necessary for monitoring the plant and conducting emergency recovery work were nominated by the leaders of the function teams of the NPS ERC.

At around 07:00 on March 15, about 650 people working at the Fukushima Dai-ichi NPS temporarily evacuated to the Fukushima Dai-ni NPS with the exception of some 50 members including Site Superintendent Yoshida, the leading staff, and the engineers and workers for monitoring the plant and conducting emergency recovery work.

(iv) At around 06:50 on March 15, radiation level (583.7 μSv/h) exceeding 500 μSv/h was detected near the main gate of the Fukushima Dai-ichi NPS. Thus Site Superintendent Yoshida judged that a specific event (abnormal increase in radiation levels at the site boundary) as defined in Paragraph 1, Article 15 of the NEPA had occurred and reported it to the relevant authorities at around 07:00 that day.

Radiation levels near the main gate rose to 807 μSv/h at around 08:11, fell slightly to 531.6 μSv/h at around 16:00, and increased again to 4,548 μSv/h at around 23:05 that day. From these changes in radiation levels, Site Superintendent Yoshida deemed that a specific event (abnormal increase in radiation levels at the site boundary) as defined in Paragraph 1, Article 15 of the NEPA had occurred and reported it to the relevant authorities.

(v) At around 09:38 on March 15, the NPS ERC received a report that a fire had broken out near the northwest corner of the 3rd floor of the Unit 4 R/B. The NPS ERC notified a local fire station. However, high radiation levels prevented the fire brigade from firefighting at the site.

Eventually at around 11:00 that day, the NPS ERC confirmed that the fire near the northwest corner of the 3rd floor of the Unit 4 R/B died down on its own.

According to the readings of the D/W pressure gage, Unit 2 D/W pressure indicated 0.730 MPa abs at around 07:20 and decreased to 0.155 MPa abs at around 11:25 that day.

Judging from the plant conditions at the Fukushima Dai-ichi NPS, Site Superintendent

Yoshida decided to order the people who had evacuated to the Fukushima Dai-ni NPS to return to the Fukushima Dai-ichi NPS from the morning of March 15 onward. To begin with, Site Superintendent Yoshida ordered group managers to return.

6. After the S/C pressure decrease of Unit 2 and the explosion in the Unit 4 R/B (after around 06:10 on March 15)

(1) Water spraying and sprinkling of the SFP

(i) At around 09:03 on March 15, the Government – TEPCO Integrated Headquarters for Response to the Incident at the Fukushima Nuclear Power Stations (hereinafter called "Integrated Headquarters") considered water sprinkling by helicopter and water spraying by fire engine in order to maintain water levels of the Spent Fuel Pools ("SFPs") of Units 1 to 4. The first priority was to maintain the water level of the SFP of Unit 4 because of its high water temperature.

At around 10:43 on March 16, white smoke was confirmed to be coming from the Unit 3 R/B and the workers temporarily evacuated. The Integrated Headquarters, therefore, deemed it necessary to spray and/or sprinkle water also on the Unit 3 SFP although its decay heat was much lower than that of the Unit 4 SFP. The Integrated Headquarters also considered water spraying with ladder trucks in case water sprinkling by helicopter was difficult.

It was decided that the helicopter crew would also visually inspect the SFPs of Units 3 and 4 when an SDF helicopter flew over the Fukushima Dai-ichi NPS to check radiation levels in preparation for water sprinkling from the air,. Based on the results of this air survey, they would decide which SFP should be the first priority.

That afternoon, an SDF helicopter with a TEPCO employee on board flew over the Fukushima Dai-ichi NPS. Under the guidance of the TEPCO employee, the helicopter approached the operating floor of Unit 4. The helicopter crew including the TEPCO employee visually inspected and took pictures of the Unit 4 SFP. From the visual inspection and photographs, they confirmed that the Unit 4 SFP had a sufficient amount of water and the spent fuel assemblies were covered.

