TEPCO Fukushima Daini Nuclear Power Station

Research on the status of response to the Tohoku-Pacific Ocean Earthquake and Tsunami and Lessons learned therefrom

(Proposals)

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Japan Nuclear Safety Institute

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1. Introduction.

For everyone associated with nuclear power, March 11, 2011 has become a day which will never be forgotten. This day will be long remembered by those in the nuclear industry for years to come.

Even now, a large number of people still have to endure stressful lives as refugees. If we consider the length of time as well as the size and range of the damage, we will profoundly recognize the enormity of the damage of the nuclear disaster.

Meanwhile, TEPCO's Fukushima Daiichi Nuclear Power Station (hereinafter referred to as "Fukushima Daiichi"), is in the middle of a restoration process for accident convergence in accordance with the roadmap, and the situation of the power plant may be considered to have subsided substantially.

National agencies, local governments, industries, academia, volunteer groups and local residents are making efforts for decontamination and other tasks toward the restoration of the region, and as a result, some areas have managed to relax access restriction. Although there were the most stringent controls on the shipment of food from the outset of the accident, restrictions have been lessened little by little but it is still necessary to continue the constant monitoring.

The level of radiation to which residents are exposed is regulated based on knowledge of the dose rate obtained from historical data, including survivors of the atomic bombs dropped on Hiroshima and Nagasaki, but this is not considered to provide clarity in indicating the late-onset effects of radiation exposure, and we do not think that a situation will develop in which there will be significant increase in cancer incidence due to radioactive materials. The national government will continuously monitor the health of residents in the future.

Extensive validations have been performed about the Fukushima Daiichi accident, and many reports have been published. Our Institute has also issued a proposal with the cooperation of TEPCO and manufacturers which was published at the end of last October as a statement from the industry. It focuses primarily on the hardware to combat tsunami to prevent accidents from expanding. We believe that the expansion of this accident and the massive release of radioactive materials into the environment could have been prevented if appropriate measures had been taken.

Dr. Hatamura, Chairman of the Accident Investigation Committee of the government, stated in a special NHK program that "this accident at Fukushima Daiichi could have been averted if proper and adequate preparations had been in place."

There is an ongoing national discussion of what to do about the energy supply in the future; we think that inexpensive natural energy is not sufficient at present, and will not be secure in the future, and that considering big problems such as energy security, global warming, and remaining internationally competitive (the hollowing out of domestic industry), it would be unrealistic to eliminate all nuclear power entirely.

Before the accident at Fukushima Daiichi, the Democratic Party, the current ruling party, promised the international community a 25% reduction of CO2 emissions and was planning to increase the proportion of nuclear power to 40%. How we can achieve our international commitment to CO2 reduction without nuclear power? And how long we can continue to pay as much as three trillion yen each year to operate thermal power plants instead of nuclear power plants, in addition to buying fossil fuels? In view of these difficult issues, we think that the realistic option for the time being is to continue using nuclear power while improving its safety.

Following the industry report analyzing the Fukushima Daiichi accident, our Institute decided to validate the post-tsunami response situation at the Fukushima Daini Nuclear Power Station (hereinafter referred to as "Fukushima Daini") which successfully led the station to convergence, both from a technical perspective and from the viewpoint of a third party, with the intent of gathering lessons in order to enhance the accident response capability of nuclear power plants and contribute to the improvement of safety.

Details of the sequence of events and responses to the Fukushima Daini accident have already been fully described in the accident analysis reports such as by the Government and by TEPCO. Therefore, this report is dedicated to summarizing the overview of the sequence of events and accident responses, and it is intended to pick out good practices which include lessons for the future. In compiling these lessons, we tried to make our recommendations as specific as possible by describing the necessary level of preparedness based on the actual accident responses.

We hope that the lessons of this report will be utilized when nuclear power plants in Japan and throughout the world consider possible measures against accidents.

As stated above, our report on the Fukushima Daiichi accident, which primarily summarizes the hardware and recommends various measures, is available at the Japan Nuclear Safety Institute's website (former Japan Nuclear Technology Institute). Please visit the page.

In this report, we basically excluded the analysis of the activities of the central and local governments and confined our analysis to gathering lessons about aspects to which electric utility companies should be able to respond.

2. Overview of Fukushima Daini Nuclear Power Station

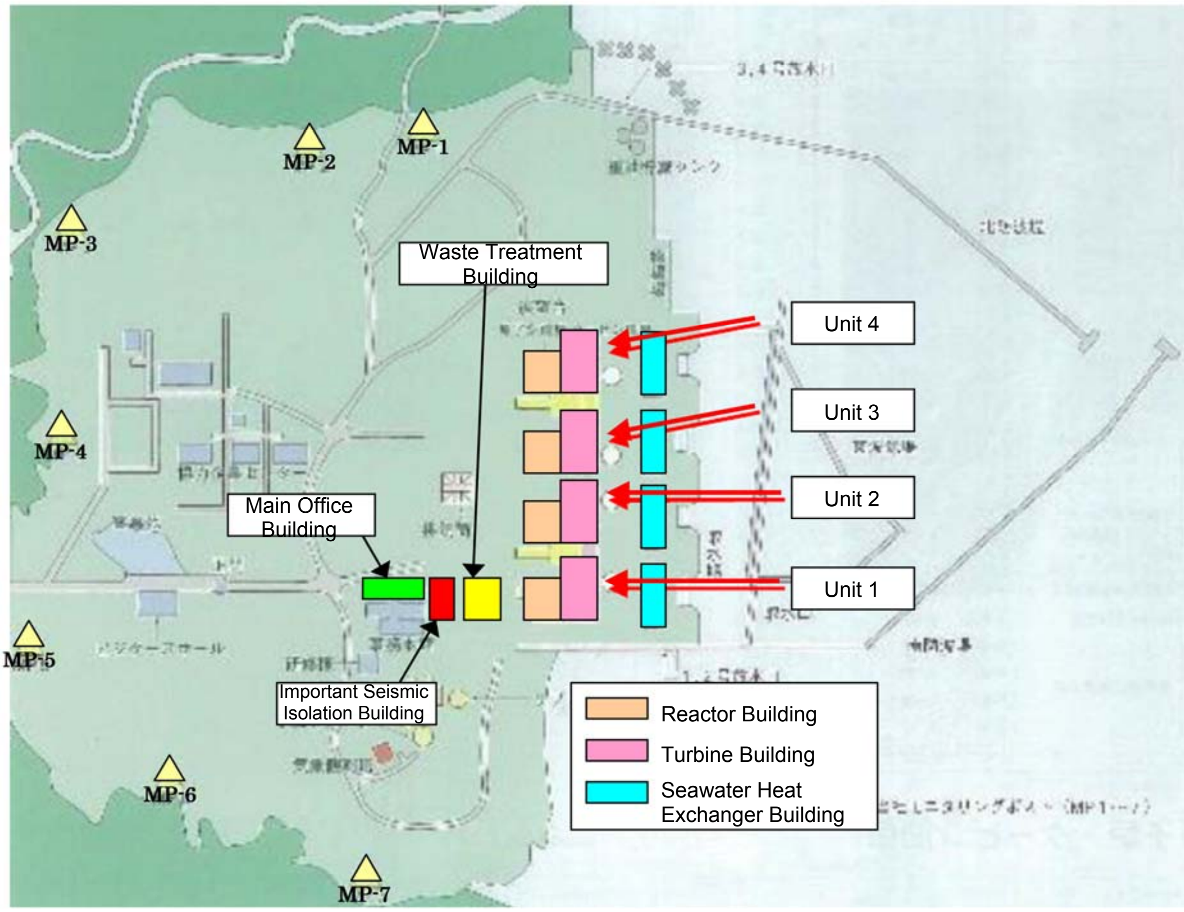
2.1 Overall Layout

Fukushima Daini is located in the towns of Naraha and Tomioka in Futaba-gun, Fukushima Prefecture, about 12 km south of Fukushima Daiichi, facing the Pacific Ocean to the east. The site is approximately 147 million m2 and its shape is almost square.

At present, four units of boiling water reactors have been installed and are arranged in the order of No. 1, 2, 3, and 4 from the south. The generating capacity of these units is 1,100 MW each, making for a total installed capacity of power generation of 4,400 MW.

When the recent disaster occurred, all units 1 to 4 were in operation at the rated thermal output.

One central control room controls two units of reactors in a twin plant design: Units 1 and 2 make up one pair and Units 3 and 4 another.



Location	Unit	Start of Operation	Type		Output(MW)	Situation when event happened
			Reactor	Pressure Vessel		
Naraha town	1	S57.4	BWR5	Mark II	1,100	In operation at the rated thermal output
	2	S59.2		Mark II R Advanced	1,100	
Tomioka town	3	S60.6			1,100	
	4	S62.8			1,100	

Fig 2.1 Overall Layout of Power Stations

2.2 System Configuration

The system configuration of each unit of Fukushima Daini is as shown in Fig 2.2.
The role of each system is as follows:

- Reactor Core Isolation Cooling System (RCIC)
  In the event that the main condenser is no longer available for any reason, such as closure of the main steam isolation valve during normal operation, steam from the reactor will activate the turbine drive pump to inject the water in the condensate storage tank (referred to as "CST" below) into the reactor, and reduce the pressure by removing the decay heat of the fuel. The system also works as an emergency water injection pump in case of the failure of the water supply system, etc., and maintains the water level in the reactor.

- Residual Heat Removal System (RHR)
  After shutting down the reactor, the system will cool the coolant (remove the decay heat of the fuel) using pumps and the heat exchangers, or maintain the level of reactor water by injecting cooling water in case of an emergency (part of ECCS). The system has the ability to bring the reactor to cold shutdown and has five modes of operation: reactor shutdown cooling mode, low-pressure injection mode (ECCS), containment spray mode, pressure suppression chamber cooling mode, and emergency heat load mode.

- Emergency Core Cooling System (ECCS)
  The system consists of four subsystems: low pressure core spray system (LPCS), low pressure water injection system, high pressure core spray system (HPCS) and automatic depressurization system. In the case that a loss-of-coolant accident (LOCA) has occurred due to a piping break in the reactor coolant pressure boundary, such as the primary loop recirculation system piping, the system will remove the residual heat and the decay heat of the fuel in the reactor core, preventing the fuel cladding tube from being damaged by the fuel overheating, and consequently, minimize and suppress the water-zirconium reaction to a negligible extent.

- Standby Liquid Control System (SLC)
  If and when control rod insertion becomes impossible for any reason during reactor operation, the system will inject a neutron-absorbing boric acid solution from the bottom of the reactor core as a backup for the control rod to stop the nuclear reaction.

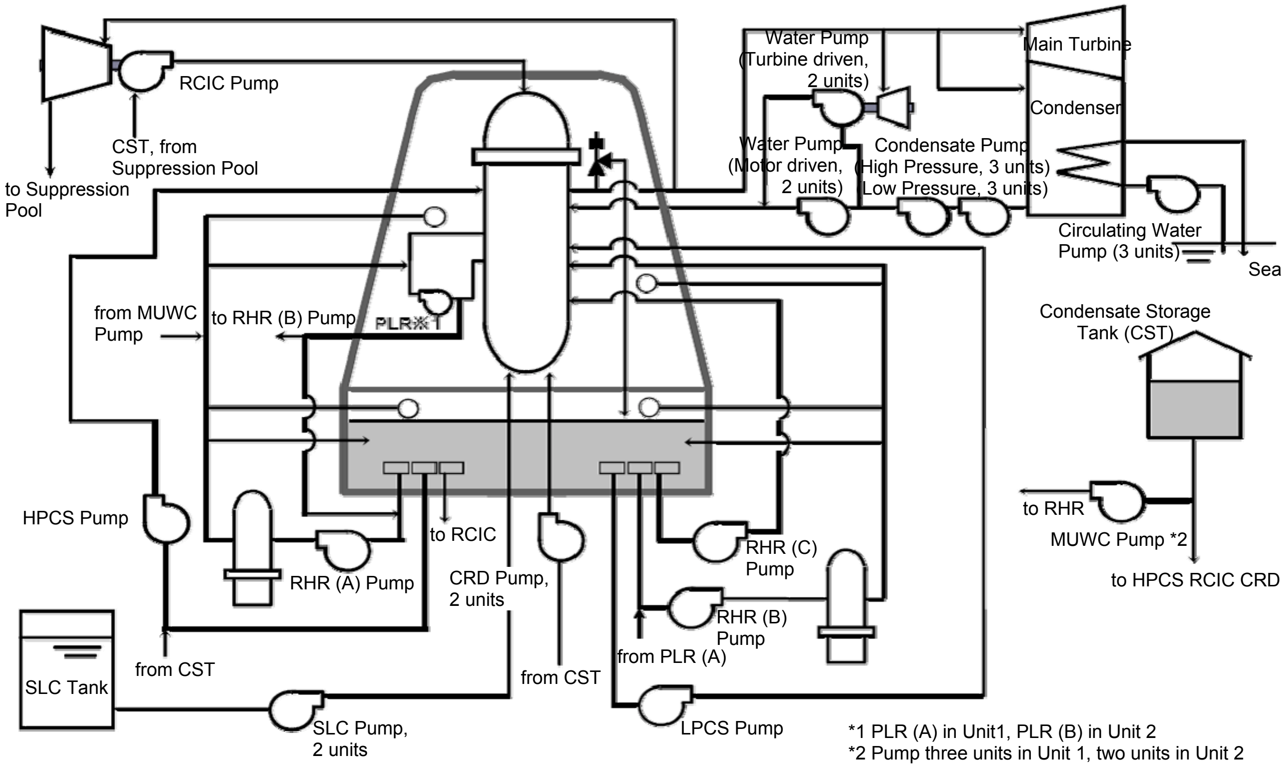


Fig 2.2-1 System configuration of Fukushima Daini Unit 1 and 2

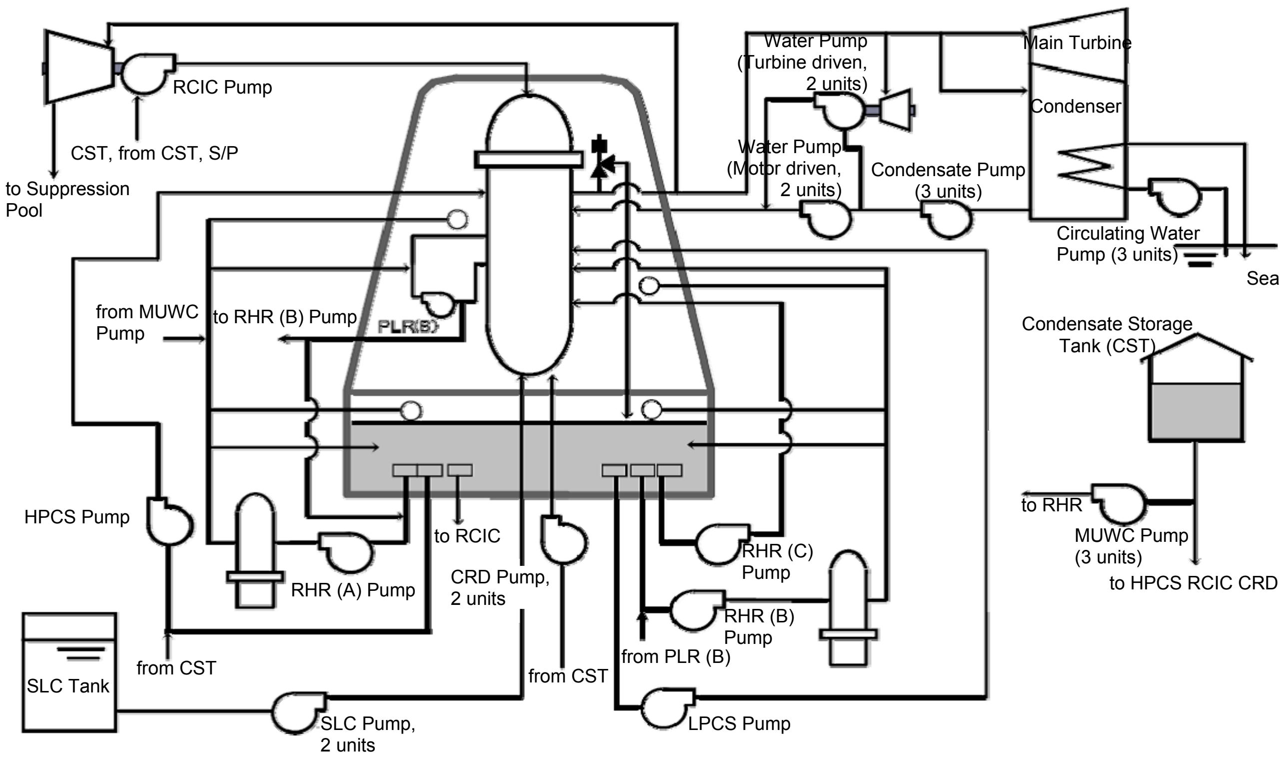


Fig 2.2-2 System configuration of Fukushima Daini Unit 3 and 4

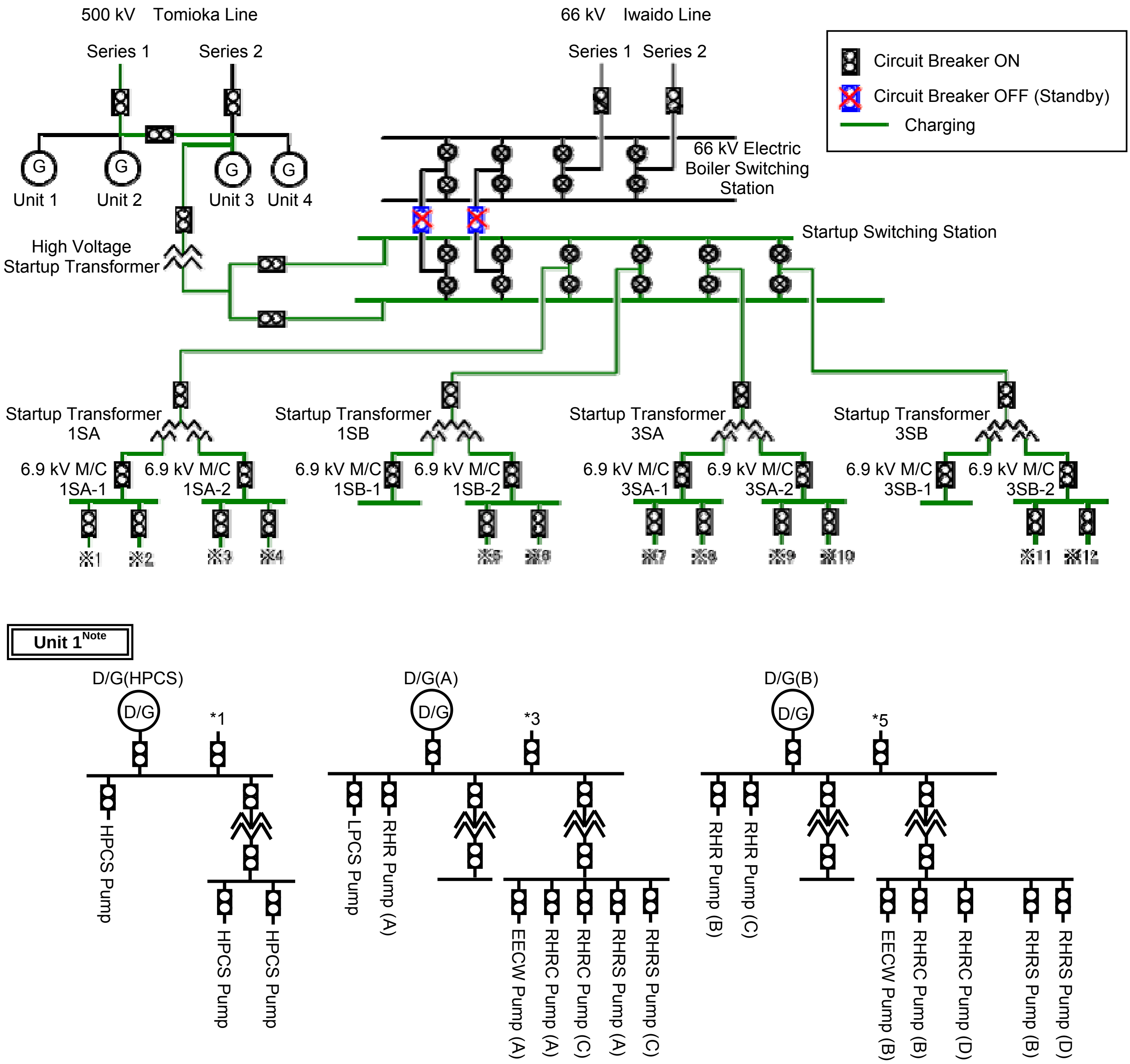
2.3 Power Supply System

The electricity generated by these units is transmitted via two 500 kV lines (Tomioka Line) to the power grid. The transmission capacity of one Tomioka line is sufficient for all the electricity generated at Fukushima Daini, and therefore the power plant can continue full output generation even in the case of failure in one transmission line.

The power plant receives the power for starting and shutting down the reactor via two Tomioka Lines as the main circuits, or via two 66 kV lines (Iwaido Line) as the backup circuit.

In the event of a blackout of these two Tomioka Lines and two Iwaido Lines, the emergency electricity to safely shut down the reactor is powered by emergency diesel generators (D/G) and D/G in the high pressure core spray system (HPCS).

The Iwaido and Tomioka lines are shared by all units.



Note : ※1,※3,※5 shall be replaced to read;

	Replace to read		
Unit 1	Unit 2	Unit 3	Unit 4
*1	*2	*7	*8
*3	*4	*9	*10
*5	*6	*11	*12

Fig 2.3-1 Power system diagram, skeleton diagram of emergency power system

2.4 Severe Accident Countermeasures; Accident Management

Table 2.4 describes Fukushima Daini's accident management.

Countermeasures are prepared to mitigate the effects in the event that the situation has expanded to a severe accident.

Table 2.4 Established Severe Accident Countermeasures

Function	Severe Accident Countermeasures
Reactor shut down	Recirculation Pump Trip (RPT)
	Alternate Rod Injection (ARI)
Water injection to reactor core and containment vessel	Alternate Water Injection (Water injection into reactor core/containment vessel by make-up water pump/fire extinguishing pump)
	Automatic Depressurization of reactor core. (Additional interlock in ADS)
Heat removal from containment vessel	Alternate heat removal (Utilization of D/W cooler/reactor coolant cleanup system)
	Restoration of damaged equipment in the residual heat removal system (Procedure)
	Hardened Vent
Support for safety functions	Power sharing (accommodation of 480 V power from the adjacent plant)
	Restoration of damaged equipment in the emergency D/G (Procedure)

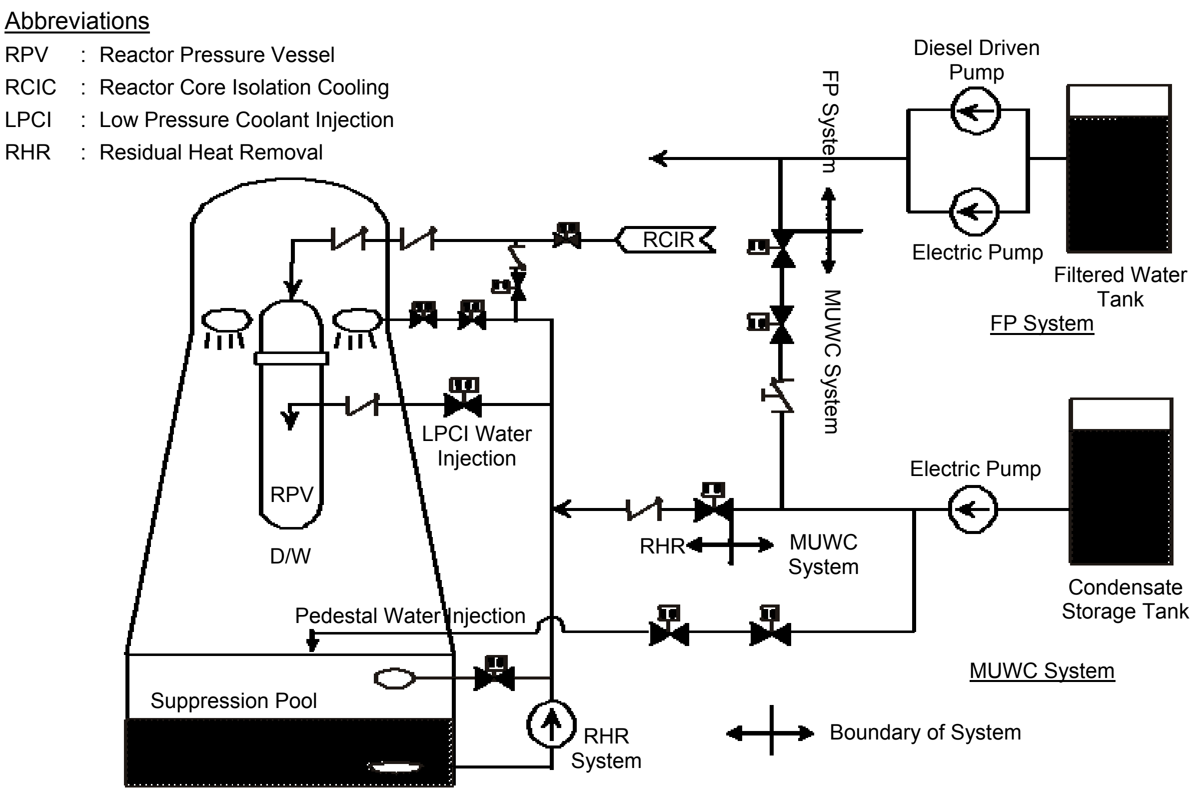


Fig 2.4-1 Alternate Water Injection

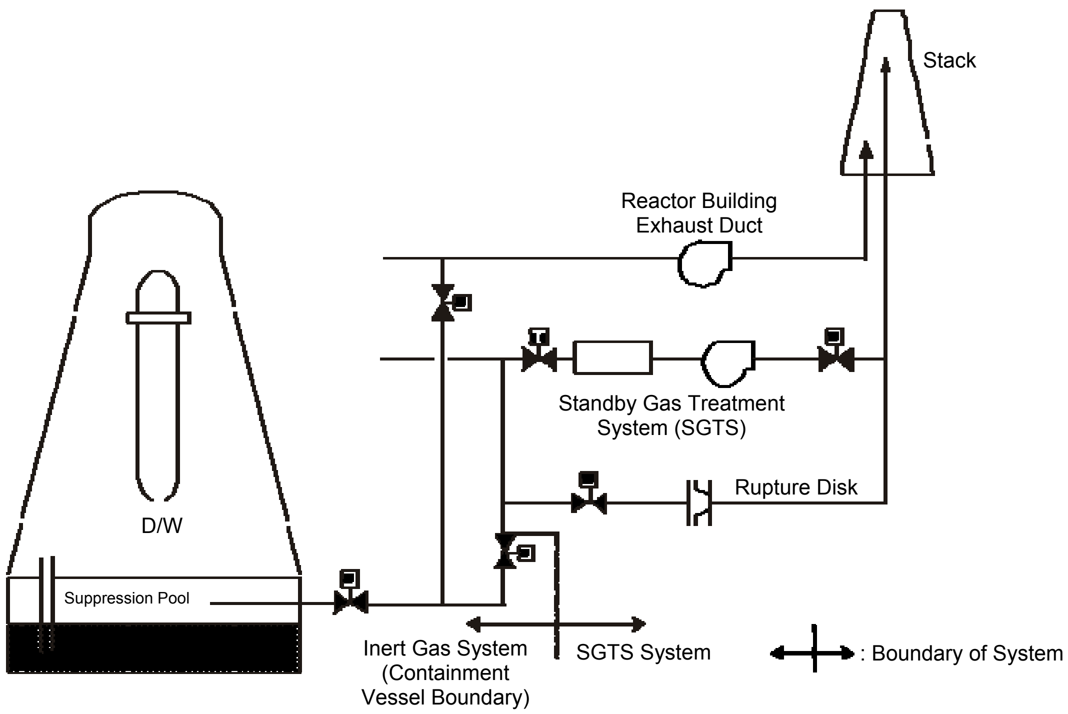


Fig 2.4-2 Hardened Vent

3. Overview of the tsunami caused by the Tohoku-Pacific Ocean Earthquake

3.1 Overview of the Earthquake and the tsunami

The Tohoku-Pacific Ocean Earthquake, which occurred on March 11, 2011, was the biggest earthquake that has ever been observed in Japan in terms of the main shock. In this earthquake, a maximum seismic intensity of 7 was observed in Kurihara City, Miyagi Prefecture.

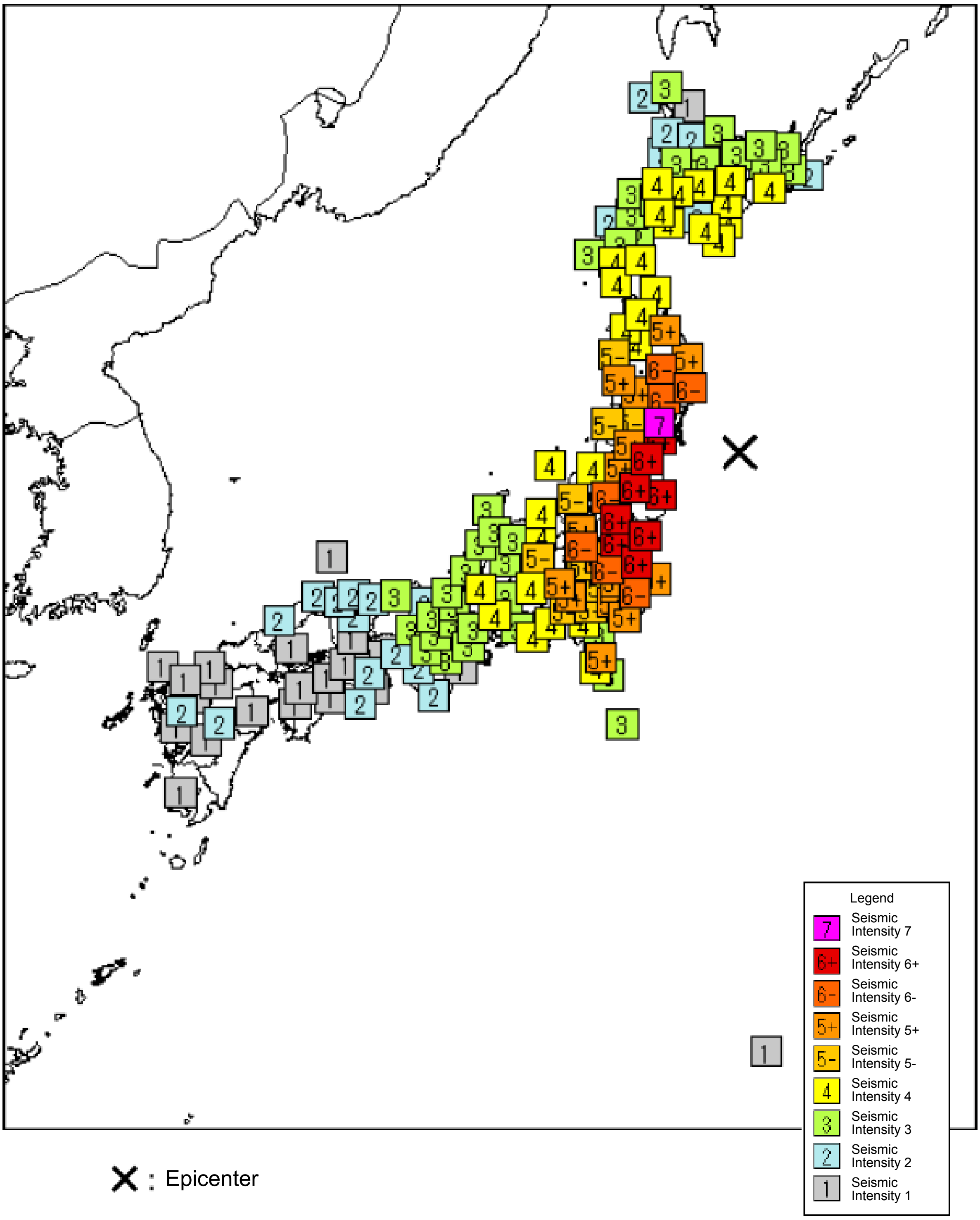
High tsunamis were observed on the coast of Pacific Ocean in Hokkaido, Tohoku, and the Kanto region.

The focal region of this earthquake ranges from offshore Iwate Prefecture to offshore Ibaraki prefecture, with a size of about 500 km in length and about 200 km in width. The length of maximum slippage was estimated at more than 50 m.

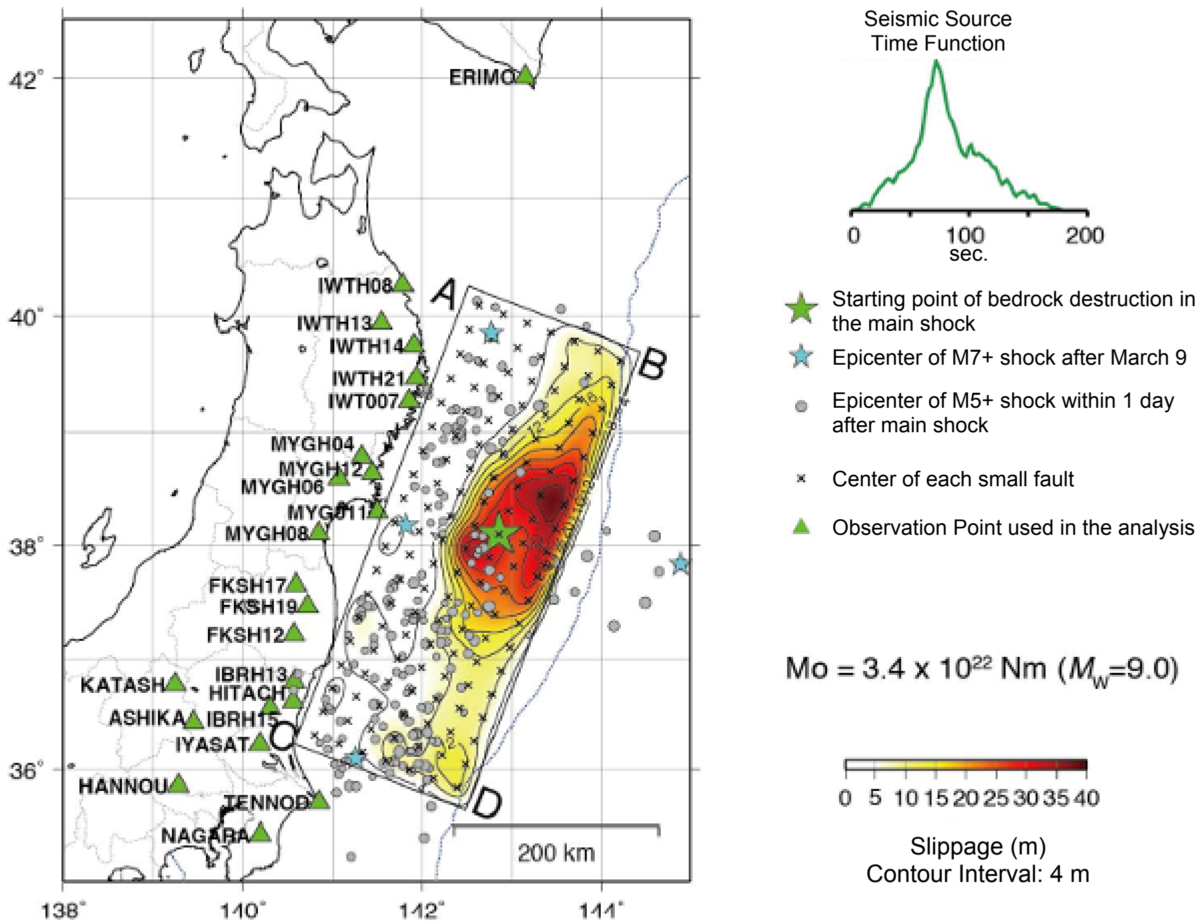
In this earthquake, several large slippages were observed in the offshore of the southern part of Sanriku near the trench, the northern part of Sanriku, and some areas off the coast of the Boso Peninsula near the trench, evidencing that multiple focal regions off the coast of central Sanriku, Miyagi, Fukushima, and Ibaraki concurrently slipped to generate a mega-earthquake of magnitude 9.0 (the fourth largest ever observed in the world). The Headquarters for Earthquake Research Promotion, a national center for the research and study of earthquakes and tsunamis, had been monitoring and evaluating the ground motion of individual regions with case records in the past, but had not assumed for the condition of quakes occurring in all of these areas in conjunction. The Expert Committee of the Central Disaster Management Council has also asserted that this enormous earthquake with a magnitude of 9.0 occurred with several source regions linking together in conjunction, which could not have been assumed from the past few hundred years of our country’s earthquake history.

The tsunami that occurred due to this earthquake and caused the most extreme devastation along the Pacific Ocean coast in the northeastern region of Japan was a magnitude 9.1 on the tsunami scale, making it the fourth largest ever observed in the world and the largest in Japan.

Earthquake off Sanriku, March 11, 2011 2:46 pm
Seismic Intensity Map

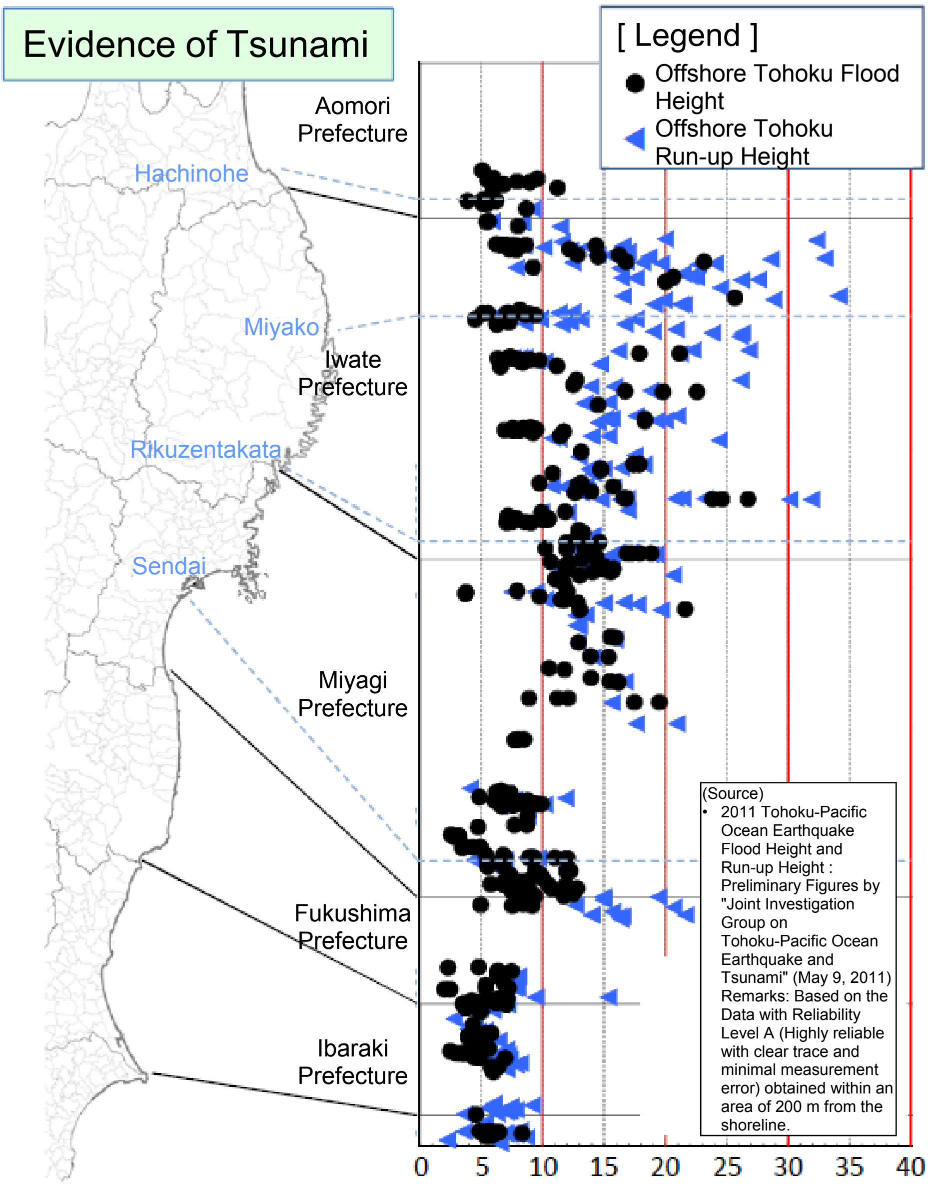


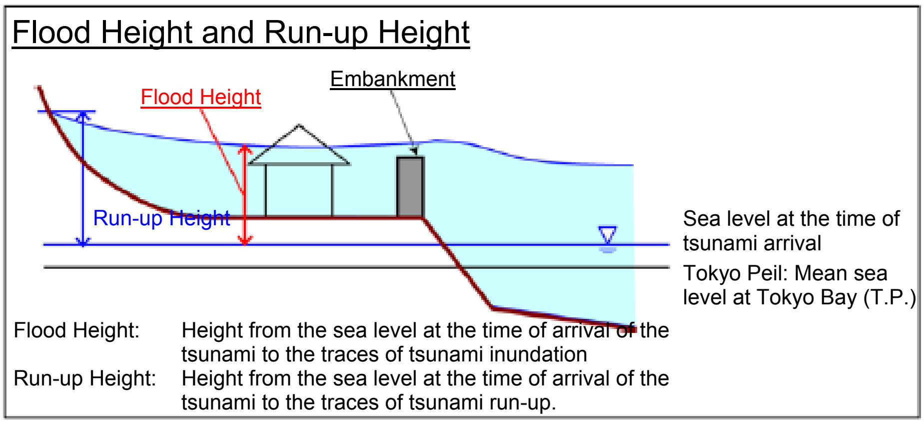
Source: Japan Meteorological Agency
(Earthquake off Sanriku, March 11, 2011 2:46 pm Seismic Intensity Map)



Source: Japan Meteorological Agency
(March 2011 Earthquake and Volcanic Activity Monthly Report)

The tsunami is thought to have occurred due to the seabed almost directly above the epicenter rising by about 3 m. The maximum height of tsunami run up above sea level was observed at nearly 35 m in northern Miyako city. The height of the flooding in the northern part of Miyako city was more than 25 m, and there were 58 km^2 of flooded areas in Iwate, 327 km^2 in Miyagi, 112 km^2 in Fukushima, and 23 km^2 in Ibaraki.





Source: Excerpt from the 1st Meeting Material by The Investigation Committee on the Countermeasures learned as Lessons from the Tohoku-Pacific Ocean Earthquake

As of July 31, 2012, the damage caused by the earthquake and the tsunami is enormous: 15,867 dead, 2,903 missing, 130,445 buildings totally destroyed, and 264,110 buildings partially destroyed.