The pool gate that separated the reactor well and the SFP of Unit 4 was pressed toward the reactor well side to keep water tightness (see Attachment IV-31). During normal operation, the reactor well was usually empty and strong hydraulic pressure was applied from the SFP side to the pool gate so that the water tightness at the gate was maintained. However, Unit 4 was undergoing a periodic inspection and its reactor well was full of water. The tsunami damaged the seawater pumps and caused the loss of all AC power, resulting in the Fuel Pool Cooling and Cleanup ("FPC") system and the secondary cooling system not functioning. Thus SFP water temperature rose, SFP water level dropped due to pool water evaporation, and accordingly the water level of the reactor well became higher than that of the SFP. As a result, the water tightness of the pool gate was lost because of its structure, and water flowed from the reactor well into the SFP until their levels were equal. Therefore it is considered that the Unit 4 SFP water level was maintained despite its high temperature.

(ii) Since it was confirmed that the Unit 4 SFP water level was secure, the Integrated Headquarters decided to prioritize water spraying and sprinkling of the Unit 3 SFP.

The Integrated Headquarters also decided to start water spraying and sprinkling of the Unit 3 SFP from the morning to afternoon of March 17 in the order of: (a) water sprinkling by SDF helicopters, (b) water spraying by high-pressure water cannon trucks from the Tokyo Metropolitan Police Department ("TMPD") riot squads, and (c) water spraying by SDF fire engines.

From around 09:48 until 10:01 that day, the SDF helicopters dropped a total of 30 tons of water on the upper part of the Unit 3 R/B over four flights. Although white steam was seen rising from the building, very little water was thought to have reached the SFP due to obstructions such as its roof and other structures broken by the explosion. After this attempt, no water sprinkling by SDF helicopters was carried out.

From around 19:05 until 19:13 that day, the high-pressure water cannon trucks from the TMPD riot squads sprayed a total of 44 tons of water on the Unit 3 SFP but due to the inadequate range of the water cannons the amount of water reaching the SFP was thought to be limited. After this attempt, no water spraying by high-pressure water cannon trucks from the TMPD riot squads was carried out.

From 19:35 to 20:09 that day, the fire engines of the SDF sprayed the Unit 3 SFP with a total of 30 tons of water in five attempts.

(iii) On March 18, water spraying to the Unit 3 SFP still remaining a priority, after the power recovery work by around 14:00, the SDF fire engines and a fire engine from the US military forces sprayed water on the SFP and then Tokyo Fire Department's ("TFD") Hyper Rescue Squad watered the pool.

From around 14:00 to 14:38 that day, the SDF fire engines sprayed the Unit 3 SFP with a total of 40 tons of water in six attempts.

From around 14:42 to 14:45 that day, the US forces fire engine sprayed the Unit 3 SFP with a total of 2 tons of water.

In the morning of March 17, employees of Toden-Kogyo Ltd. (hereinafter called "Toden-Kogyo") and Nanmei workers participated in a water spraying drill with a US forces fire engine at Yokota Air Base. They were transferred to the J village by helicopter and car. There they received a fire engine provided by the US military forces and drove it to the Fukushima Dai-ichi NPS. Thus it was the Toden-Kogyo and Nanmei employees who drove and operated the US forces fire engine.

The TFD Hyper Rescue Squad consisting of 10 fire engines and 139 members assembled at the J village. Its advance squad team went to the site of the accident under the guidance of a TEPCO employee to inspect the conditions there. During the inspection, the compressed air cylinders for their gas masks were running out of air so the squad team had to return to the J village. For several reasons including the return of the advance squad team to the J village, the Hyper Rescue Squad's water spraying was performed far behind the originally scheduled time of 15:00 on March 18. The TFD special taskforces sprayed 60 tons of water on the Unit 3 SFP from around 00:30 to 01:10 on March 19

From that day until March 25, water spraying to the Unit 3 SFP with fire engines continued, mostly using seawater (see Attachment IV-32).

(iv) Although its water level was confirmed to be acceptable, they started spraying water on the Unit 4 SFP from March 20 in light of its large decay heat.

From around 08:21 to 09:40 that day, the SDF sprayed the Unit 4 SFP with a total of 80 tons of freshwater in 11 attempts and most of the water was thought to have reached the SFP.

As for the Unit 4 SFP, water spraying with fire engines was conducted also on March 21 and concrete pumping trucks were used to spray seawater on the SFP from March 22 to March 27 (see Attachment IV-32).

Concrete pumping trucks are designed to pump concrete with long pumping arms at a construction site. Since the long arm could be extended to reach above the SFP, with water instead of concrete, they could spray the SFP with water more accurately than fire engines. As a result of actual water spraying at Unit 4, the stability was determined sufficient though had been deemed to be questionable in the beginning. Therefore since then, concrete pumping trucks were employed successively to spray water on the SFPs of Units 1 and 3.