3.2 Results of observation at Fukushima Daini

The observed values of ground motion at the foundation of the reactor building (the lowest basement floor) of Fukushima Daini was below the maximum acceleration of design earthquake ground motion Ss (the maximum acceleration observed was 305 Gal on the B2 floor of the Unit 1 reactor building), and therefore this ground motion can be considered to be within the expected range of the seismic safety evaluation of the equipment.

Furthermore, using the recorded values of ground motion at the free field obtained during the earthquake, a soil structure model was identified for the strip analysis. As a result, ground motion of the strip analysis proved to be generally at the same level as actual observations, although the calculated values exceeded the design earthquake ground motion Ss in some of the periodic bands.

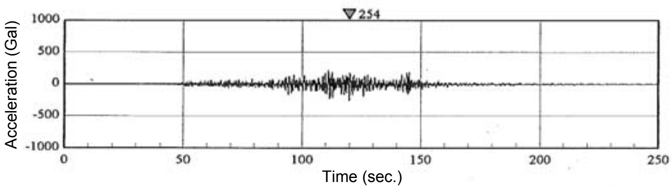


Fig. 3.2-1-1 Time History of Acceleration on the Ground Level of Reactor Building, Unit 1 (NS Direction)

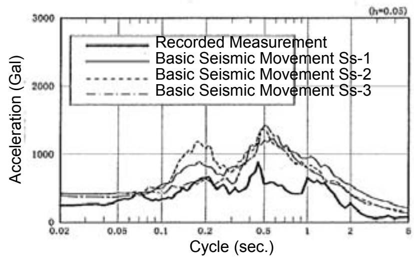


Fig. 3.2-2-1 Response Spectrum on the Ground Level of Reactor Building, Unit 1 (NS Direction)

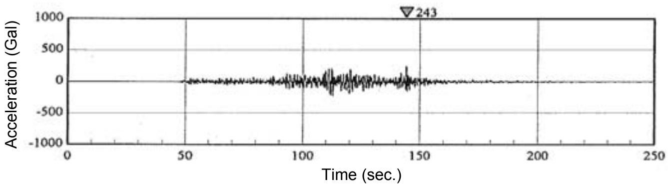


Fig. 3.2-1-2 Time History of Acceleration on the Ground Level of Reactor Building, Unit 2 (NS Direction)

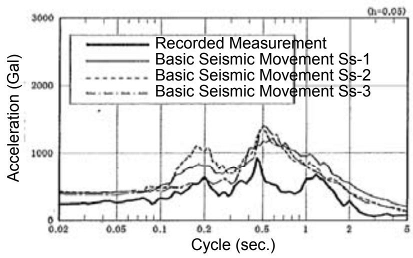


Fig. 3.2-2-2 Response Spectrum on the Ground Level of Reactor Building, Unit 2 (NS Direction)

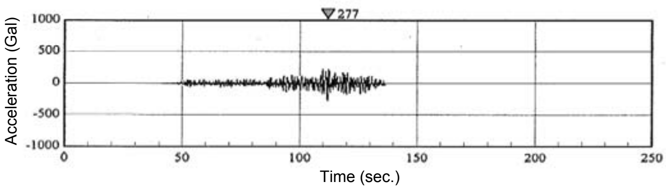


Fig. 3.2-1-3 Time History of Acceleration on the Ground Level of Reactor Building, Unit 3 (NS Direction)

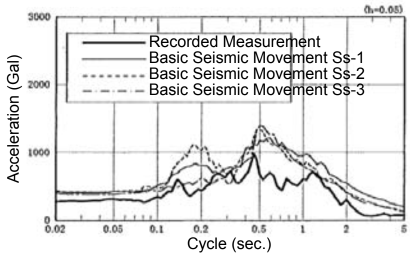


Fig. 3.2-2-3 Response Spectrum on the Ground Level of Reactor Building, Unit 3 (NS Direction)

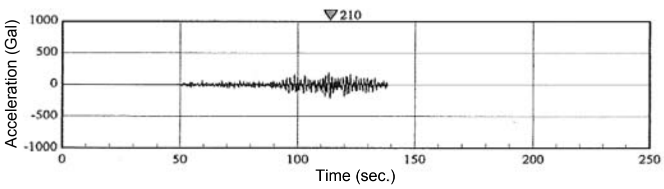


Fig. 3.2-1-4 Time History of Acceleration on the Ground Level of Reactor Building, Unit 4 (NS Direction)

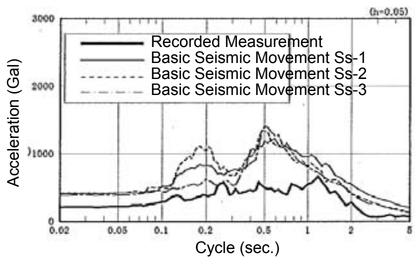


Fig. 3.2-2-4 Response Spectrum on the Ground Level of Reactor Building, Unit 4 (NS Direction)

Exemplification of larger horizontal direction in table

3.3 Data on the earthquake and subsequent tsunami

(1) Date and time of occurrence
March 11, 2011, 2:46 pm

(2) Epicenter
Off the coast of Sanriku
(38.1 N/142.9 E, 130 km ESE of Oshika Peninsula, focal depth 24 km)

(3) Magnitude
9.0

(4) Peak ground acceleration
305 Gal at B2 floor of the Unit 1 reactor building (Vertical)

(5) Distance from Fukushima Daini
183km to epicenter, 185 km to hypocenter

(6) Data on tsunami
a Inundation height
(a) Seaside area (Ground height at base level of Onahama Port Construction site (hereinafter O.P.) + 4 m)
- About +7 m*1 (flood depth about 3 m)

*1) South side of Unit 1 seawater heat exchanger building. Highest point

(b) Main building*2 area (Ground height O.P. + 12 m)*2 Reactor building and Turbine building
- O.P. about +12~+14.5 m*2 (flood depth less than 2.5 m)

*2) Between the area south of Unit 1 Main building and the important seismic isolation building.
Locally O.P. about+15~+16 m (flood depth about 3-4 m)

b Flooded area
The flooded area extended across the entire seaside area, but no entry of tsunami seawater into the main building area beyond the slope from the seaside area was observed. The tsunami run up was mostly from the southeast side of the main building area toward the road leading to the important seismic isolation building. As a result, flooding was limited only to the area surrounding the Unit 1 and 2 buildings and the south side of the Unit 3 building (no flooding around the Unit 4 building).

(7) Arrival of the first wave of the tsunami
March 11, 2011 3:22 pm Visual sighting)

3.4 Damage of Equipment

3.4.1 Damage by the earthquake

The external power supply of Fukushima Daini consists of a total of four lines: 500 kV of Tomioka 1L and 2L and 66kV of Iwaido 1L and 2L, all from the Shin Fukushima substation. On the day of the earthquake, however, Iwaido 1L was out of service for inspection and only three lines were available.

After the earthquake, Tomioka 2L went out of service at around 2:48 pm on March 11 due to damage to the breakers at the Shin Fukushima substation. After the earthquake, patrol inspection of facilities found damage at the arrester of Iwaido 2L, so after confirming that Tomioka 1L was continuously receiving all the power necessary for the station, Iwaido 2L was put out of service for restoration works in order to prevent the damage from spreading further.

As a result, after the earthquake, the external power supply was only available from a single line for the time being. However, Iwaido 2L resumed service at 1:38 pm on the next day, March 12, and Iwaido 1L was also revived at 5:15 am on March 13 after temporary restoration, giving the receiving configuration three lines.

Maintaining the external power through this single transmission line made it possible to supply power to the available facilities, contributing a great deal to preventing the spread of the accident, and led to early convergence. All the equipment such as circuit breakers, etc. at the substation and switching stations has basically the same specifications as at Fukushima Daiichi.

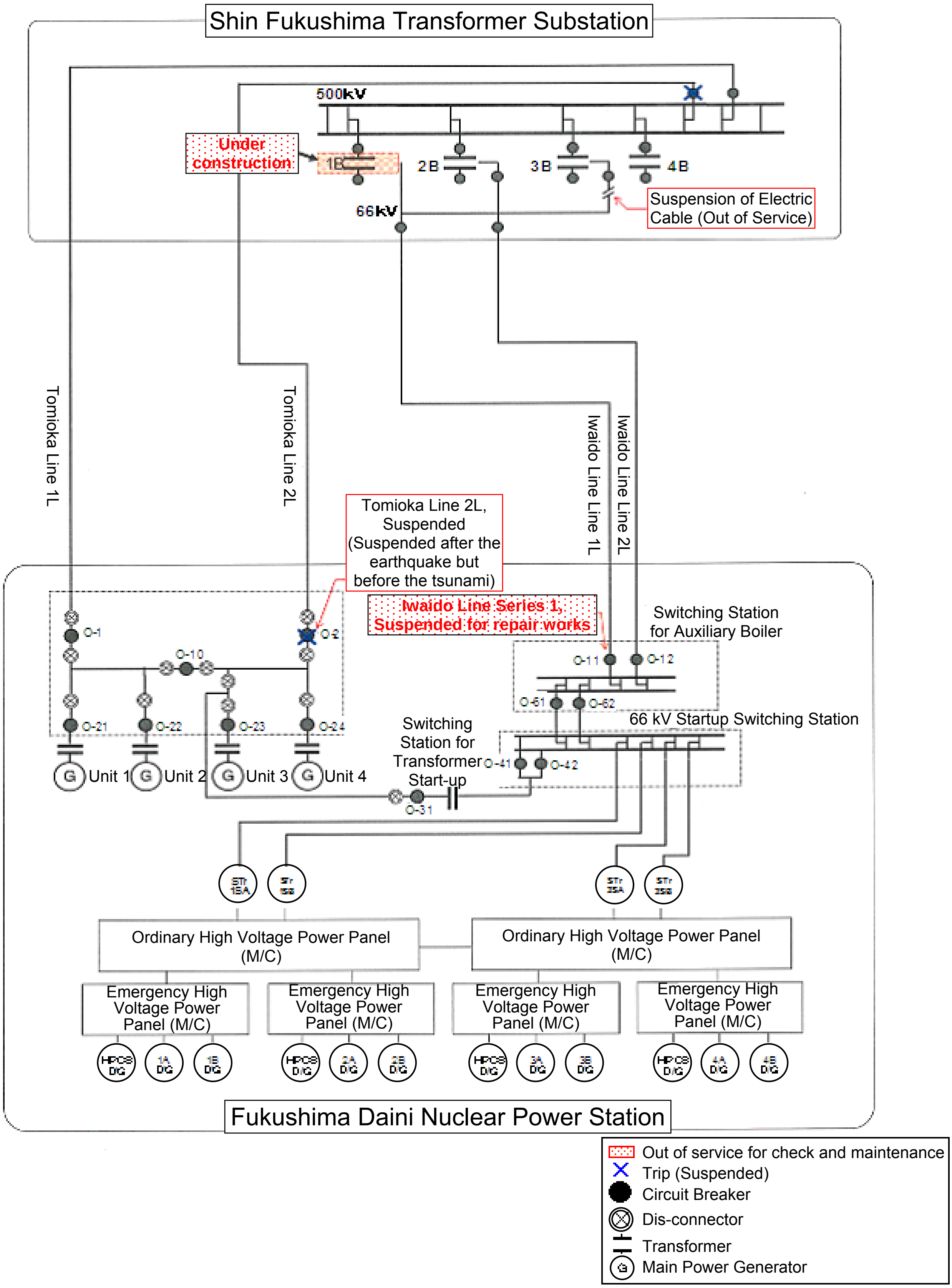


Fig 3.4.1-1 Fukushima Daini Outline Diagram of External Power Supply

3.4.2 Damage by the tsunami

(1) Entry of flood water into Main building (Ref: Fig 3.4.2-1, 3.4.2-2)

Inundation surrounding the main buildings of Fukushima Daini (reactor building and turbine building; Ground Level OP +12 m) was not significantly deep, with the exception of intensive run up on the south side of Unit 1.

Intensive tsunami run up entered the Unit 1 building through the openings at ground level located on the south side of the reactor building (air intake louver for the emergency D/G, equipment hatch on the ground level) which flooded the reactor building (annex building) and caused the loss of function of all three units of emergency D/G, emergency power supply (for the C system and high pressure core spray system).

The depth of run up around Unit 2 through Unit 4 was not significant, and thus flooding into the reactor buildings or turbine buildings through the openings at ground level was not detected. However, flooding was confirmed in the basement of the reactor building of Unit 3 (Annex) and the basements of turbine buildings Unit 1 through Unit 3. It is thought that tsunami inundation entered the buildings through the cables and pipes leading to the underground trenches and ducts.

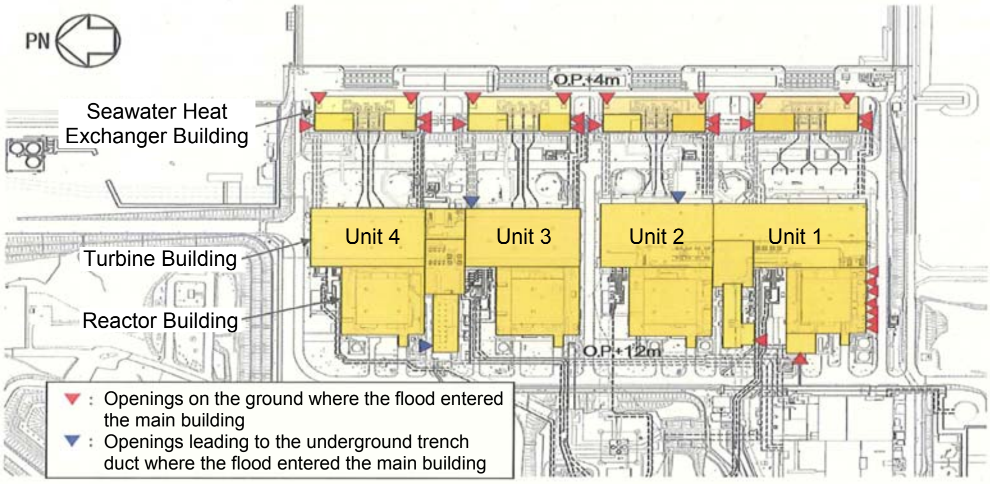


Fig 3.4.2-1 Openings of flood entrance into the main building

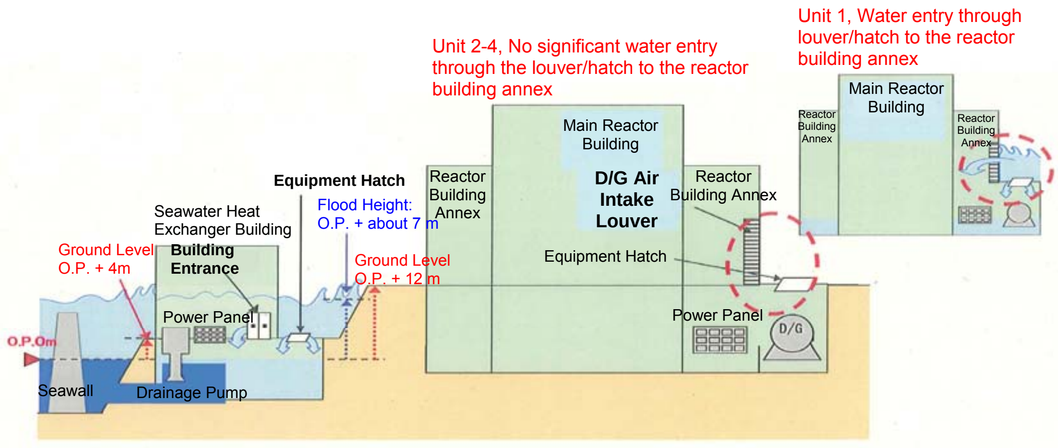


Fig 3.4.2-2 Flow path of flood to the main buildings of Fukushima Daini

Table 3.4.2-1 Location of D/G and damages thereto

		Unit 1	Unit 2	Unit 3	Unit 4
Height of tsunami[*1]		About +9 m			
Ground Level		O.P.+12 m			
Flood depth around main buildings [Inundation Height]		Less than 2.5 m (nearly zero except around Unit 1) [O.P .about+12 m~+14.5 m] [*2]			
Building where D/G is installed [Floor]	A	Reactor Bldg. Annex [B2F]	Reactor Bldg. Annex [B2F]	Reactor Bldg. Annex [B2F]	Reactor Bldg. Annex [B2F]
	B	Reactor Bldg. Annex [B2F]	Reactor Bldg. Annex [B2F]	Reactor Bldg. Annex [B2F]	Reactor Bldg. Annex [B2F]
	H	Reactor Bldg. Annex [B2F]	Reactor Bldg. Annex [B2F]	Reactor Bldg. Annex [B2F]	Reactor Bldg. Annex [B2F]

□:D/G unit flooded
□:D/G unit not flooded

*1 Estimate at tide station. Actual measurement unknown because of instrument damage.

*2 Locally about OP+15 – 16 m [flood depth about 3 – 4 m] in the area between the south side of the Unit 1 main building and the important quake proof building.

(2) Damage situation

Among the equipment for reactor cooling that was also damaged by the tsunami, the damage situation of the facilities that clearly show characteristics of equipment damage caused by the recent tsunami is explained as below.(Please refer to Table 3.4.2-2.)

① Emergency equipment cooling pump

Units 1 through 4 use seawater to remove decay heat from the reactor. The emergency D/G unit also uses seawater to cool its engine. Therefore, the pumps for the emergency equipment cooling water system (the seawater intake pump and the fresh water cooling pump sourced from seawater) are installed in the seaside area. These pumps are installed in the seawater heat exchanger building. The purpose of the overall layout in which seawater is not sent directly to the reactor building but to the intermediate seawater heat exchanger building, which is not a radiation control area, where a freshwater loop is installed with a heat exchanger and cooling pump for auxiliary equipment constituting an independent set of equipment cooling facilities, is to prevent seawater from mixing with reactor water and to improve maintenance works. The pumps for the emergency equipment cooling water system are specified for outdoor use, but they were installed indoors in the heat exchanger building as part of the independent set of equipment cooling facilities. The ground level of the seaside area where the pumps for the emergency equipment cooling water system are installed had OP +4 m elevation, and its precautionary measures ensured safety against a tsunami height of 5.1 - 5.2 m, based on the tsunami height evaluation results in 2002 provided by the Japan Society of Civil Engineers “Tsunami Evaluation Technology”. However, this tsunami greatly exceeded expectations, and the motors of the pumps were submerged under the water and the system lost function. The pumps for the emergency equipment cooling water system at Fukushima Daini were housed in the seawater heat exchanger buildings. The area surrounding the buildings was inundated to a depth of 3 m by the tsunami, and while there was no damage to the building structures, all the seawater heat exchanger buildings were flooded by seawater through the damaged doors and other openings on ground level. As a result, the power panels and the motor of the pumps were submerged underwater and the total of eight emergency equipment cooling water systems lost function except for one system of Unit 3. In addition, the cooling system of the three D/G units, A, B and H installed for each reactor Unit also lost all function except for three systems: B and H of Unit 3 and H of Unit 4.

② Power panel

The scale of the tsunami at Fukushima Daini was different from that at Fukushima Daiichi, and inundation of the main building was also different. Accordingly, the situations of power panel damage also differ as a result.

The Reactor building of Unit 1 (Annex), which was flooded by the tsunami, saw inundation on the emergency power panels of the C and H systems, but the D system power panel was not flooded and all the power panels of other reactor Units were free of damage. Due to this situation, it was possible to distribute electric power received from outside sources to various pieces of equipment through these emergency circuits, making it possible to use the necessary facilities to cope with the emergency situation (distribution through Normal A and B2, Emergency C and D2, and high pressure core spray system H). On the other hand, the power panels in the seawater heat exchanger buildings located in the seaside area were all submerged in the tsunami because of flooding in the buildings, and seven power panels lost function, with the exception of one low voltage power panel (P/C) situated in the seawater heat exchanger building of Unit 3.

Therefore, the residual heat removal seawater system lost function except for one system of Unit 3 out of the total of eight.

Table 3.4.2-2 Damage situation of the cooling pumps for emergency equipment and emergency P/C located in the seawater heat exchanger buildings after the tsunami

○ Usable △ Out of service due to flooding of Power Panel
× Out of service due to flooding of Power Panel and Motor

Seawater Pump (RHRC, RHRS and LLCW)

Location of Installation	Unit 1		Unit 2		Unit 3		Unit 4	
	North side	South side	North side	South side	North side	South side	North side	South side
2nd Floor			△ RHRC(A) △ RHRC(C)	△ RHRC(B) △ RHRC(D) △ EECW(B)				△ EECW(B)
Ground Floor	△ RHRS(B) △ RHRS(D) × RHRC(B) × RHRC(D) × EECW(B)	△ RHRS(A) △ RHRS(C) × RHRC(A) × RHRC(C) × EECW(A)	× RHRS(A) × RHRS(C) × EECW(A)	△ RHRS(B) × RHRS(D)	△ RHRS(A) △ RHRS(C) × RHRC(A) × RHRC(C) × EECW(A)	○ RHRS(B) ○ RHRS(D) ○ RHRC(B) ○ RHRC(D) ○ EECW(B)	× RHRS(A) × RHRS(C) × RHRC(A) × RHRC(C) × EECW(A)	× RHRS(B) △ RHRS(D) × RHRC(B) × RHRC(D)

Emergency P/C

○ Usable
× Out of service due to flooding

Location of Installation	Unit 1		Unit 2		Unit 3		Unit 4	
	North side	South side	North side	South side	North side	South side	North side	South side
Ground Floor	× P/C1D-2	× P/C1C-2	× P/C2C-2	× P/C2D-2	× P/C3C-2	○ P/C3D-2	× P/C4C-2	× P/C4D-2

③ Emergency Diesel Generator

In the Fukushima Daini power station, each reactor Unit has three (A, B, H) emergency diesel generators (hereinafter referred to as "emergency D/G"). Unit 1 lost all three emergency D/Gs because the tsunami had entered the reactor building (Annex) through the opening at the ground level. Some of the emergency D/Gs which were able to avoid the flooding still lost function because of the loss of diesel engine cooling due to the flooding of the power panel and the pump motor for the cooling system. The cooling system of the emergency D/G was lost for most of the systems except for three: B and H of Unit 3 and H of Unit 4. As a result, nine D/Gs lost function: A, B and H of Unit 1, A, B and H of Unit 2, A of Unit 3 as well as A and B of Unit 4.

However, Fukushima Daini had a continuous supply of electric power from the external sources and there was no need to activate such surviving emergency D/G after all.

④ Situation of other outdoor damage

In the Fukushima Daini power station area, no major equipment and/or structure was observed being washed up by the tsunami to the main building area (elevation OP +12 m).

However, five cases of openings/holes caused by the tsunami washing away or damaging the lid of the hatch duct in the main building area have been reported.

Source;

Tokyo Electric Power Company

The impact of Tohoku-Chihou Taiheiyo-Oki Earthquake to Nuclear Reactor Facilities at Fukushima Daini Nuclear Power Station (May 9, 2012)

Fukushima Nuclear Accident Analysis Report (June 20, 2012)

Investigation Committee on the Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company

Final Report (July 23, 2012)

4. Response to the accident at Fukushima Daini

The status of the accident at Fukushima Daini has already been reported in detail in the reports of TEPCO and the Investigation Committee of the Government. Therefore, this report puts the emphasis on describing the situation, including points of suggestion in considering the lessons learned, and giving a brief overview of the other points.

Fig 4-1 shows the operational status of the responses of Units 1 through 4, and Figs 4-2 to 4-5 show the operational status of each Unit in conjunction with the changes in the main parameters of each Unit.

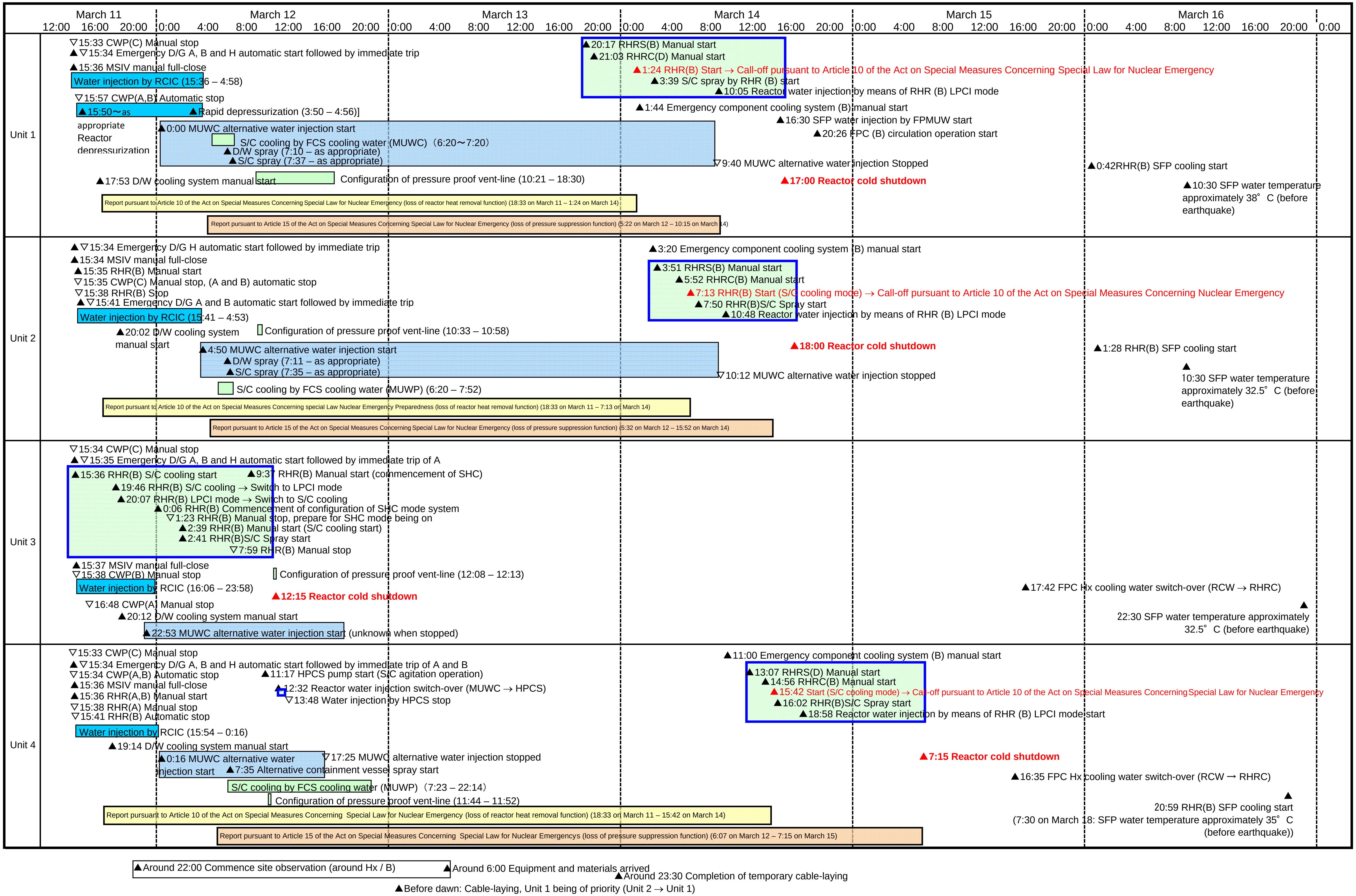


Chart 4-1: Situation of action in response to the Unit 1 – Unit 4 accident

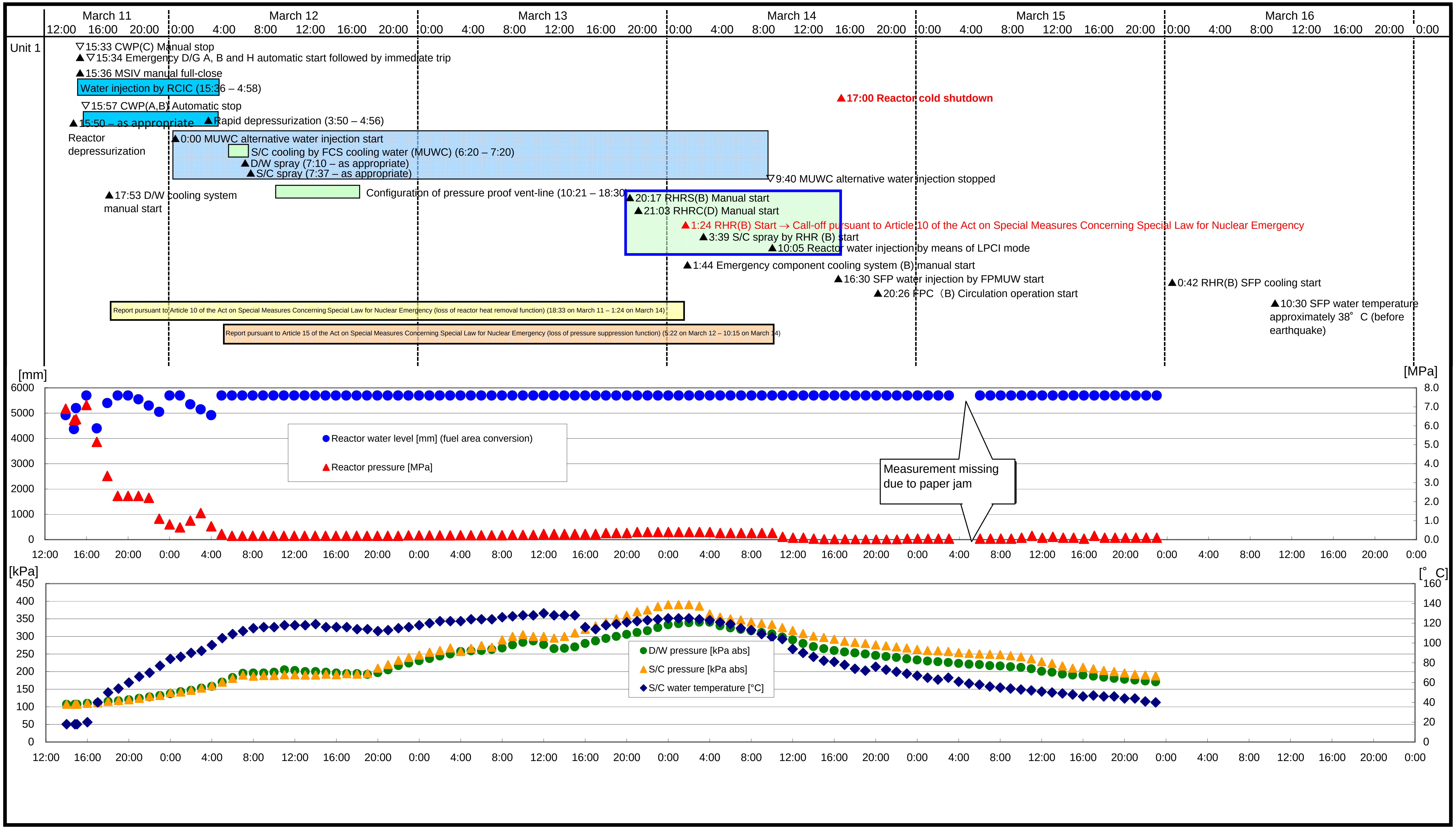


Chart 4-2: Situation of action in response to accident and plant parameter of Unit 1

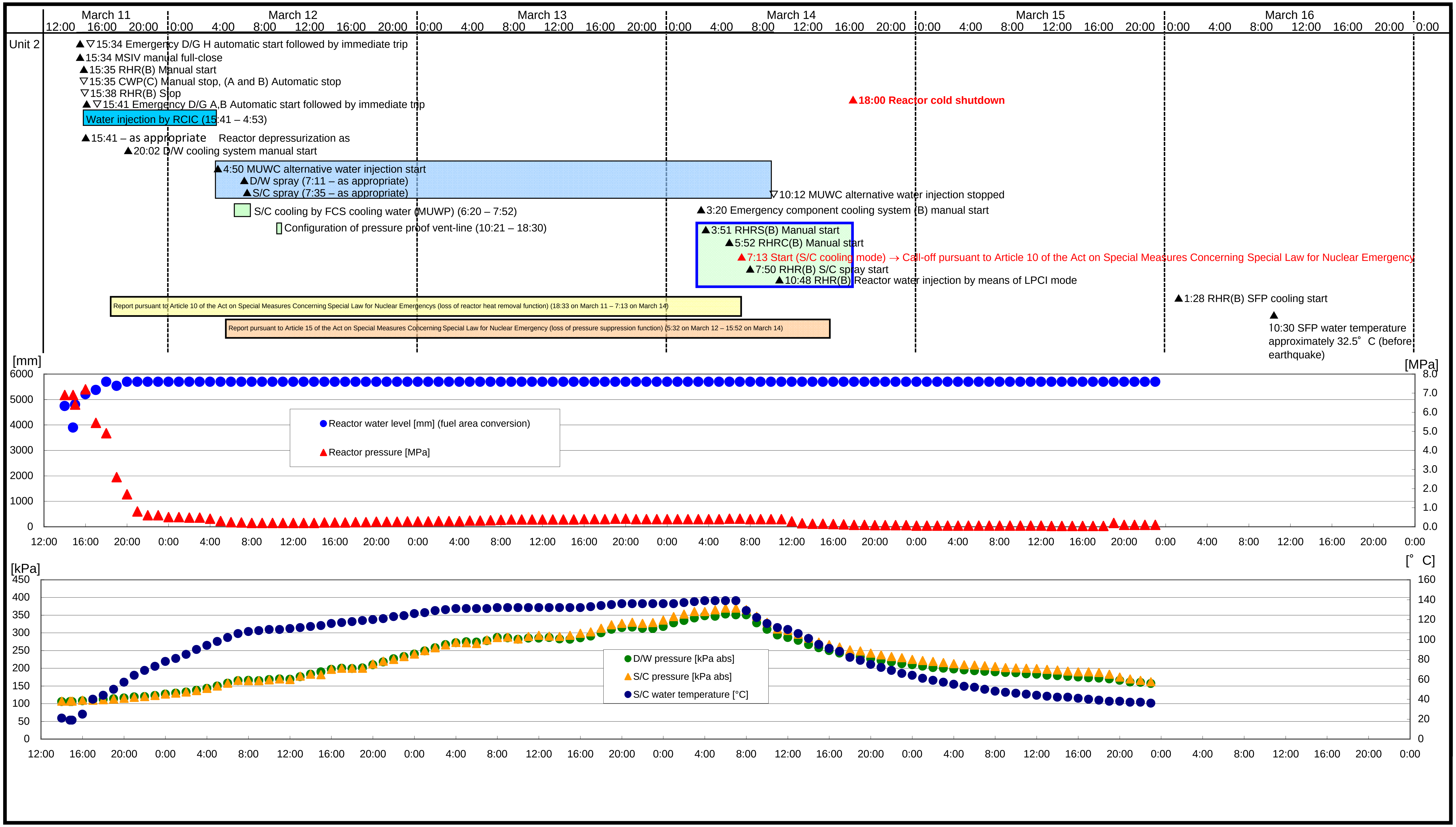


Chart 4-3: Situation of action in response to accident and plant parameter of Unit 2

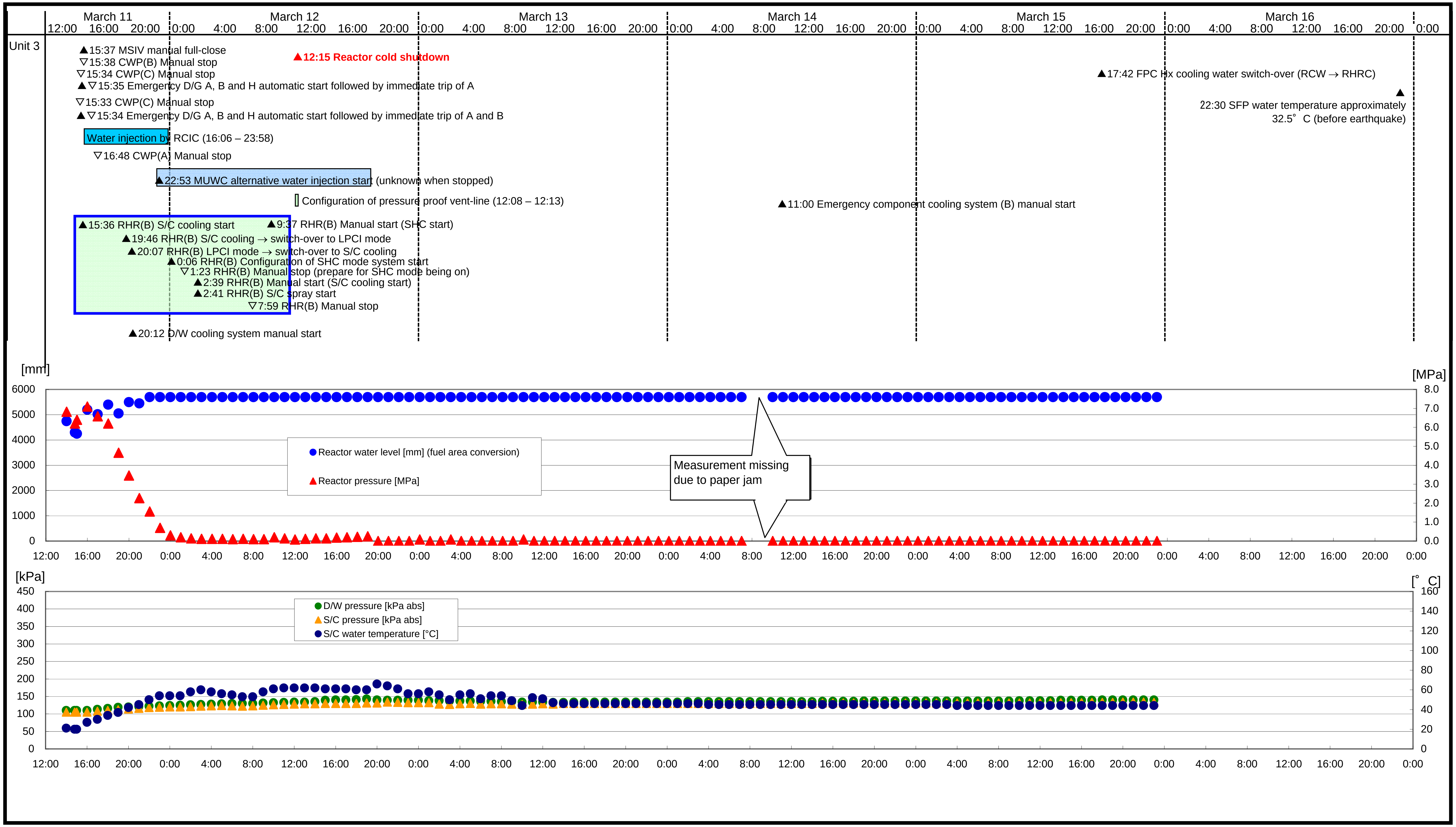


Chart 4-4: Situation of action in response to accident and plant parameter of Unit 3

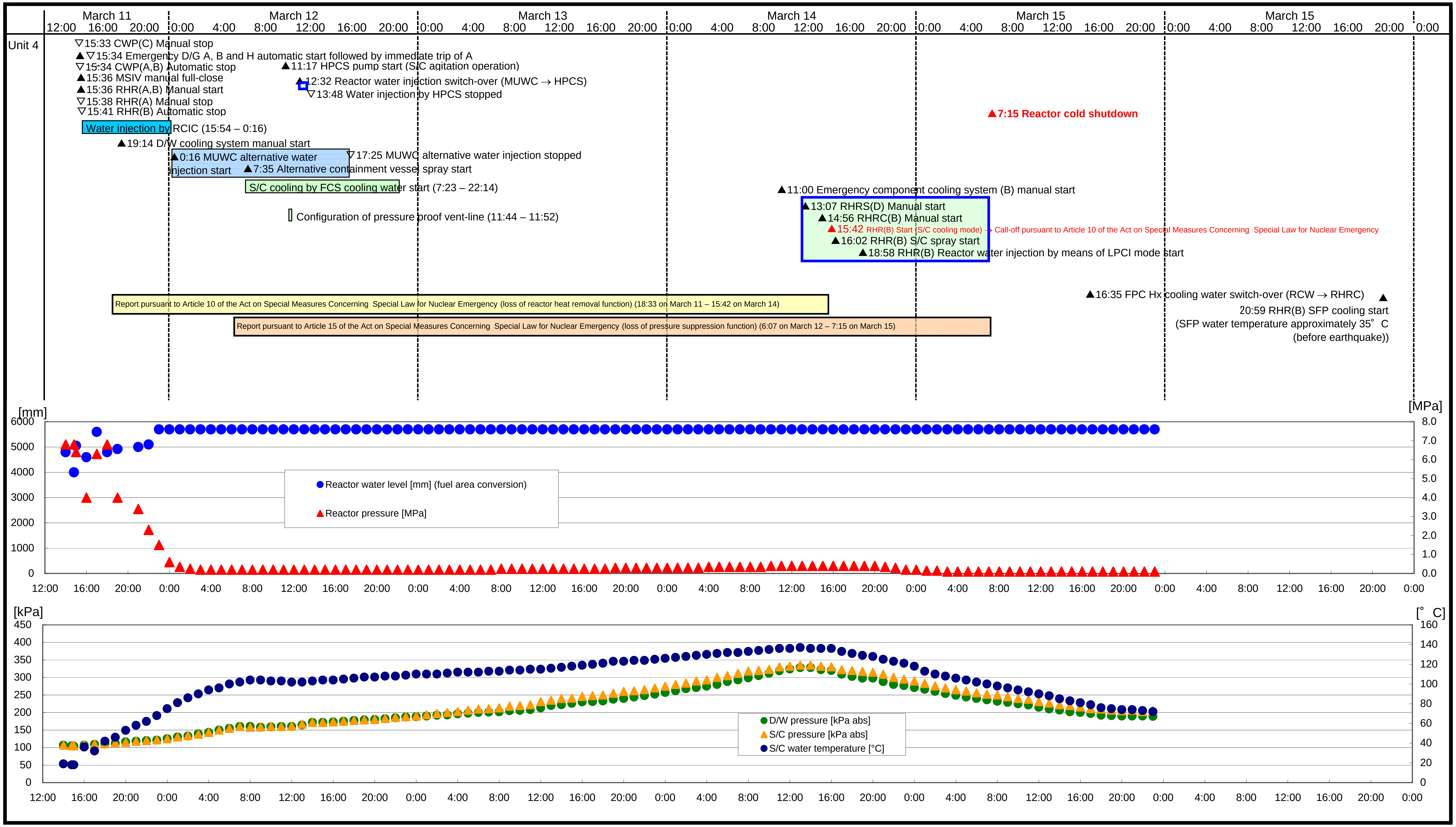


Chart 4-5: Situation of action in response to accident and plant parameter of Unit 4

4.1 Response status from the time of the earthquake and tsunami until restoration and cold shutdown

Just before the earthquake, all Units 1 through 4 were in operation at the rated power. All control rods were fully inserted by the automatic scram signal triggered by the earthquake, and all reactors shut down automatically. In this way, the water level in the reactor was lowered to "(L-3) low reactor water level," but the normal level was recovered without reaching the level which would automatically activate the emergency core cooling system by supplying water from the reactor feedwater system. Further, as designed, the "(L-3) reactor water level low" automatically activated the containment vessel isolation system and the emergency gas treatment system, and isolation of the containment vessel and negative pressure of the reactor building were achieved.