TEPCO procured and transported concrete pumping trucks to the Fukushima Dai-ichi NPS but it was specially trained Nanmei and Toden-Kogyo employees who actually operated the vehicles.

(2) Implementation of FPC system water injection

(i) The R/B and T/B of Unit 2 were not damaged in the explosions. Only its blow-out panel was displaced by the impact of the Unit 1 explosion.

Therefore, the Integrated Headquarters decided to review a more reliable method of FPC system water injection to the SFP instead of water spraying with fire engines and other trucks, as the Unit 2 FPC system line was considered to keep its integrity since March 15.

Such FPC system water injection had already been reviewed by the recovery team of the NPS and TEPCO ERCs ahead of the Integrated Headquarters.

The Integrated Headquarters also examined the possibility of water injection through the MUWC system line to the Unit 2 SFP. However, it was necessary to replace the inundated power distribution panel and install a new pump inside the Unit 2 T/B. where, radiation levels indicated too high to work inside the building. Thus the Integrated Headquarters abandoned MUWC system water injection and decided on FPC system water injection to the SFP.

Accordingly, a flow sight glass for visual flow monitoring was removed from the Unit 2 FPC system line located in the Radioactive Waste Treatment building where the radiation levels indicated relatively low, and a fire hose was connected in place of the removed flow sight glass. It was also decided to use fire pumps to inject seawater from the north shallow draft quay through the FPC system line to the Unit 2 SFP (see Attachment IV-33).

(ii) On March 19, the NPS ERC conducted the work necessary to construct this water injection line. On March 20, they started injecting water through the FPC system to the Unit 2 SFP. During the water injection, they paid attention to water leak from the line by monitoring the amount of water injected and changes in water level.

When they injected water into the Unit 2 SFP again on March 22, they confirmed skimmer surge tank level rose from 6,350 mm to 6,500 mm. Consequently the Integrated Headquarters thought that the increase in skimmer surge tank level had been caused by the overflow of water from the SFP (see Attachment IV-34) and concluded that the SFP had been filled with water.

The amount of water injected into the SFP to fill it up was 58 tons.

From that day onward, FPC system water injection was conducted every few days to maintain the water level of the Unit 2 SFP (see Attachment IV-32). There was, however, a concern about fire pump failure, since the fire pumps used for water pumping are not designed for continuous operation for many hours. Therefore a temporary motor-driven pump was set on the rear deck of the truck parked at the fire cistern near Unit 2 on March 27 (for future use at Units 1, 3 and 4, four connecting plugs were installed). Thereafter, the temporary motor-driven pump would be used for FPC system water injection.

On March 29, however, water in large amounts leaked from the FPC injection hose, resulting in insufficient flow for water injection, soon after FPC system water injection into Unit 2 started using the temporary motor-driven pump. Consequently, water pumping had to be back to the fire engine.

On March 30, Unit 2 FPC system water injection using fire engines was conducted but again resulted in insufficient flow for water injection.

On March 31, facility inspection found that sludge had deposited in the strainer of the temporary motor-driven pump. On April 1, FPC system water injection was performed with the temporary motor-driven pump with the strainer removed and sufficient flow rate was secured, and thereafter FPC system water injection resumed using the temporary motor-driven pump.

(iii) In addition, as to Units 3 and 4, water injection lines were constructed to pump seawater at the north shallow draft quay using fire pumps via the FPC system line to the SFPs. Test injections through the FPC system line were conducted for Unit 3 on March 23 and 24, and for Unit 4 on March 25 (see Attachment IV-35 for FPC system water injection of Units 3 and 4).

Neither of the units, however, showed an increase in SFP water level corresponding to the amount of injected water, and accordingly clogged piping and/or water leakage was suspected. In particular, as to Unit 4, a picture taken on March 16 clearly identified that there had been a crushed area near the check valve on the FPC system line, resulting in FPC system water injection to Unit 4 being impossible without replacing the damaged part.

Therefore, ongoingly concrete pumping trucks were used to spray water on Units 3 and 4 (see Attachment IV-32).