After the entry of the tsunami, the main condenser could not be used as a heat sink, so the main steam isolation valve was fully closed manually (core isolation) and reactor pressure was controlled by the main steam safety relief valve. In this operation, in accordance with the core isolation operating procedures (when the main steam isolation valve is closed), the reactor core isolation cooling system (hereinafter referred to as "RCIC") was manually started up in order to control the water level of the reactor by repeating automatic shutdown and manual start up based on the water level.

The entry of the tsunami caused part of the emergency core cooling system to become unusable due to the flooding of the pump motor and power source in the seawater system. Water was injected to the core by RCIC and the main steam safety relief valve was opened to depressurize the reactor core in order to maintain the alternate water injection (application of Accident Management (AM) procedure) via the condensate water makeup system (hereinafter referred to as "MUWC"). Before switching over to MUWC, it was confirmed that water injection via MUWC to the reactor core would be possible with RCIC in operation. The water temperature of the S/C rose. Therefore, water was injected to the S/C using the drain line in the water cooler of the combustible gas control system to cool down the containment vessel, together with dry well spray and S/C spray. This dry well spray was executed at the discretion of the Director at the power plant.

The equipment at the south area of the heat exchanger building of Unit 3 was not flooded, and so the emergency D/G and the residual heat removal system remained operative. Therefore, Unit 3 was able to achieve cold shutdown using the cooling system that is used in normal reactor shutdown cooling mode.

An external power supply was available through Tomioka 1L and a number of operations, and monitoring of major parameters were possible at the central control room with little damage on transformers and power panel, making the emergency responses quick and resulting in early convergence. Expeditious recovery was tried on the damaged line before it was lost; Iwaido 2L recovered at 1:38 pm on the 12th, and Iwaido 1L recovered at 5:15 am on the 13th. It was fortunate that the plant was able to use Tomioka IL continuously from the very beginning without power outage. This situation made it possible to respond to the accident appropriately and prevented the expansion of the accident.

The development of AM measures such as the use of MUWC contributed significantly to the convergence of the accident at Fukushima Daini. Also, as another AM measure which would have been quickly available if the accident situation had rapidly deteriorated, a containment vent facility was prepared and available, although it was ultimately not used because of the swift convergence of the accident. When a report was sent to the national and local governments in accordance with Article 10 of the Nuclear Disaster Special Measures Law (hereinafter referred to as "Nuclear Emergency Law"), TEPCO explained that they were preparing to implement a vent from the containment vessel.

In parallel with the response operations described above, the plant’s emergency headquarters (hereinafter referred to as "Headquarters") made a thorough check of the damage at the site, ensured the supply of necessary equipment for restoration (motors, high-voltage power supply cars, transformers, cables, etc.) in consultation with the emergency headquarters at the head office and developed a recovery plan for the residual heat removal system, taking into account the priority.

Upon the arrival of the recovery equipment, power cables were installed and pump motors were replaced simultaneously, and the pumps for the residual heat removal system were put in motion within two or three days after the entry of the tsunami.

As a result of the residual heat removal system starting up, all the Units had access to cooling by S/C and the usual reactor cooling water, which ensured the cold shutdown of all reactors.

About two days after cold shutdown, Units 1, 2, and 4 experienced a tendency of rising hydrogen concentration in the containment vessel. However, the operation of the flammable gas control system successfully suppressed the hydrogen concentration below the level at which a mix of hydrogen and oxygen concentration becomes flammable, and there was no danger of a hydrogen explosion. It is theorized that the hydrogen was generated by chemical reactions of zinc and aluminum in the containment vessel.

4.2 Emergency response situation

4.2.1 Immediately after the earthquake

As a result of the big earthquake and the scram of the plant, an emergency situation was declared and key members of the emergency disaster management system assembled immediately at the Headquarters in the important seismically isolated building. The manual calls for seven teams and 250 personnel in the emergency disaster countermeasures organization. (See Fig 4.2.1-1.) Because it was a weekday afternoon, there were approximately 400 engineering staff on duty in the plant office and all of them were incorporated into the emergency disaster management system. All of these employees stayed in the Headquarters or in the office and engaged in accident response in rotation in accordance with their physical capabilities until the morning of March 15, when the reactors were brought to cold shutdown and the situation calmed down to some extent.

As from around 8 pm on the 11^{th} when the tsunami situation subsided, the site patrol had started to check the status of the equipment. Various works requiring much manpower continued thereafter: draining water from the building, laying cables for restoration, deploying vehicles to ensure a landing site for helicopters bringing relief supplies, and transportation of goods, etc.

The operators in the central control room were engaged in plant control and monitoring accident responses in a normal rotational shift. The central control rooms of Fukushima Daini, as a twin plant system, are each shared by two Units: Units 1 and 2, and Units 3 and 4, respectively. Each control room has one shift supervisor, one deputy s/v, two foremen, one deputy foreman, two main system operators, and three sub system operators, totaling 10 persons per shift.

In addition, a part of about 1,900 employees of cooperating companies who were present in the plant at the time were also involved in the recovery efforts.

With regard to TEPCO employees, a contact network for mobilization at night or on holidays had been established, and a special contact person was assigned to mobilize the employees of cooperative enterprises. Therefore, if this accident had happened at night or on a holiday, these network channels would have been used for the mobilization of manpower. However, when mobilizing at night or on a holiday, it takes substantially longer for people to convene than with an immediate input of manpower like there was this time, meaning that the initial response to the accident could not have been as quick or smooth as it was this time.

The Headquarters dispatched an experienced operator each as a contact courier to both of the central control rooms for Units 1/2 and Units 3/4 to provide a variety of information to the Headquarters and also to transmit instructions from the Headquarters to the control rooms. Dispatching such operators is not a procedure prescribed in the manual, but it was put into practice between the teams to define their roles and responsibilities, especially in the case of troubleshooting.

Contact with the local government was maintained using the direct lease line and the satellite phones of the power plant when ordinary telephone and FAX lines were interrupted because of the disruptions of communication lines.

As long as the power supply to the Headquarters was online, contact with the head office was possible via PHS and video conference for effective information sharing. This video conference system was also connected with Kashiwazaki-Kariwa Nuclear Power Station (hereinafter referred to as "Kashiwazaki-Kariwa"), which was able to join the video conference at the same time.

Despite the severity of the earthquake tremors, nobody at the plant office had suffered injuries and so initial response was started right away, thanks to the practical countermeasures as a reflection of the lessons of the Chuetsu-oki Earthquake, such as thorough works to prevent cabinets from tipping. The central control room has a grip bar attached to the control panel, also as a reflection of such lessons, so that the operator can hold onto the grip during tremors and keep their eyes on the panel and continue operation, which proved to be effective in this earthquake. Thanks to day-to-day efforts for preparedness, the main control room did not experience any disruption or interference from the movement of large objects due to the quake.

Of the documents and drawings needed for restoration works, the materials prescribed in the disaster plan, such as P&ID, were stored in the important seismically isolated building. Other drawings, such as those of individual hardware like valves and pumps, were retrieved from the library of the main office building. Since the library was free from earthquake and tsunami damage, there were no problems in the search for these reference materials.

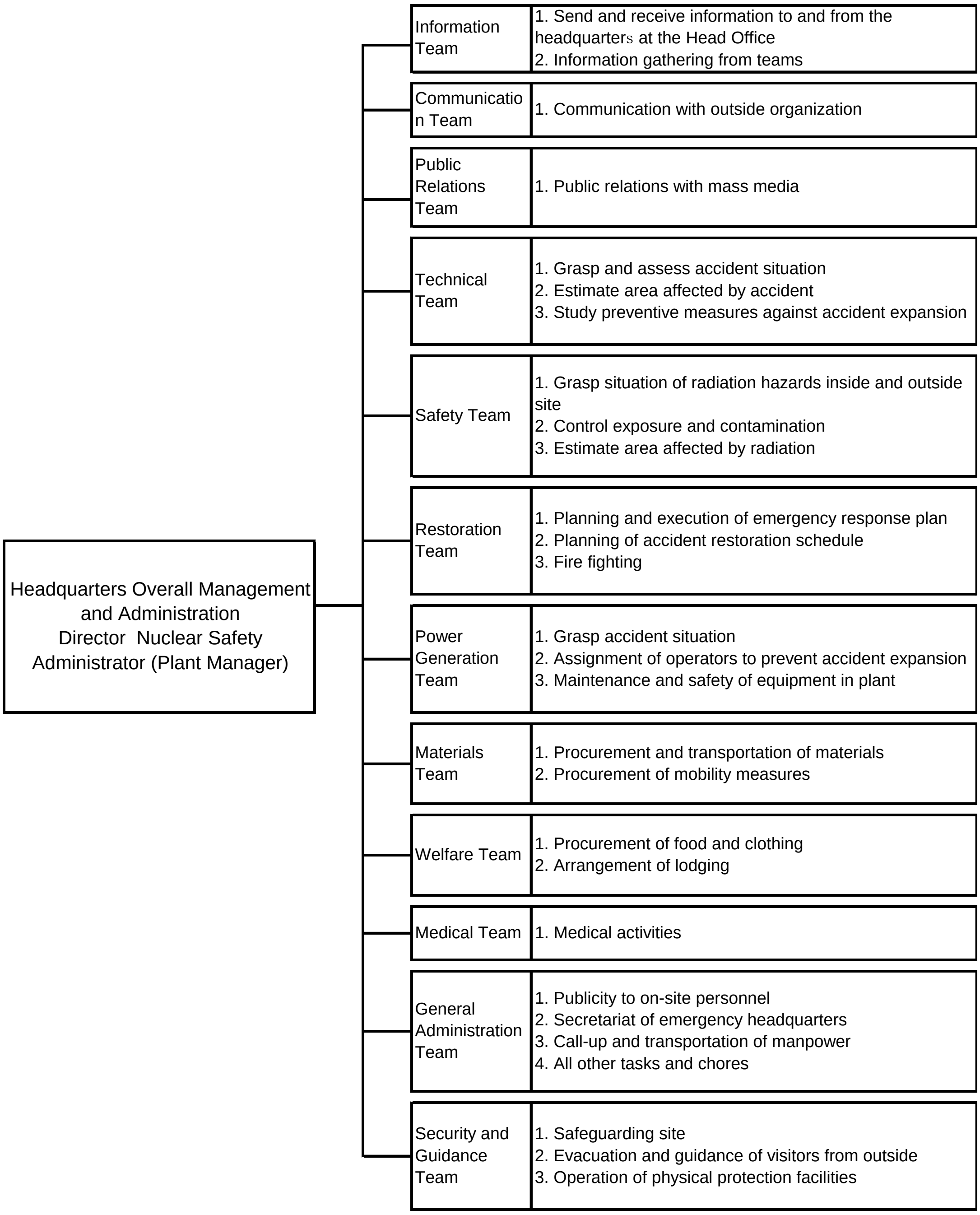


Fig 4.2.1-1 Emergency response organization

4.2.2 Immediately after the arrival of the tsunami

By the time the tsunami arrived, seawater had entered into the seawater heat exchanger building built on the ground at 4 m elevation, and the pumps for the emergency equipment cooling water system had lost function. Since a tsunami warning was issued after the earthquake, preparations were in place for the entry of the tsunami. After the arrival of the first wave of the tsunami, one circulating water pump was manually shut down based on the manual for tsunami backwash precautions. The other two pumps, however, also shut down automatically due to the impact of the tsunami. (All pumps of Unit 3 were manually shut down.) The lamp display on the control panel of the central control room could confirm the shutdown of these seawater pumps.

Starting from around 2003, precautionary measures for tsunamis had been gradually carried out for the seawater heat exchanger building by installing watertight doors, strengthening the pipe penetration seal, and measures to prevent water entering manholes. However, these measures assumed only a tsunami height of 5.1 m to 5.2 m in accordance with the 2002 evaluation results and were not able to prevent the entrance of tsunami seawater in this incident, where it was far higher than the height assumed in the precautions. Nonetheless, as the equipment was installed in the building, it was not destroyed or washed away and the loss of function was caused mainly by water damage due to the tsunami.

The tsunami reached the start-up transformer but it was not submerged to a significant extent, so it was able to maintain its function.

As soon as the entry of the tsunami calmed down, patrollers were dispatched to inspect the status of the equipment which had lost function in order to evaluate whether function could be restored through minor repair and maintenance. The patroller team consisted of each group of the restoration team. Patroller clothing and gear, such as helmets and flashlights, was as usual except for a pair of long boots for entering buildings flooded by seawater. The PHS signal was not reliable and the paging system in the area had lost function because of the tsunami. In order to ensure the delivery of any further tsunami warnings to patrollers while on patrol, a liaison was placed with a PHS phone to be kept connected at all times, who would deliver evacuation instructions to patrollers if and when warnings were issued.

Patrollers performed visual inspection and rough measurement of the equipment to determine whether it was functional. Their findings were illustrated in matrix form on a whiteboard in the Headquarters to share the information with everybody and were used to develop the recovery plan.

Electric power to the seismic isolation building, where the Headquarters was set up, had been supplied by an external power source; however, the onslaught of tsunami water caused a blackout. The plant had an emergency gas turbine generator but due to flooding, it did not start up either. At around 7 pm on the 11th, the power supply to the important seismic isolation building was restored by laying a cable from the external power source via the main office building. At around 11 pm, SPDS was restarted and monitoring of the plant situation was resumed. Until SPDS was restarted, such monitoring had relied on the information brought back by the experienced operators dispatched to the central control room. After SPDS resumed, the Headquarters was able to monitor and confirm various parameters of the displayed plant right away in order to develop a recovery plan. Security telephones were also available and used as a communication channel.

4.2.3 Responses toward restoration after the arrival of the tsunami

4.2.3.1 Overview of the power plant

(1) Responses and operations at the Headquarters

All works toward the restoration had been done only by the Fukushima Daini staff stationed at the site from the beginning, except for the support staff dispatched from the Power Distribution Department for restoration works on the power supply. The total number of support staff from the Distribution Department during the work period from March 11 to March 15 was 114 TEPCO employees and 35 cooperating company employees. These support staff worked on the management of power vehicles and cable laying works. Temporary cables were laid by 11:30 pm on the 13th, in between the power panel that was not affected by the tsunami, the high voltage power vehicle and the pump motor, by a combined work force of 200 personnel from TEPCO and cooperating companies (total length of cable in the four Units: approx. 9 km).

All the schedules for work toward restoration were developed by TEPCO employees at the Fukushima Daini headquarters. The plant manufacturer was not involved in the planning. In the development of restoration plans, the status of the plant and the sequence of events were carefully evaluated according to a variety of parameters such as reactor pressure, reactor water level, drywell pressure, S/C pressure, water temperature at S/C, and water level at S/C. The rate of pressure increase of the S/C was closely monitored to determine its priority in the recovery works of plants. This approach was based on the common understanding among the staff of the power plant that the vent from the containment vessel should be avoided as much as possible so as to minimize the possibility of releasing radioactive materials into the environment.

After the recovery of the residual heat removal system, in addition to the cooling of the S/C, water from the S/C was injected into the reactor from the low-pressure water injection line using the pump of the residual heat removal system in order to expedite the cooling of the reactor. At the same time, reactor water was returned to the S/C via the main steam safety valve, creating a circular flow of water where the water in the S/C was cooled down by the heat exchanger of the residual heat removal system and returned again to the reactor via a low-pressure injection line. Emergency Operating Procedure (EOP) prescribes a procedure where one unit of the residual heat removal system should be dedicated to the cooling of S/C water, and the other unit should be dedicated to the cooling of reactor water. In reality, however, there was only one available residual heat removal system, so this was devised as a practical solution. Prior to the implementation of this idea, there was thorough discussion by the generation team and final approval was given by the power plant manager. The flow rate of the residual heat removal system was 1,300 m3/h in Unit 1, 1,600 m3/h in Unit 2 and 1,400 m3/h in Unit 4 respectively.

The injection of water into the reactor by RCIC caused the water level of the S/C to rise as the steam which drove the RCIC turbine was exhausted into the S/C. So the source of water was switched to S/C from CST in order to ensure pressure suppression capability. After that, since the reactor pressure fell, water injection was switched to water from MUWC, but CST, the source of the MUWC water, was supplied with water from the pure water tank in order to continue the injections into the reactor. In performing this maneuver, priority was given to CST of Units 1 and 2 because the decay heat at these units was greater than at Unit 4. Unit 4 at first stirred water in the S/C, and then switched to water injection by HPCS. The water level in the tanks of Units 1 and 2 gradually decreased so the water from the condenser was sent to CST to secure the water source. After March 16, when the pipeline from the river was restored, river water was supplied to the filtered water tank. A condensate water pump was used to transport water from the water condenser but the system to supply the water to cool down the pump and motor was inoperable, and use of the condensate water pump was limited because of the tendency of the pump to heat up.

As for possible instrument failure, continuity of the parameters and cross checking of the readings between plural instruments were evaluated after the earthquake and the instruments were duly confirmed to be free from abnormalities.

Given how the tsunami struck, it was easy to assume that the equipment located in seaside areas was damaged, so procurement of cables and power supply vehicles was arranged without waiting for the results of the patrol. By the time of the patrol on the night of March 11, the status of the equipment was known and a list of the necessary equipment had been prepared by the restoration team. Some were directly requested from the restoration team to Kashiwazaki-Kariwa Plant, and the rest from the material team to head office. Kashiwazaki-Kariwa Plant removed motors from their own system to ship out cooling system motors. These measures were proposed by Kashiwazaki-Kariwa, which was able to share information via the video conference system. In regard to requests to cooperating companies in the recovery works, the TEPCO Material Department of the head office had entered into a cooperation agreement with each cooperating company and manufacturer for cooperation and support arrangements during "disaster situations" or "emergency situations." On the basis of this agreement, cooperation was requested for the supply of material and the dispatch of workers.

Equipment and materials were delivered by transport companies and SDF, but transportation was truly chaotic because of adverse situations such as the national highway system being cut off, a lack of accurate information on detours or bypasses, disconnected mobile phones, etc. After the explosion at Fukushima Daiichi, it became impossible for transport to reach Fukushima Daini directly. Therefore, TEPCO employees/subcontractor staff went to Hirono Town Hall to pick up the motors or to J Village for other equipment and materials to transport.

The radiation control equipment was not damaged by the earthquake and tsunami, and so there was no inconvenience or shortage with regard to the works.

As for the emergency stock of food, the plant already had a stockpile of foods as countermeasures for the Chuetsu-oki Earthquake and the influenza pandemic, sufficient for 250 emergency personnel for three days, duty officers for 40 days, and 60 percent of the main office staff for two weeks. In addition, five days of drinking water were also stockpiled for 250 emergency personnel. Therefore, all personnel at the site were able to get by during the first three days, until the 13th when aid materials arrived. Since the plant had no equipment to make drinking water, the stockpiled drinking water and food were distributed not only to TEPCO employees but also to the staff and workers of cooperating companies, and thus, the allocation per capita was decreased from the second day, making the situation rather grim and tough.

The medical team looked after health and hygiene problems in response to the situation resulting from a large number of people being forced to work and live in a small, crowded area. Stress-induced physical problems were also observed later, necessitating mental health care for the workers.

(2) On-site restoration works

Since it was possible to receive external power supply via one transmission line, power was supplied to the equipment in the seawater heat exchanger building, such as the pump of the residual heat removal seawater system, by laying a cable from the power panel of the waste treatment building. Until 11:30 pm on the 13th, all 200 workers, including employees of TEPCO and cooperating companies, finished laying the temporary cables to directly connect the un-flooded power panel to the high-voltage power supply car with the pump motor (total length 9km for 4 plants). Routing for cable laying was determined in consideration of various factors and the assessment of the overall situation, such as available power panels, distance of cables to the target equipment, environment in the area to lay the cable, other restrictive conditions, and the ease of the laying works. The power supply vehicle was used as the power source for the equipment installed in local areas, such as the EECW pumps of Unit 1 and Unit 4 located in the seaside area or the river water intake pump. The power supply vehicle could operate only for few hours at a time because of the volume of fuel required, so continuous operation was maintained with a refueling team conducting refueling every three hours. In this situation, ensuring the supply of diesel oil for the power supply vehicle and gasoline for general vehicles within the site was difficult.

Restoration works were suspended at the time of every aftershock and tsunami warning. Works were also suspended due to evacuation instructions in response to the Fukushima Daiichi explosion. In addition, starting from the evening of the 14th, when the air dose rate had increased due to radioactive materials descending from Fukushima Daiichi, workers were required to wear Tyvek and full-face masks for all outdoor works. Fig 4.2.3.1-1 shows the rise of the dose rate at monitoring post No. 4 in the west part of the power plant. (See Fig 2.1 for location details.)

In addition, it was not possible to ensure a sufficient number of workers for some tasks such as maintenance of office equipment and protective gear, and driving of heavy machinery. TEPCO staff engaged in these tasks.

(3) Arrangements of personnel and materials/equipments /others

Except for support staff dispatched from the Power Distribution Division for power recovery, the persons present at Fukushima Daini when the earthquake occurred were engaged in restoration efforts. From March 11 to 15, all 114 TEPCO employees and 35 cooperating company employees were dispatched as support staff from the Power Distribution Division. They were engaged in the maintenance of the power supply cars and support for cable laying.