(3) Switching from seawater to freshwater

(i) Until late March, seawater was mainly used for water spray and injection into the SFPs. Since it was concerned that corrosion would develop at SFP-related facilities and the FPC system line, it was decided that freshwater would be secured and water sources for spray and injection would be switched from seawater to freshwater sequentially.

(ii) On March 29, for FPC system water injection into Unit 2, water source was switched from seawater to freshwater and FPC system freshwater injection continued until May 31 (see Attachment IV-32).

(iii) Additionally on March 29, for water spray by concrete pumping trucks on the Unit 3 SFP, water source was switched from seawater to freshwater and freshwater spray continued until April 22 (see Attachment IV-32).

On April 12, a concrete pumping truck equipped with a video camera was employed for Unit 3, enabling water spray under monitoring water level increase with the video camera. Consequently it was confirmed for the first time that the Unit 3 SFP had been filled with water. The amount of injected water totaled approximately 35 tons. On May 8, a video picture taken at the sampling survey of Unit 3 SFP water found that a lot of rubble and debris in the pool prevented the fuel assemblies stored in the pool from being confirmed for their conditions. Therefore, it cannot be denied that some of the spent fuel was damaged.

(iv) In addition, on March 30, for water spray by concrete pumping trucks to the Unit 4 SFP, water source was also switched from seawater to freshwater and thus freshwater spray continued until June 14 (see Attachment IV-32).

(4) Implementation of water spray on the Unit 1 SFP

(i) As the spent fuel assemblies stored in the Unit 1 SFP had been cooled at least for about one year since shutdown on March 25, 2010, Priority was given to cooling of the SFPs of other units than Unit 1.

In late March 2011, the Integrated Headquarters started reviewing Unit 1 SFP cooling as water spray and injection had relatively been stable with the other SFPs.

Like Units 3 and 4, the Unit 1 R/B was damaged by the explosion, so it was highly likely that the FPC system line inside the R/B had also been damaged and radiation levels indicated high in the Radioactive Waste Treatment Building. The Integrated Headquarters thus decided to take precedence of water spray with concrete pumping trucks over FPC system water injection.

(ii) From March 31, a total of 240 tons of freshwater was sprayed by concrete pumping trucks onto Unit 1 (see Attachment IV-32).

(5) Implementation of FPC system water injection into the Unit 3 SFP

(i) On April 22, FPC system water injection into the Unit 3 SFP was carried out for 20 minutes with the strainer removed from the Unit 3 FPC system line. This trial confirmed that water level increased with no significant leak.

Accordingly, the Integrated Headquarters determined that the strainer in the FPC system line caused for some reason insufficient injection water during FPC system water injections on March 23 and 24.

(ii) After that, FPC system water injection was performed at the Unit 3 SFP by confirming the integrity of the FPC line. According to the changes in water level resulted from FPC system water injection until May 9, it was evaluated that the FPC system line was virtually functioning, and FPC system water injection continued until June 29 (see Attachment IV-32).

As alkali metals (including calcium) eluted from the rubble and debris turned the water alkaline in the Unit 3 SFP, alkaline corrosion of the aluminum fuel racks became a concern. Therefore on June 26 and 27, borated water was injected to neutralize the alkaline water in the Unit 3 SFP.

(6) Installation of alternative cooling systems

(i) The SFPs were cooled in various ways including water spraying with fire engines and FPC system water injection depending on the condition of each unit and the extent of building damage, integrity of the piping inside the building and the level of radiation. They were, however, only tentative responses and water was refilled to compensate for the amount of water lost and/or evaporated.

In order to constantly cool the SFPs, it needed to address and construct circulation cooling systems that had a primary cooling loop in which SFP water circulated and a secondary cooling loop in which the SFP water was cooled via a heat exchanger.

Since mid-April, according to the policy of the Integrated Headquarters, TEPCO had consulted with two plant manufacturers for Units 1 to 4 (Units 1 and 4 were by one company and Units 2 and 3 were by an another) about the installation of such alternative cooling systems. As a result, as to Units 1 to 4, it was decided to construct a primary system in which SFP water would circulate mainly through the FPC system line, to install a new cooling tower for cooling secondary loop water, and to construct a secondary cooling loop, to remove heat by using a heat exchanger from water circulating in the primary loop. Construction was started at different times depending on the conditions of the respective units.