Transport companies or the Self-Defense Forces carried equipment/materials; however, transportation was in a state of confusion due to bad conditions such as blockages of the national roads, insufficient guidance as to detours and disconnected mobile phones. After the explosion at Fukushima Daiichi, there were difficulties in directly delivering materials/equipment to Fukushima Daini, and therefore employees of TEPCO and cooperating companies went to the Hirono Town Office to pick up motors and to J-Village for other materials/equipment, and then transported them to Fukushima Daini.

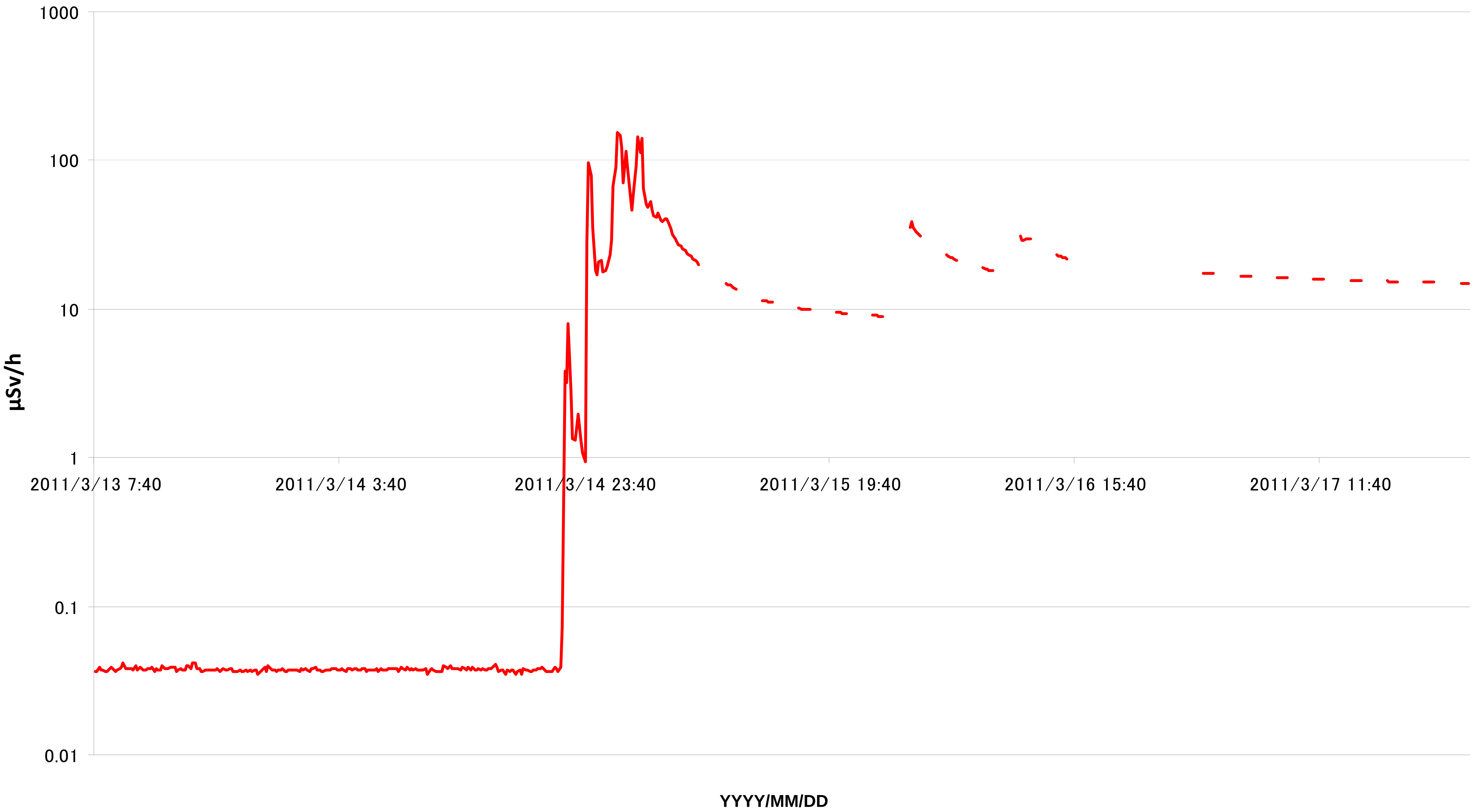


Fig 4.2.3.1-1 Monitoring Data at Fukushima Daini (Near MP4)

4.2.3.2 Situation of Fukushima Daini Unit 1.

(1) From the earthquake to immediately after the arrival of the tsunami
At 2:48 pm on March 11, the reactor automatically shut down and at 3:00 pm, it was confirmed that it had become subcritical.

As a countermeasure against the tsunami (visual confirmation of the arrival of the first wave at 3:22 pm on March 11), the main steam isolation valve was fully closed manually at 3:36 pm on March 11and RCIC was activated manually to inject water into the reactor, and at 3:55 pm on the same day, depressurization of the reactor by the main steam relief safety valve was begun.

Due to the impact of the tsunami, some of the motors and power panels were flooded and became unusable. As a result, all of the pumps in the emergency core cooling system entered a non-bootable state. (At 6:33 pm, the plant manager determined the situation to be an incident to which Article 10 (loss of reactor heat removal function) of the Nuclear Emergency Law applies.)

(2) Injection of water into reactor and cooling of pressure vessel
Water was injected into the reactor by RCIC but starting at 0:00 am on the 12th, alternative water injection by MUWC (AM measures) was carried out concurrently.

Because of the drop in pressure in the RCIC turbine driving steam due to the decrease in reactor pressure, RCIC was manually isolated at 4:58 am on the 12th and the water level in the reactor was adjusted by alternative water injection by MUWC thereafter.

The water temperature of the S/C gradually rose due to the operation of RCIC and the opening of the main steam relief safety valve, and at 5:22 am on the 12th, the water temperature of the S/C reached above 100°C. (The plant manager determined the situation to be an incident to which Article 15 (loss of pressure control capability) of the Nuclear Emergency Law applies.)

For the cooling of the S/C, starting from 6:20am of the 12th, the injection of cooling water (MUWC) to the S/C was carried out using the cooling water drain line in the cooler of the flammability gas control system, and dry well spray by MUWC (starting from 7:10 am on the same day), and S/C spray (starting from 7:37 am on the same day) were conducted from time to time to cool the containment vessel.

Because there was an upward tendency in the pressure of the containment vessel due to the loss of the heat removal function of the reactor, it was assumed that it would take time to recover the heat removal function of the reactor, and line configuration (completing all necessary actions except one last action to open the outlet valve to the S/C) was conducted for the vent of the containment vessel between 10:21 am and 6:30 pm on the 12th. However, containment vessel vent was not implemented because the pressure of the containment vessel did not reach the level that would require a vent.

(3) Recovery of residual heat removal system and cold shutdown of reactor
At about 10 pm on the 11th, after establishing communication and evacuation procedures, the restoration team began investigation of the status of tsunami damage on the seawater heat exchanger building located in the seaside area in full safety gear.

Based on the findings of the investigation of the restoration team, the headquarters established a restoration plan for the power plant, on a priority basis, to carry out inspection and repair of pumps in the residual heat removal cooling system located in the seawater heat exchanger building (D), seawater pumps in residual heat removal system (B), and cooling pumps of emergency diesel generator (B) (while the motor of the pump in the residual heat removal cooling system and the cooling pump of the emergency diesel generator were to be replaced). Headquarters asked the Kashiwazaki-Kariwa Nuclear Power Plant for the urgent supply of motors.

The equipment and materials for which procurement was requested of the headquarters of the head office and the Kashiwazaki-Kariwa plant arrived at Fukushima Daini by 6:00 am on the 13th.

Temporary cables were laid from the power panel of the waste treatment building through the south side of the reactor building of Unit 1, which was not affected by the tsunami, to connect directly with the motor. Also, another cable was laid from the power transformer installed at the large equipment entrance of the turbine building of Unit 3. In parallel to the cable laying, the status of the mechanical parts of the pump were checked and mounting of the motor was carried out, and at 8:17 pm on the 13th, the seawater pump of the residual heat removal system started up.

At 1:24 am on the 14th, the pump of the residual heat removal system (B) started in S/C cooling mode, and the plant manager concluded that this situation signified the end of the situation of Article 10 of the Special Law for Nuclear Emergency (loss of reactor heat removal function).

As a result of the cooling of the S/C in the (B) pump in the residual heat removal system, the S/C temperature declined gradually and dropped below 100°C at 10:15 am on the 14th, and the plant manager concluded that the situation had recovered from the situation of Article 15 (the loss of pressure suppression function) under the Special Law for Nuclear Emergency.

In order to cool down the reactor water expeditiously, in addition to cooling of the S/C, at 10:05 am on the 14th, injection of water from S/C into the reactor from the low-pressure water injection line using the pump of the residual heat removal system (B) began. At the same time, reactor water was returned to the S/C via main steam safety relief valve after cooling down the water in S/C using the heat exchanger of the residual heat removal system and returning it again to the reactor via a low-pressure injection line, making for a circular flow of water (S/C → pump in the residual heat removal system (B) → heat exchanger in the residual heat removal system (B) → low-pressure water injection line → reactor → main steam safety relief valve → S/C), as a temporary measure.

The temperature of the reactor water dropped below 100°C at 5:00 pm of the same day and cold shutdown was achieved.

At 5:12 am on March 16, about two days after cold shutdown, the monitor of the containment vessel showed a rising tendency of hydrogen concentration (Hydrogen Approx.5%, Oxygen Approx. 2%). Therefore, the flammable gas control system was operated and hydrogen and oxygen concentration was successfully controlled below the flammable level of concentration.

4.2.3.3 Situation of Fukushima Daini Unit 2.

Except for minor differences in the time frame, the operation and actions in Unit 2 were essentially same as those at Unit 1.

(1) From the earthquake to immediately after the arrival of the tsunami
At 2:48 pm on March 11, the reactor automatically shut down and at 3:00 pm on

the same day, it was confirmed that the reactor it had become subcritical.

As a countermeasure against the tsunami (visual confirmation of the arrival of the first wave at 3:22 pm on March 11), the main steam isolation valve was fully closed manually at 3:34 pm on March 11 and RCIC was activated manually to inject water into the reactor, and at 3:41 pm on the same day, depressurization of the reactor began via the main steam relief safety valve.

Due to the impact of the tsunami, some of the motors and power panels were flooded and became unusable. As a result, all of the pumps in the emergency core cooling system entered a non-bootable state. (At 6:33 pm on the same day, the plant manager determined the situation to be an incident to which Article 10 (loss of reactor heat removal function) of the Special Law for Nuclear Emergency applies.)

(2) Injection of water into reactor and cooling of pressure vessel

Water was injected into the reactor by RCIC but starting at 4:30 am on the 12th, alternative water injection by MUWC (AM measures) was carried out concurrently.

Because of the pressure drop in the RCIC turbine driving steam due to the decrease in the reactor pressure, RCIC was manually isolated at 4:53 am on the 12th and the water level in the reactor was adjusted by alternative water injection by MUWC thereafter.

The water temperature of the S/C gradually rose due to the operation of RCIC and the opening of the main steam relief safety valve, and at 5:32 am on the 12th, the water temperature of the S/C reached above 100°C. (The plant manager determined the situation to be an incident to which Article 15 (loss of pressure control capability) of the Special Law for Nuclear Emergency applies.)

For the cooling of the S/C, starting from 6:30 am of 12th, injection of cooling water (MUWC) to the S/C was carried out using the cooling water drain line in the cooler of the flammability gas control system, and dry well spray by MUWC (starting from 7:11 am on the same day), and S/C spray (starting from 7:35 am on the same day) were conducted from time to time to cool the containment vessel.

Because there was a rising tendency in the pressure of the containment vessel due to the loss of the heat removal function of the reactor, it was assumed that it would take time to recover the heat removal function of the reactor, and line configuration (completing all necessary actions except one last action to open the outlet valve to the S/C) was conducted for the vent of the containment vessel between 10:33 am and 10:58 am on the 12th. However, containment vessel vent was not implemented because the pressure of the containment vessel did not reach the level that would require a vent.

(3) Recovery of residual heat removal system and cold shutdown of reactor

For the restoration works of Unit 2, it was decided to give priority to carrying out inspection and repair of the pump in the residual heat removal cooling system (B), the seawater pump in residual heat removal system (B), and the cooling pump of the emergency diesel generator (B).

By 11:30 pm on the 13th, temporary cables were laid from the power panel of the radioactive waste treatment building and the power panel of seawater heat exchanger building of Unit 3 to connect directly with the motor, and starting from 3:20 am of 14th, pumps started up one by one as soon as they become available.

At 7:13 am on the 14th, the pump of the residual heat removal system (B) was started. (The plant manager concluded that the situation constituted the end of the situation of Article 10 of the Special Law for Nuclear Emergency (loss of reactor heat removal function).)

As a result of the continuous cooling of the S/C by the pump of residual heat removal system (B), the temperature of the S/C gradually declined and fell below 100 °C at 3:52 pm on the 14th. (The plant manager concluded that the situation constituted the end of the situation of Article 15 of the Special Law for Nuclear Emergency (loss of the pressure suppression function).)

In order to cool down the reactor water expeditiously, in addition to the cooling of the S/C, at 10:48 am on the 14th, the injection of water from the S/C into the reactor from the low-pressure water injection line using the pump of the residual heat removal system (B) started. At the same time, reactor water was returned to the S/C via the main steam safety relief valve after cooling down the water in the S/C using the heat exchanger of the residual heat removal system and returning it again to the reactor via a low-pressure injection line, making for a circular flow of water (S/C → pump in the residual heat removal system (B) → heat exchanger in the residual heat removal system (B) → low-pressure water injection line→reactor → main steam safety relief valve → S/C), as a temporary measure.

The temperature of the reactor water dropped below 100°C at 6:00 pm of the same day and cold shutdown was achieved.

At 7:58 am on March 16, about two days after cold shutdown, the monitor of the containment vessel observed a rising tendency of hydrogen concentration (Hydrogen Approx.5%, Oxygen Approx. 2%). Therefore, the flammable gas control system was operated, and hydrogen and oxygen concentration was successfully controlled below the flammable level of concentration.

4.2.3.4 Situation of Fukushima Daini Unit 3.

(1) From the earthquake to immediately after the arrival of the tsunami
At 2:48 pm on March 11, the reactor automatically shut down and at 3:05 pm, it was confirmed that it had become subcritical.

Because of the flooding of the seawater heat exchanger building by the tsunami and from the indications of on/off lamps at the control panel, it was thought that the water pump in residual heat removal system (A, C), the seawater pump in residual heat removal system (A, C) and the cooling pump of emergency diesel generator (A) were all unable to start up. (At a later date, it was confirmed that these failures were caused by the inundation of some of the motors and the emergency low voltage power panel (P/C 3C-2)). Therefore, it became impossible to start up the pumps in the low pressure core spray system (A) and the residual heat removal system.

Since the entry of flood water into the seawater heat exchanger building of this unit was small in relation to that of other units, the impact of flooding on the equipment in the building was not significant and this equipment was considered to be in usable condition: emergency low-voltage power panel (P/C 3D-2), its load, water pump for residual heat removal system pump (B, D), seawater pump for residual heat removal system pump (B, D), cooling pump for emergency diesel power generator (B), water cooling pump for diesel power generator for the high-pressure core spray system, and seawater cooling pump for diesel power generator for the high-pressure core spray system.

Since there was no flooding from the tsunami on the B2 floor of the reactor building, pumps in the residual heat removal system (B, C) and high pressure core spray system were all ready to use.

(2) Injection of water into reactor and cold shutdown

At first, water injection into the reactor was carried out by RCIC but starting from 10:53 pm of March 11, alternate water injection by MUWC, which was introduced as an accident management measure, was also implemented. Because of the drop in pressure in the RCIC turbine driving steam due to the decrease in the reactor pressure, RCIC was manually isolated at 11:58 pm of the same day by opening the main steam relief safety valve.

Alternative water injection by MUWC was continued thereafter in accordance with the Emergency Operation Procedure [symptom basis] (EOP).

As a precaution for the contingency of an increase in pressure of the containment, line configuration of the containment vent was performed (completing all necessary actions except one last action to open the outlet valve to the S/C).

At 9:37 am on March 12, the pump in the residual heat removal system (B) was activated to inject cooling water, and the water temperature of the reactor dropped below 100°C and cold shutdown was confirmed at 12:15 pm on the same day.

4.2.3.5 Situation of Fukushima Daini Unit 4

The basic operation of Unit 4 is the same as Units 1 and 2. However, in consideration of securing water sources, priority was given to Units 1 and 2 in water injection operations because their decay heat was more intense. The decay heat of Unit 4 was considered to be less intense, so the water from S/C was injected into the reactor by HPCS after stirring the water.

(1) From the earthquake to immediately after the arrival of the tsunami

At 2:48 pm on March 11, the reactor automatically shut down and at 3:05 pm on the same day, it was confirmed that it had become subcritical.

As countermeasures against the tsunami (visual confirmation of the arrival of first wave at 3:22 pm on March 11), the main steam isolation valve was fully closed manually at 3:36 pm on March 11 and the depressurization of the reactor was started at 3:46 pm on the same day by the opening of the main steam relief safety valve followed by the manual activation of RCIC for injection of water into the reactor,

Due to the impact of the tsunami, some of the motors and power panels were flooded and became unusable. As a result, all of the pumps in the emergency core cooling system entered a non-bootable state. (At 6:33 pm on the same day, the plant manager determined the situation to be an incident to which Article 10 (loss of reactor heat removal function) of the Special Law for Nuclear Emergency applies.)

(2) Injection of water into reactor and cooling of pressure vessel

At first, water injection into the reactor was carried out by RCIC but after the automatic isolation of RCIC due to the pressure drop in the RCIC turbine driving steam at 0:16 am on the 12th, alternate water injection by MUWC was carried out for the control of the reactor water level.

Starting from 12:32 pm on the 12th, the control of the reactor water level was conducted by the On/Off of HPCS, which was not impacted by the tsunami and was available at that time.

The water temperature of the S/C gradually rose due to the operation of RCIC and the opening of the main steam relief safety valve, and at 6:07 am on the 12th, the water temperature of the S/C reached above 100°C. (The plant manager determined the situation to be an incident to which Article 15 (loss of pressure control capability) of the Special Law for Nuclear Emergency applies.)

For the cooling of the S/C, starting from 7:23 am on the 12th, injection of cooling water (MUWC) to the S/C was carried out using the cooling water drain line in the cooler of the flammability gas control system, and dry well spray by MUWC (starting from 7:11 am on the same day) and S/C spray (starting from 7:35 am same day) were conducted from time to time to cool the containment vessel.

Because there was an upward tendency in the pressure of the containment vessel due to the loss of the heat removal function of the reactor, it was assumed that it would take time to recover the heat removal function of the reactor, and line configuration (completing all necessary actions except one last action to open the outlet valve to the S/C) was conducted for the vent of the containment vessel between 11:44 am and 11:52 am on the 12th. However, the containment vessel vent was not implemented because the pressure of the containment vessel did not reach the level that would require a vent.

(3) Recovery of residual heat removal system and cold shutdown of reactor

It was decided to give priority to carrying out inspection and repair of pumps in the cooler of residual heat removal system (B), seawater pump in residual heat removal system (D), and cooling pump of emergency diesel generator (B). (The motor of the seawater pump in residual heat removal system (B) was to be replaced.)

Temporary cables were laid from the power panel of Unit 3 and the power transformer located near the large equipment entrance of the turbine building of Unit 3.

At 3:42 pm on the 14th, the pump of residual heat removal system (B) was started. (The plant manager concluded that the situation constituted the end of the situation of Article 10 of the Special Law for Nuclear Emergency (loss of reactor heat removal function).)

As a result of the continuous cooling of the S/C by the pump of residual heat removal system (B), the temperature of the S/C gradually declined and dropped below 100 °C at 7:15 am on 15th. (The plant manager concluded that the situation constituted the end of the situation of Article 15 of the Special Law for Nuclear Emergency (loss of the pressure suppression function).)

In order to cool down the reactor water expeditiously, in addition to the cooling of the S/C, at 6:58 pm on the 14th, the injection of water from S/C into the reactor from the low-pressure water injection line using the pump of the residual heat removal system (B) was started. At the same time, reactor water was returned to

S/C via the main steam safety relief valve after cooling down the water in S/C using the heat exchanger of the residual heat removal system and returning it again to the reactor via the low-pressure injection line, making for a circular flow of water (S/C → pump in the residual heat removal system (B) → heat exchanger in the residual heat removal system (B) → low-pressure water injection line → reactor → main steam safety relief valve → S/C), as a temporary measure.

The temperature of the reactor water dropped below 100°C at 7:15 am on the 15th and cold shutdown was achieved.

At 1:21 am on March 17, about two days after cold shutdown, the monitor of the containment vessel observed a rising tendency of hydrogen concentration (Hydrogen Approx.5%, Oxygen Approx. 2%). Hence, the flammable gas control system was operated and hydrogen and oxygen concentration was successfully controlled below the flammable level of concentration.

4.3 Cooling of spent fuel pool of Fukushima Daini

The temperature of the spent fuel pool of Fukushima Daini Units 1-4 was monitored by the temperature gauge in the main control room. The temperature gauge of Unit 2, however, was not functional because the heat sensor tip was exposed out of the water due to the decreased water level of the pool. Therefore a temporary thermometer was installed to continue the monitoring.