(ii) As the first step, the construction work of an alternative cooling system for Unit 2 was conducted from late April to late May. At around 17:21 on May 31, the alternative cooling loop pumps were started to cool the Unit 2 SFP (see Attachment IV-36).

According to the SFP temperature gauge, SFP water temperature indicated 70°C when cooling started, stabilized around June 5 and remains stable at temperature of about 30°C since then.

(iii) The plant manufacturer company that built the alternative cooling system for Unit 2 also built an alternative cooling system for Unit 3. On June 30, Unit 3 SFP cooling with the alternative system started (see Attachment IV-37).

Unit 3 SFP water temperature (alternative cooling system inlet temperature) indicated about 62°C when cooling started, stabilized around July 7 and remains stable at temperature of about 30°C since then.

(iv) As for Units 1 and 4, it was decided to provide a temporary SFP cooling method until the completion of an alternative cooling system because its construction would take a long time due to high radiation levels and more serious damage.

As for Unit 1, it was found that radiation levels indicated relatively low near the FPC pump and the heat exchanger located in the southwest corner of the 3rd floor of the R/B. Thus the construction work necessary for FPC system water injection would be conducted there.

Specifically, workers constructed a line to feed freshwater via the FPC system line to the SFP, using a temporary motor-driven pump, by removing the head of the check valve on the FPC system line, connecting temporary piping in the place of the removed head, and fixing with a jig a fire hose to the end of the temporary piping (see Attachment IV-38). On May 29 they started FPC system water injection into the Unit 1 SFP. FPC system water injection continued intermittently until August 10 when an alternative cooling system started cooling the Unit 1 SFP (see Attachment IV-32).

As a result of FPC system water injection on May 29, skimmer surge tank level rose from 2,050 mm to 4,550 mm, and was deemed to be the result of overflow in the SFP. Accordingly it was concluded that the SFP had been filled up. The amount of SFP water at the normal water level was approximately 1,000 tons and the amount of injected water totaled about 413 tons.

On the other hand, as for Unit 4, FPC system water injection could not be performed since an aerial photograph showed that damages seemed serious in the area near the check valve on the FPC system line. Accordingly it was decided to construct a temporary SFP water injection facility, "Mizuha", by installing hoses from outside the R/B through the damaged part of the building to the SFP for delivering water by means of pumping. On June 16, Mizuha started injecting water into the Unit 4 SFP. The temporary facility fed water into the SFP five times till July 31 (see Attachment IV-32).

Additionally, on June 19, it was also decided to inject water from the in-core neutron monitor tubes (“ICM Tubes”) to the reactor well and DS pit in order to reduce radiation dose from the in-core structures stored in the DS pit (see Attachment IV-40). As a result, reactor well water level decreased even after the reactor well had been filled up. Meanwhile, skimmer surge tank level increased during water injection to the reactor well. Therefore, it was assumed that water was flowing from the reactor well to the SFP. Consequently, from June 19 until July 30, water injection from the ICM Tubes to the reactor well and DS pit of Unit 4 was conducted intermittently so as to use the flow to the SFP to maintain its water level (see Attachment IV-32).

(v) Alternative cooling systems for Units 1 and 4 were constructed (see Attachments IV-41 and IV-42 for the alternative cooling systems of Units 1 and 4 respectively). The alternative cooling systems started cooling the Unit 4 SFP on July 31 and the Unit 1 SFP on August 10.

As for Unit 4, SFP water temperature (alternative cooling system inlet temperature) indicated 75°C when cooling started, stabilized around August 3 and remains stable at temperature of about 40°C since then.

As for Unit 1, SFP water temperature (FPC system pump inlet temperature) indicated 47°C when cooling started, stabilized around August 27 and remains stable at temperature of about 30°C since then.

(7) Preparations for SFP cooling of Units 5 and 6

(i) The Unit 5 SFP lost its cooling capability and water supply capability on March 11, then its water temperature continued to rise. Therefore a temporary cooling facility was constructed using a temporary submerged pump in place of the damaged seawater pump. The temporary cooling facility was put into full operation at around 05:00 on March 19. Consequently, pool water temperature did not exceed 68.5°C and thus stable cooling was maintained (see Attachment IV-43). Since the temporary cooling facility was also used to cool the fuel in the reactor, SFP water temperature, though with occasional rises during the cooling facility was operated in the reactor cooling mode, stayed between about 30°C and

50°C.

(ii) As for the Unit 5 SFP, operation mode moved to the shutdown cooling (SHC) mode on May 6, and dedicated operation became available on June 25, resulting in more stable cooling with pool water temperature at around 30°C.

(iii) The Unit 6 SFP also lost its cooling capability and water supply capability on March 11, then its water temperature continued to rise. Like the Unit 5 SFP, a temporary cooling facility was constructed. The temporary cooling facility was put into full operation at around 22:00 on March 19. Consequently pool water temperature did not exceed 67.5°C and thus stable cooling was maintained (see Attachment IV-44). The temporary cooling facility was also used to cool the fuel in the reactor, SFP water temperature, though with occasional rises during the cooling facility was operated in the reactor cooling mode, stayed between about 20°C and 40°C.

On May 6, the Unit 6 SFP went into the SHC mode, resulting in stable pool water temperature.

7. Hydrogen gas explosion in the R/B (outside the Primary Containment Vessel)

(1) Recognition of related parties

As mentioned in Sections 3 to 5 above, the supposed hydrogen gas explosions occurred in Units 1, 3 and 4. Until the explosion at Unit 1, no one at the Fukushima Dai-ichi NPS, TEPCO Head Office or the Japanese government considered the possibility of a hydrogen gas explosion occurring in the R/B.

(2) Japan domestic and international knowledge about hydrogen explosions in the R/B

It is universally known that a hydrogen explosion can occur at nuclear power stations and a great number of documents are available mentioning its risk and countermeasures. However, they are all about hydrogen explosions that occur in the Primary Containment Vessel (“PCV”). There were only two documents that discussed a hydrogen explosion in the R/B (outside the PCV) before this earthquake took place. Not even the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD/NEA) had discussed a hydrogen explosion in the R/B.

For instance, "Flame Acceleration and Deflagration-to-Detonation Transition in Nuclear Safety"[79] published by the OECD/NEA in 2000, "Mitigation of hydrogen hazards in water

[79] The title of the formal paper is “Flame Acceleration and Deflagration-to-Detonation Transition in Nuclear Safety”

cooled power reactors"[80] by IAEA in 2001, and "Design of Reactor Containment Systems for Nuclear Power Plants"[81] by IAEA in 2003 discuss the risk and other aspects of a hydrogen explosion in the containment but do not mention events where hydrogen leaks from the PCV and explodes in the R/B.

The two documents that discussed the hydrogen explosion in the R/B before the earthquake were "Analysis of Long-term Station Blackout Without Automatic Depressurization at Peach Bottom Using MELCOR (Version 1.8)"[82] (hereinafter called "Brookhaven paper"), published by the Brookhaven National Laboratory in 1994, and "Simulation of hydrogen deflagration and detonation in a BWR reactor building"[83] (hereinafter called "Manninen paper"), published by M. Manninen et al in 2002.

The Brookhaven paper concluded that hydrogen burns would occur several times in the R/B and on the refueling platform soon after damage to the PCV as a result of the analysis where the reactor vessel depressurization had also failed during the long-term loss of power in an accident at a Boiling Water Reactor ("BWR") having a Mark I containment, taking the Peach Bottom Nuclear Power Station as a model. The Manninen paper evaluated the possibility of hydrogen deflagration and detonation in the R/B of the Olkiluoto Nuclear Power Station in Finland, considering the possibility that hydrogen could possibly leak from a relatively small containment of a BWR at the time of a severe accident and build up in the R/B. It is also discussed in this paper that if there was hydrogen leak with an opening of $20mm^2$ in the containment, the possibility of flame acceleration, deflagration and detonation could not be excluded.

As of the date of this report, no evidence was found that the Brookhaven paper and/or the Manninen paper had ever been discussed in Japan or even by authoritative international organizations including IAEA and OECD/NEA.

80 The title of the formal paper is "Mitigation of hydrogen hazards in water cooled power reactors"
81 The title of the formal paper is "Design of Reactor Containment Systems for Nuclear Power Plants"
82 The title of the formal paper is "Analysis of Long-term Station Blackout Without Automatic Depressurization at Peach Bottom Using MELCORE (version 1.8)"
83 The title of the formal paper is "Simulation of hydrogen deflagration and detonation in a BWR reactor building"