Because of the loss of the seawater circulation system, it became impossible to deliver heat from the spent fuel pool to the ultimate heat sink. However, the decay heat of the spent fuel was not so large, so the rise of the pool water temperature could be suppressed by circulating the pool water to the cooling system of the pool, which is powered by the emergency power source. After the recovery of RHR, the temperature of the pool water was maintained below the limit prescribed by the nuclear facility security regulations. (The temperature of spent fuel pool water shall be below 65°C.)

5. Analysis of accident response

5.1 Purpose of the analysis of accident response

We believe that we can learn a variety of lessons from the experience of Fukushima Daini, where they were able to swiftly lead the plant to convergence after the devastation of the tsunami. In this aim, we not only took the lessons from the response merely as best practices, but also made an in-depth analysis of the accident response.

5.2 Concept of analysis

The INSAG-10 in-depth report on nuclear defense defined the following five levels of purpose and requirement. (Note 1)

- Level 1: Prevention of abnormal operation and failures; Conservative design and high quality in construction and operation.
- Level 2: Control of abnormal operation and detection of failures; Control, limiting and protection systems, and other surveillance features.
- Level 3: Control of accidents within the design basis; engineered safety features and accident procedures.
- Level 4: Control of severe conditions including prevention of accident progression and mitigation of the consequences of a severe accident; Complementary measures and accident management.
- Level 5: Mitigation of the radiological consequences of significant external release of radioactive materials; Off-site emergency response

Levels 1 to 3 can be achieved through engineered safety features that have been built or constructed. As such, it is possible to confirm their design capability, such as rated capacity, by analysis, etc. in the design stage.

However, due to human errors, etc. the actual response after the accident may not be same as in normal circumstances and the accident may not be handled as intended, or, the analysis of actual experience in serious accidents that we have encountered will show us what is important to cope with.

(Note 1: Excerpt from Nuclear Safety Commission reference material "I-Kou-Ki-Gen No. 5-3-2" by Mr. Masahiro Yamashita, JNES)

In response to the Fukushima Daiichi accident, many companies have been promoting a variety of facility enhancements as permanent or temporary countermeasures, such as the installation of embankments and the deployment of power vehicles. As a result, the status of the equipment of each power plant now differs from that of Fukushima Daini at the time of the disaster.

In the concept of defense in depth, defensive response to unrecognizable "uncertainties" is required based on the "ignore lower level defense" principle. (Please see Note 1 above.) This means that in Level 4 defense, the conditions of engineered safety features to be used in Level 3 or below may not be assumed. Therefore, support from the internal and external resources of the power plant to leverage in Level 4 or above (such as use of temporary equipment or materials, restoration of power supply using off-site cables, and expeditious recovery of damaged equipment) might be assumed in a variety of patterns.

It should be a meaningful exercise to extract factors that can be used as the universal success factors from these various response patters by analyzing the experience of Fukushima Daini as it can give us lessons that can be utilized in the event of plant accident with a different design and equipment or in the extreme situation of an accident which has not been assumed.

5.3 Specific analysis procedures

There is a variety of established methodologies in root cause analysis (RCA) for planning countermeasures against nonconformity. On the other hand, we don’t see any established methodology for extracting successful factors from the events.

For this reason, we have analyzed the successful factors in the Fukushima Daini response (such as full closure of main isolation steam valve, evaluation of damage to the heat exchanger building, early recovery of emergency pumps, etc.) using the following steps:

① Describe the incident.

② Describe the response of Fukushima Daini corresponding to the above based on the TEPCO accident investigation report.

③ Extract possible mistakes in the above incident and response set by assuming a hypothetical mistake in the response which should result in a mistake in the incident.

④ Analyze and identify the possible factors that could cause such assumed mistake using the m-SHEL model, a method for human-factor accident analysis, for each of the five factors below:

- m (Management and organization)
- S (Software, such as manuals)
- H (Hardware, such as machinery)
- E (Environment)
- L (Live ware, such as yourself and the people around you)

⑤ In reality, at Fukushima Daini, an assumed mistake did not occur because the factors that might have caused such mistake had been overcome and prevented. Extract the reason why such mistakes were avoided from the features of Fukushima Daini.

⑥ From among the reasons you extracted, derive the important lessons learned.

The above analysis was carried out for the Unit 1 experience, as a representative.

Fig. 5.3-1 shows the flow of the analysis and Table 5.3-1 shows the results thereof.
① through ⑥ in the attachments correspond to ① through ⑥ above.

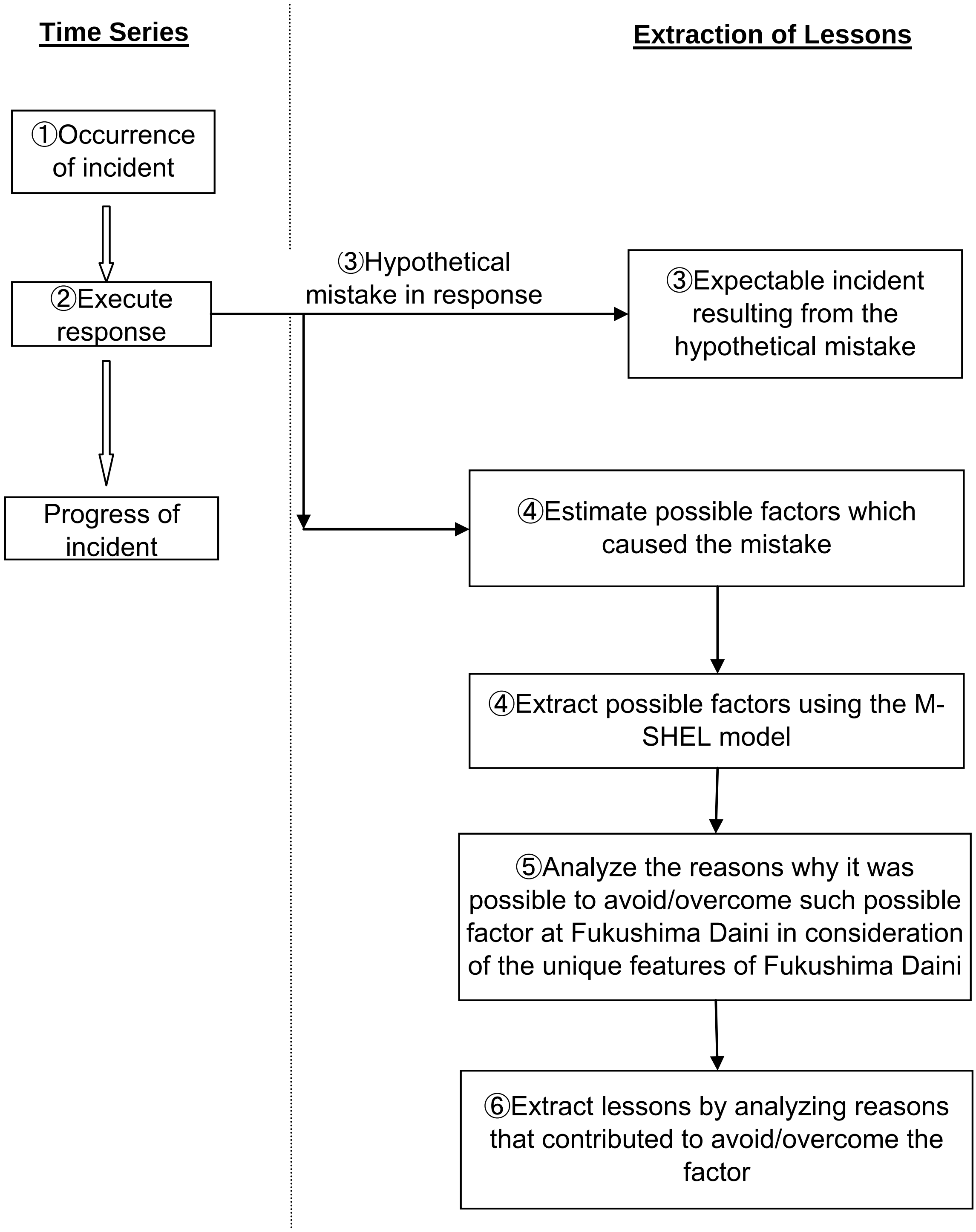


Fig. 5.3-1 Flow of analysis

Table 5.3-1 result of Analysis of accident response（1/11）

Note: Text written in red is quoted from TEPCO's report.
Analysis of response at Unit 1

Date and Time		(1) Event occurred	(2) Response	(3) Anticipated errors related to response		(4) Factors of occurrence of anticipated errors						(5) Reasons why factors of occurrence of errors could be prevented or overcome	(6) Lesson
						Category							
Date	Time			Description of errors	Events caused by occurrence of anticipated errors	Management	Software	Hardware	Environment	Liveware	Occurrence of supposed secondary cause	Description	
March 11	14:46	Occurrence of earthquake											
	14:46-		Operators remained waiting low to the ground, with their hands grasping a handrail in front of the control panel, and, a shift chief simultaneously made a pre-announcement of scram operation and directed operators to commence operations responding to the evacuation operation while waiting for the earthquake tremors to stop (page 136 of Attachment2).	• Operator injury due to the earthquake. • Operators struck operating switches when they fell down due to the earthquake tremors.	Failure in operation responding to scram				No measures to hold the body position	Impossible to hold the body position	No.	Since the tremor was very large, operators remained waiting low to the ground with their hands grasping a handrail in front of the control panel (page 136 of Attachment 2). Operators are routinely trained as to how to wait in the event of an earthquake.	Detailed countermeasures other than the earthquake-resistant design of the main facilities and operation procedures are also effective. (Handrails in front of the central control panel, what posture operators shall maintain during a continuous earthquake tremor.)
			An assistant shift chief used simultaneous paging to make an announcement to all about the occurrence of the earthquake and evacuation instructions. Operators at the site were communicated to via PHS and were instructed to evacuate.										
	14:48	Automatic reactor scram	(15:00: It was confirmed that the reactor had not reached criticality (page 136 of Attachment 2))										
Operation responding to scram (14:48 ~)													
March 11									Worsening of environment in central control room due to the earthquake (scattering of furnishings, occurrence of injuries, etc.)		No.	Furnishings, etc. were fixed, reflecting experience in Kashiwazaki (2007 Chuetsu Offshore Earthquake).	Detailed countermeasures other than the earthquake-resistant design of the main facilities and operation procedures are effective (fixing of furnishings, etc.).
								Damage to equipment necessary for recovery after scram due to the earthquake			No.	The safety system's earthquake-resistant design worked effectively. Training	The earthquake-resistant design worked effectively (the safety system's earthquake-resistant design).
			A shift chief judged that in addition to activation of many alarms, the sound of the fire alarms was too loud for operators to hear instructions, and gave instructions by means of a hand microphone which was provided behind the shift-chief's chair as a piece of emergency equipment (The fire alarms were later found to be erroneous.) (page 136 of Attachment 2)						Difficulty of communication between shift chief and operators due to activation of fire alarms (page 136 of Attachment 2).		Yes.	Provision of a hand microphone as emergency equipment	Detailed countermeasures other than the earthquake-resistant design of the main facilities and operation procedures are effective (arrangement of a hand microphone).
			Following the automatic stoppage of the reactor, a work management team (a team consisting of the shift chief and operators, separate from the operation) working in an office near the central control room rushed into the central control room and assisted the shift of operators (page 216 of Main Text).	Failure in recovery operations after scram	Failure in core cooling	No or insufficient personnel and framework required to follow up operators at the central operating room				Excessive burdens placed on operators in conducting surveillance of the plant, judgment of the situation, operation, communication to those involved, etc.	No.	Burdens were reduced thanks to the support of the work management team immediately after scram. • The support of the work management team at the time of scram is not a necessary condition to respond to scram. • The work management team is a team stationed in the room next to the central control room on a daily shift basis for preparation for regular inspections such as preparation of tags. • It was not obligatory for the team to support operators at the time of scram. This team, however, voluntarily provided immediate support with a firm sense of mission to protect the plant, taking advantage of the fact that it consisted of a shift chief and operators with corresponding operational skill. • It functioned effectively for restoration.	• What is important is as the attitude to voluntarily perform whatever necessary, with a strong sense of mission, to make the accident come to an end.

Table 5.3-1 result of Analysis of accident response (2/11)

Date and Time		(1) Event occurred	(2) Response	(3) Anticipated errors related to response		(4) Factors of occurrence of anticipated errors						(5) Reasons why factors of occurrence of errors could be prevented or overcome	(6) Lesson
Date	Time			Description of errors	Events caused by occurrence of anticipated errors	Category: Management	Software	Hardware	Environment	Liveware	Occurrence of supposed secondary cause	Description	
			Support staffs were dispatched from the power station Emergency Response Headquarters and the structure was established to enable close contact between the central control room and the headquarters so that the operators could dedicate themselves to the surveillance and operation of the plant in the response thereafter (page 216 of Main Text).							Excessive burdens placed on operators in conducting surveillance of the plant, judgment of the situation, operation, communication to those involved, etc.	No.	Support staffs were dispatched from the power station Emergency Response Headquarters and a structure was established to enable close contact between the central control room and the headquarters, while operators were able to dedicate themselves to the surveillance and operation of the plant in the response thereafter (page 216 of Main Text).	Importance of backup in order for operators in the central control room to dedicate themselves to operation.
			Upon hearing the announcement of a large tsunami warning from the power station Emergency Response Headquarters, the shift chief used simultaneous paging to give emergency evacuation instructions due to the announcement of a large tsunami warning (page 136 of Attachment 2).	Insufficient notification on major tsunami warning to the on-site staff	Human damage	Lack or delay of communication of the large tsunami warning announcement from the power station Emergency Response Headquarters to the shift chief, or missing of simultaneous paging by the shift chief → possibility of occurrence of human injury.		Paging system failure			No.	It was expressly stated that simultaneous paging should be made at the time of announcement of a large tsunami warning. Desktop exercises such as regular review of procedures were conducted.	Detailed countermeasures other than the earthquake-resistant design of the main facilities and operation procedures are effective (simultaneous paging of the large tsunami warning).
	15:06		The Emergency Response Headquarters for disasters had been established in the head office (page 126 of Attachment 2).										
Offsite power situation													
	14:48	Shutdown of one (1) line of the Tomioka Line (page 136 of Attachment 2)											
	(15:50)	One (1) line of the Iwaido Line was shut down due to equipment faults in Shin-Fukushima Substation (page 136 of Attachment 2). There were a total of four (4) lines as offsite power; two (2) lines of the Tomioka Line (500kV) and two (2) lines of the Iwaido Line (66kV). One (1) line of the Iwaido line had been in a planned outage prior to the earthquake, and the two (2) lines of the Tomioka Line were shut down after the earthquake, and then power was continuously received from the Tomioka No. 1 Line (page 136 of Attachment 2).											
(March 12)	(13:38)	On the Iwaido Line, one (1) line was restored (page 136 of Attachment 2).		Delay in early restoration of the Iwaido Line	Continuous situation of less reliable offsite power supply with only one (1) line.	Delay in preparation of personnel, equipment and materials, etc. for restoration of the Iwaido Line.					No.	Since the Iwaido Line, like the power station, is property of TEPCO, the situation of the power station could be quickly shared (advantage of vertical integration of generation and transmission).	It is important to establish in advance a structure which allows for swift support from any organization outside the power station (advantage of vertical integration of generation and transmission).
(March 13)	(5:15)	On the Iwaido Line, one (1) line was restored (page 136 of Attachment 2).											
Responsive operation immediately after the arrival of the tsunami													
March 11	15:22	Observation of the first wave of the tsunami (thereafter, the tsunami was intermittently observed until 17:44 (page 126 of Attachment 2).	It was observed by an on-site surveillance camera that the tsunami was progressing toward the breakwater (page 137 of Attachment 2).	The fact that a large tsunami has struck or that damage to equipment could have been caused by large tsunami was not fully recognized.	Delay in response thereafter			Visual means for observation is not available.			No.	Observation by means of on-site surveillance camera	Importance of means of observing damage situation

Table 5.3-1 result of Analysis of accident response（3/11）

Date and Time		(1) Event occurred	(2) Response	(3) Anticipated errors related to response		(4) Factors of occurrence of anticipated errors						(5) Reasons why factors of occurrence of errors could be prevented or overcome	(6) Lesson
						Category							
Date	Time			Description of errors	Events caused by occurrence of anticipated errors	Management	Software	Hardware	Environment	Liveware	Occurrence of supposed secondary cause	Description	
		Surveillance of plant conditions was possible because approximately half of the instruments and lamp indicators for surveillance of parameters and observation of operation condition were secured (page 137 of Attachment 2).	While continuing to perform surveillance mainly on the reactor system control panel, a shift chief, taking the consequences of the tsunami into consideration, placed operators at the control panels where the operation condition of seawater system components (seawater intake pumps and cooling water pumps), which are important for reactor heat removal, could be observed and instructed them to report information as appropriate (page 137 of Attachment 2).										
		With regard to emergency component cooling system pumps, stoppage of operating pumps was confirmed by means of operation/stop lamp indicators, etc. (page 137 of Attachment 2).											
	15:33		In accordance with tsunami response procedures (page 137), circulation water pumps were manually stopped (page 126 of Attachment 2).	Omission or delay in conducting manual stop of circulation water pumps						Omission of operation by shift operators	No.	• CWP stop was described in the tsunami response operation procedures. • Since operators were familiar with the tsunami response operation procedures, they were able to perform operations properly.	The procedures prepared and training conducted in advance functioned effectively.
	15:34	Emergency diesel generators (A), (B) and (H) were automatically started and, immediately thereafter, were automatically stopped as a consequence of the tsunami (page 126 of Attachment 2).											
	15:36		Since main steam condensation by condensers had become impossible (page 137 of Attachment 2), MSIVs were fully closed by manual operation (page 126 of Attachment 2).	Omission or delay in conducting MSIV full-close	Lowering of reactor water level due to continuous leakage of steam from a reactor to a condenser Unavailability of RCIC due to drop of reactor pressure					Omission or delay in conducting MSIV full-close	No.	• Description in procedures • Training	The procedures prepared and training conducted in advance functioned effectively.
	15:36		The reactor core isolation cooling (RCIC) system was manually started (thereafter start/stop occurred as appropriate) (page 126 of Attachment 2).	Omission or delay in conducting manual start of RCIC						Omission or delay in conducting start of RCIC	No.	• Description in procedures • Training	The procedures prepared and training conducted in advance functioned effectively.
	15:55		Depressurization of reactors (safety relief valves (SRVs) open) was started (thereafter core pressure was controlled by repeated open /shut) (page 126 of Attachment 2). Control of reactors' water level and pressure (depressurization) was conducted by using relevant parts of emergency operation procedures (EOP) [symptoms basis] (page 137 of Attachment 2). Reactor water level was maintained by RCIC (page 220 of Main Text).	Failure to maintain reactor water level due to an operational error	Core damage due to failure to maintain reactor water level					Operational error	No.	Procedures (EOP) (page 137 of Attachment 2) Training	The procedures (EOP) prepared and training conducted in advance functioned effectively (maintaining reactor water level, depressurization and transfer to alternative water injection).

Table 5.3-1 result of Analysis of accident response（4/11）

Date and Time		(1) Event occurred	(2) Response	(3) Anticipated errors related to response		(4) Factors of occurrence of anticipated errors						(5) Reasons why factors of occurrence of errors could be prevented or overcome	(6) Lesson
						Category							
Date	Time			Description of errors	Events caused by occurrence of anticipated errors	Management	Software	Hardware	Environment	Liveware	Occurrence of supposed secondary cause	Description	
	15:57	Circulation water pumps (A) and (B) were automatically stopped (page 126 of Attachment 2).											
Maintaining of reactor water level and cooling of containment vessel													
March 11			As it was not possible to start the residual heat removal (RHR) system, which has functions to inject water to cool reactors and for heat removal after the depressurization of a reactor, because emergency component cooling system pumps were unavailable as a consequence of the tsunami, in order to prepare for water injection cooling to reactors after stopping RCIC, preparation of an alternative water injection by means of make-up water condensate (MUWC) system, which had been introduced as an accident management (AM) measure, was commenced (page 137 of Attachment 2). Because the power to drive valves necessary for configuration of line was lost as a consequence of the tsunami, manual opening operation was conducted on site. After configuration of line was completed, injection valves were opened from the central control room, and then water injection capability was confirmed (page 138 of Attachment 2).	Configuration of alternative water injection by means of MUWC could not have been completed before RCIC became unavailable.	Core damage due to failure to maintain reactor water level		Description of line configuration is not arranged as in the procedures.				No.	Line AM guidance procedures prepared as a measure against AM	Alternative water injection by means of MUWC, which had been introduced as an accident management measure, functioned effectively.
	17:35		Because the possibility of reactor coolant leakage in reactor containment vessels could not be denied, it was judged that the specified event pursuant to Item 1 of Article 10 of the Act on Special Measures Concerning Nuclear Emergency Preparedness had occurred, and accordingly, it was reported to the competent authorities, etc. at 17:55. It was later judged that it did not correspond to such specified event (page 126 of Attachment 2).										
	17:53		The drywell (D/W) cooling system was manually started (page 126 of Attachment 2). With the expectation of causing suppression against the pressure increase of PCV, D/W cooling system (no cooling source) was manually started. A drop in D/W temperature was observed immediately after the start, and this information was reported to the Unit 3 and Unit 4 shift chiefs. Following this, said shift chiefs conducted similar response and observed a drop in D/W temperature (page 138 of Attachment 2).	D/W cooling system is unavailable due to loss of offsite power.					Loss of offsite power		No.	Offsite power was available.	
	18:33		Because of the failure to start the facility with the reactor heat removal function, it was judged that the specified event pursuant to Item 1 of Article 10 of the Act on Special Measures Concerning Nuclear Emergency Preparedness had occurred and accordingly, it was reported to competent authorities, etc. at 18:49 (page 126 of Attachment 2).										
			By means of SRV, reactor pressure was gradually decreased to such pressure level that water injection by MUWC became possible (page 220 of Main Text).										
March 12	0:00		Alternative water injection by means of MUWC was started (page 127 of Attachment 2). Water injection to reactors using a combination of RCIC and MUWC was started (page 216 of Main Text)	MUWC is unavailable.				Damage to MUWC system due to earthquake	Loss of offsite power		No.	• It remained free from earthquake damage thanks to the resistance capability of equipment of MUWC, which was used for AM but whose category of earthquake-resistant design was classified as base load system. • Since offsite power was available, it was possible to use MUWC.	The earthquake-resistant design functioned effectively. (Earthquake-resistant capability of base load equipment)
	3:50		Fast depressurization of reactors was started (page 127 of Attachment 2).										

Table 5.3-1 result of Analysis of accident response (5/11)

Date and Time		(1) Event occurred	(2) Response	(3) Anticipated errors related to response		(4) Factors of occurrence of anticipated errors						(5) Reasons why factors of occurrence of errors could be prevented or overcome	(6) Lesson
						Category							
Date	Time			Description of errors	Events caused by occurrence of anticipated errors	Management	Software	Hardware	Environment	Liveware	Occurrence of supposed secondary cause	Description	
	4:56		Fast depressurization of reactors was completed (page 127 of Attachment 2).										
	4:58		RCIC was manually isolated in order to decrease steam pressure to drive the RCIC turbine in association with reactor pressure drop while maintaining conditions under which it was possible to maintain the reactor water level by MUWC (page 220 of Main Text). As a result, it was possible to maintain the reactor water level as high as the normal water level and switch-over to water injection by low pressure system could be made seamlessly (page 220 of Main Text). After this, the reactor water level was controlled only by MUWC (page 127 of Attachment 2) (page 216 of Main Text).	Occurrence of blank period during which water level could not be maintained by RCIC or MUWC due to an operational error	Core damage due to failure to maintain reactor water level					An operational error	No.	• Procedures were well prepared. • Training was conducted. • Personnel were dispatched and assigned to communicate with the Emergency Response Headquarters so that shift operators could dedicate themselves to operation.	• Procedures prepared and training conducted in advance functioned effectively. • Importance of backup so that operators in the central control room can dedicate themselves to operation.
	5:22		Because temperature and pressure in suppression chamber (S/C) rose due to RCIC exhaust and reactor depressurization by SRV (page 127 of Attachment 2) and the temperature in S/C rose to no less than 100℃, it was judged that this was an event to which Article 15 of the Act on Special Measures Concerning Nuclear Emergency Preparedness (loss of suppression function) applies (page 217 of Main Text).										
	6:20		The power station Emergency Response Headquarters investigated measures and methods for cooling of S/C. A shift chief instructed operators to utilize the discharge line from FCS coolers to S/C and conduct cooling of S/C by MUWC or MUWP in accordance with the instructions given by the headquarters (page 138 of Attachment 2). S/C cooling was conducted by using flammable gas control system (FCS) cooling water (MUWC) (page 127 of Attachment 2).										
	7:10		Drywell spray was conducted using MUWC (thereafter conducted as appropriate) (page 127 of Attachment 2).	Omission or delay in conducting drywell spray	Reaching maximum operating pressure of drywell due to omission of temporary suppression of temperature and pressure, or conducting containment vessel vent	Hesitating to conduct drywell spray from the viewpoint of property protection					No.	The sense of making safety the first priority was thoroughly kept in mind.	
			Alternative water injection to reactors by MUWC was switched to drywell spray and S/C spray as appropriate and efforts to suppress PCV pressure increase were conducted (page 138 of Attachment 2).										
			Drywell and S/C spray by means of MUWC was introduced as one of measures for accident management and reflected in EOP (page 217 of Main Text).	Oversight of D/W and/or S/C spray operation by means of MUWC		Oversight of D/W and/or S/C spray operation by means of MUWC					No.	Procedures were reflected in EOP. Training	• Procedures prepared in advance functioned effectively.
	7:37		S/C spray was conducted using MUWC (page 127 of Attachment 2).										
	7:45	The Prime Minister directed people in the zone within 3 km from the power station to evacuate and people in the zone within 10 km therefrom to remain indoors (page 127 of Attachment 2).											
	7:45	S/C cooling using FCS cooling water was stopped (page 127 of Attachment 2).											

Date and Time		(1) Event occurred	(2) Response	(3) Anticipated errors related to response		(4) Factors of occurrence of anticipated errors						(5) Reasons why factors of occurrence of errors could be prevented or overcome	(6) Lesson
						Category							
Date	Time			Description of errors	Events caused by occurrence of anticipated errors	Management	Software	Hardware	Environment	Liveware	Occurrence of supposed secondary cause	Description	
Preparation of PVC pressure-proof vent													
March 12	10:21		Configuration of PCV pressure-proof vent-line was commenced (page 127 of Attachment 2). In contrast to containment vessel pressure-proof vent after core damage under accident management, this is done for the purpose of decreasing pressure that has risen in containment vessels by releasing steam, etc. through pools in suppression chambers while maintaining the integrity of the core through continuous water injection to reactors in the case that there is delay in restoration of reactor heat removal function (page 217 of Main Text).										
			It was recognized by the power station Emergency Response Headquarters that PCV pressure tended to rise because the plant parameters, such as reactor water level and D/W pressure, could be obtained through communication with the central control room (PHS) (page 139 of Attachment 2).	Delay in commencement of preparation for vent	Vent cannot be conducted when necessary. (As for results, it never reached the pressure under which vent should have been required.)	・Cannot recognize that preparation for vent takes much more time than expected. ・Cannot understand the risk resulting from the delay of RHR recovery efforts.			Delay of RHR recovery efforts		No.	・Because preparation for vent took much more time than expected at the Fukushima Daiichi nuclear power plant, the head office recommended earlier preparation for vent. The Headquarters at 2F was also aware of the necessity of vent preparation. ・RHR recovery efforts went smoothly.	Importance of establishing a plan with foreseeability.
			Anticipating that it would take time to restore reactor heat removal function, it was determined that configuration of the line for the PCV pressure-proof vent (the condition that one action of opening operation an exit valve at S/C side remained untaken) should be conducted (page 139 of Attachment 2).										
			Because the power for pressure-proof vent-line inlet valve- (air controlled valves) driven electromagnetic valves for air control was lost, the opening operation could not be conducted. The power station Emergency Response Headquarters, therefore, investigated countermeasures (a method of connecting a small cylinder directly to the valve driving part or a method of performing the opening operation by restoring power to such electromagnetic valve), judged that there should be a time margin in view of the trend of PCV pressure rising, and determined that the opening operation should be conducted by restoring power to such electromagnetic valve (page 139 of Attachment 2).										
	14:05	It was confirmed that the government's evacuation action of evacuated residents had been completed.											
	17:39	The Prime Minister directed the population in the zone within 10 km from Fukushima Daini Nuclear Power Station to evacuate (page 127 of Attachment 2).											
	18:30		Configuration of PCV pressure-proof vent-line was completed (page 127 of Attachment 2).										
(March 13)		Drywell pressure was gradually rising due to loss of the function to remove heat from reactors, and it reached design pressure (0.38 MPa [abs]) on the third day, but never reached maximum operating pressure (0.41 MPa [abs]) (page 220 of Main Text).											

Table 5.3-1 result of Analysis of accident response（7/11）

Date and Time		(1) Event occurred	(2) Response	(3) Anticipated errors related to response		(4) Factors of occurrence of anticipated errors						(5) Reasons why factors of occurrence of errors could be prevented or overcome	(6) Lesson
						Category							
Date	Time			Description of errors	Events caused by occurrence of anticipated errors	Management	Software	Hardware	Environment	Liveware	Occurrence of supposed secondary cause	Description	
Restoration of residual heat removal system													
(March 11)			The power station Emergency Response Headquarters examined the situation of damage to the facility through site observation and made a plan for restoration strategy and prioritization of works (page 217 of Main Text).	Omission of prioritizing restoration works among units	Delay in restoration of plant, which is of high priority	Failure to perform prioritization					No.	The plant data which had been regularly collected by the central control room were arranged into trends by the Emergency Response Headquarters, containment vessel pressure rising trends were monitored, the time when rupture disk pressure would reach setting pressure was estimated, and then prioritization among units was determined.	Importance of early planning and arrangement of materials based on site observation.
			It was, however, unable to dispatch a restoration team to the site immediately because the situation of the site was such that no lighting was available, extensive debris and openings posed danger, the paging system could not be used as a means of communication for evacuation at the time of tsunami striking under continuous announcement of after-shocks and large tsunami warnings and in addition, PHS could not be used in the buildings damaged by the tsunami (page 217 of Main Text).	Further delay in site observation	Delay in establishing a restoration plan due to delay in observation of site situation			Means of communication unavailable at site.	• No lighting at site • Dangerous environment due to existence of extensive debris and openings	Fear of the tsunami striking again during site observation	Yes.	• Sense of responsibility overcoming fear • A means to communicate about sheltering was established by arranging messengers according to circumstances, etc.	• Importance of overcoming fear with a strong sense of mission to restore after an accident • Establishment of countermeasures and an implementation structure to perform the countermeasures by the power station Emergency Response Headquarters according to circumstances • Preparation of portable temporary lighting
			During site observation at Hx/B, desperate efforts to examine the damage situation were made, relying only on a small number of flashlights available in the unlit darkness, being submerged into pool of water made by the tsunami and clearing over debris and waste, and, repeatedly evacuating to high ground at every after-shock while tsunami warnings were continuously announced (page 139 of Attachment 2).										
	(Around 22:00)		It was around 22:00 on March 11 when a restoration team commenced examination of the damaged site, such as a seawater heat exchanger building near the sea coast, etc. after having established a means of communication, using messengers, with regard to sheltering and having prepared safety equipment.										
March 12			Based on site examination results given by the restoration team (conditions of equipment and situation of flooding of power system (page 139 of Attachment 2)), the power station Emergency Response Headquarters determined the policy that priority should be given to conducting restoration works for residual heat removal component cooling pump (D), residual heat removal seawater pump (B) and emergency diesel generator facility cooling system pump (B) in the seawater heat exchanger building (page 217 of Main Text). Regarding residual heat removal component cooling pump (D) and emergency diesel generator facility cooling system pump (B), the policy that motors should be replaced was determined (page 217 of Main Text).	• Fault in observation of site situation • Omission of prioritizing restoration works	Delay in restoration works due to establishment of an incorrect wrong restoration policy	Omission of prioritizing restoration works due to absence of governance of the power station Emergency Response Headquarters			• Deterioration of environment of the location of the power station Emergency Response Headquarters (scattering of furnishings, etc.) • Failure to take out drawings to be used for restoration works as a consequence of the earthquake	Deficiency in skills to observe the situation of the facility in question	No.	•Available equipment (pumps) was selected based on the results of site observation, and these results were indicated in a matrix, and priority equipment to be repaired in order to restore the heat removal function were selected. • Adequate judgment of the power station Emergency Response Headquarters • Routine skill concerning repair of such facility ・The seismic isolation building was effective although it lost the power for 2 to 3 hours due to the tsunami. • Countermeasures had been taken for racks for documents in an office building based on the experiences of the 2007 Chuetsu Offshore Earthquake, and documents could be taken out.	• Importance of sharing information • Importance of the power station Emergency Response Headquarters grasping the situation (situation of damage to equipment) • Importance of the power station Emergency Response Headquarters establishing an adequate response strategy (prioritization of restoration) • The important anti-seismic building functioned effectively. • Careful consideration with regard to earthquakes is effective (fixing furnishings, etc.)
			Urgent procurement of motors was requested to Kashiwazaki Kariwa Nuclear Power Station. Kashiwazaki Kariwa Nuclear Power Station gave proactive assistance in procuring the equipment and materials required by Fukushima Daiichi and Fukushima Daini Nuclear Power Stations (page 217 of Main Text).	Delay in support from the side of Kashiwazaki Kariwa Nuclear Power Station	Delay in restoration	Delay in establishing cooperation across organizations				Poor communication for mutual understanding between organizations (communication for mutual confirmation of usable motor models, etc.)	No.	Kashiwazaki Kariwa Nuclear Power Station, which is an organization within the same company, also participated in a video conference and shared the situation of Fukushima Daini.	Importance of establishing in advance a structure to allow for swiftly receiving support from outside of the power station (Importance of sharing the situation in order to swiftly receive necessary support from the other nuclear power stations)

Date and Time		(1) Event occurred	(2) Response	(3) Anticipated errors related to response		(4) Factors of occurrence of anticipated errors						(5) Reasons why factors of occurrence of errors could be prevented or overcome	(6) Lesson
						Category							
Date	Time			Description of errors	Events caused by occurrence of anticipated errors	Management	Software	Hardware	Environment	Liveware	Occurrence of supposed secondary cause	Description	
			Regarding motors for some of the emergency component cooling system pumps of Unit 1, insulation resistance could not be recovered in spite of cleaning the motors. Therefore, motors were transported from Mie Prefecture to Fukushima Airport by a Self Defense Forces transport plane. As soon as they arrived at the site, installation and connection with temporary cables were commenced immediately and were completed by the evening of March 13 (page 140 of Attachment 2).	Delay in orders of motors from manufacturers	Delay in restoration	Delay in locating motors Delay in response by contractors					No.	• A procurement list had been prepared in advance. • Good business relationships had been established; even though requests were only made by telephone, contractors made quick responses favorably.	Importance of establishing in advance a structure to allow for swiftly receiving support from outside of the power station (Preparation of procurement sources of necessary equipment and materials and information about availability in advance)
				Delay in transportation of motors	Delay in restoration				Delay in long distance (from Mie Prefecture to Fukushima) transportation due to deterioration of road traffic conditions due to earthquake damage		No.	• Transportation by a Self-Defense Forces transport plane • The head office's Emergency Response Headquarters for disasters made a request to the Self-Defense Forces.	Importance of establishing in advance a structure to allow for swiftly receiving support from outside of the power station (Importance of swift support of government organizations)
			The power station Emergency Response Headquarters requested from the head office the urgent procurement of high voltage power source cars, portable transformers and cables in order to connect motors with power panels remaining free from the consequences of the tsunami and power source cars, because power panels supplying power to motors of pumps had lost function due to flooding (page 217 of Main Text).	Delay in support from the side of the head office	Delay in restoration	Delay in establishing cooperation across organizations				Poor communication for mutual understanding between organizations (communication for mutual confirmation of necessary equipment and materials, etc.)	No.	• The head offices' Emergency Response Headquarters for disasters also had control over organizations within the same company outside the nuclear power division (advantage of vertical integration of generation and transmission). • Corporate-wide emergency response manual	Importance to establish in advance a structure to allow for swiftly receiving support from outside of the power station (Advantage of utilities vertical integration of generation and transmission)
			Among the power panels which were available and remained free from the consequences of the tsunami, it was determined that a power panel in a radioactive waste treatment building should be used. The reason why the panel in the radioactive waste treatment building, which was the farthest from the seawater heat exchanger building, was chosen was that since there would be fewer complicated cabling works and most routing would run on the ground along a straight road, it would be appropriate for laying heavy and hard cables manually. This was the judgment made by a restoration team based on the actual situation of the site (page 218 of Main Text).	Selection of other routing for cabling works	Delay in restoration of power	Poor conduct in taking up the opinions of each team member within the team				No understanding of actual situation of manual cabling works	No.	There was the capability to respond according to circumstances to such unexpected events, such as the case of manual cabling works. • Understanding of cabling works obtained through routine maintenance • Calm judgment within the team	Importance of establishing an adequate response policy • (Proper selection of routing for cabling works) • (Adequate judgment made by a leader of the power station Emergency Response Headquarters based on proper implementation of function by each team and information and/or opinions properly taken up from each team)
			The equipment and materials which the head office had been requested to procure arrived one after another at Fukushima Daini by around 6:00 on March 13. Incidentally, transportation took longer than expected as a consequence of mobile phones being unavailable between the power station Emergency Response Headquarters and the transportation team, etc. (page 218 of Main Text).	Unavailability of a driver for a large trailer to transport heavy cargoes to the power station, including cargoes from places other than Kashiwazaki						Refusal by drivers of companies to which transportation was outsourced to enter the controlled evacuation area	Partially occurred.	• Transportation by drivers with licenses to drive large vehicles belonging to TEPCO subsidiaries and subcontractors working in the power station • Transportation by governmental emergency response organizations such as Self-Defense Forces	• Appointment of drivers with licenses for large vehicles as emergency personnel • Advance preparation of a structure to allow for receiving support from the Self-Defense Forces and so on more thoroughly (preparatory radioactive education to be provided for Self-Defense Forces personnel, etc.)
			It was decided that temporary cables would be transported from outside by helicopter. It was hurriedly decided that a field or a baseball field would be used as a heliport, and works to prepare to receive cargo were conducted overnight; the fence around the baseball ground was removed before dawn on March 12 and twenty (20) cars owned by employees were arranged for lighting to guide helicopter landing. Under bad road conditions resulting from the earthquake, car transportation was also arranged (page 139 of Attachment 2).	• Delay in preparing to receive, such as guiding lighting, etc.	Delay in restoration of power	Delay in establishing preparedness to receive, such as guiding lighting, etc.					No.	Governance of the power station Emergency Response Headquarters functioned effectively.	Establishment of a plan for countermeasures according to circumstances in line with the situation of the site and a structure for the implementation of the countermeasures
			The total length of temporary cables amounted to as much as 9 km for the four units of the plant. Laying works for these cables were completed manually by as many as 200 personnel, including employees from the distribution division and workers of subcontractors no later than around 23:30 on March 13 (page 218 of Main Text).									• Head office Emergency Response Headquarters had control over divisions other than Nuclear Power Division in the same company (advantage of vertical integration of utilities). • Mass procurement of cables,	

Table 5.3-1 result of Analysis of accident response (9/11)

Date and Time		(1) Event occurred	(2) Response	(3) Anticipated errors related to response		(4) Factors of occurrence of anticipated errors						(5) Reasons why factors of occurrence of errors could be prevented or overcome	(6) Lesson
						Category							
Date	Time			Description of errors	Events caused by occurrence of anticipated errors	Management	Software	Hardware	Environment	Liveware	Occurrence of supposed secondary cause	Description	
			For the cabling works, several combined teams consisting of 40 personnel including employees and workers of on-site subcontractors as well as personnel from the distribution division of each branch office (employees and subcontractors) were formed, and works were conducted as after-shocks occurred and debris was scattered around as a consequence of the tsunami. The works were conducted at nighttime, relying on head lights since it was completely dark (page 140 of Attachment 2).	Necessary workers cannot be arranged.	Delay in restoration of power	• Divisions other than the Nuclear Power Division refuse to dispatch personnel to the site where nuclear disaster has occurred, • Subcontractors hesitate to dispatch their employees to the nuclear emergency evacuation area.		Necessary stock of equipment and materials is not available.		Dispatched personnel refuse to enter the site declared a nuclear emergency evacuation area.	No.	etc. was possible as the company was a vertically integrated electric power company including distribution and construction divisions. • Company loyalty: Divisions other than the Nuclear Power Division had a strong will to stop the nuclear disaster. • The subcontractors' sense that the plant belonged to them (preparedness of on-site subcontractors stationed at the power station) • Regarding requests to contractors for restoration works, the head office's Procurement Department had made agreements with contractors and manufacturers concerning support and cooperation in case of "emergency disasters" and "emergency events." Within this framework, special cooperation could be requested.	• Importance of establishing in advance a structure to allow for receiving swift support from organizations outside the power station (advantage of utilities with respect to vertical integration of generation and transmission). • Importance of establishing a routine relationship with on-site subcontractors who provide cooperation in case of emergency
			Temporary cables were made up of a package of three (3) 2-3 cm thick wires twisted, and one (1) 200 m long cable weighed no less than 1 t. It was required that the cable be laid as long as approximately 800 m from the RW building to Hx/B. Under normal conditions, the work should have been conducted by machine over the course of several days; this time, however, the works were conducted manually at a very high pace and the cabling work for total extension of approximately 9 km was partly completed on March 12 and mostly completed on March 13 (page 140 of Attachment 2).										
			Based on continuous surveillance and estimation of plant data (containment vessel pressure) made by a technical team of the power station Emergency Response Headquarters, first priority was originally given to the cabling work for Unit 2, of which containment vessel pressure had been rising fastest. Since, however, it was discovered before dawn on March 13 that the containment vessel pressure of Unit 1 was rising faster than that of Unit 2, the priority of cabling work was changed to Unit 1 (page 218 of Main Text).	• Omission of prioritization of cabling works among units • Mistake in selection of priority unit for cabling works	Unit 1 drywell pressure reaches maximum operating pressure, or containment vessel vent shall be conducted.	Omission of prioritization of cabling works among units due to absence of governance in the power station Emergency Response Headquarters	A team in charge of surveillance and estimation of plant data is not clearly identified.					• Governance of the power station Emergency Response Headquarters • Clear identification of division of the roles and tasks to be performed by each team (technical team) of the power station Emergency Response Headquarters	Importance of the power station Emergency Response Headquarters establishing an adequate policy for response • (Prioritization of cabling works among units) • (Adequate judgment made by a leader of the power station Emergency Response Headquarters based on proper implementation of function by each team, and information and/or opinions properly taken up from each team)
			Observation of condition of mechanical parts for pumps and installation of motors were conducted in parallel with the cabling works (page 218 of Main Text)	Delay in works	Delay in restoration	Necessary personnel cannot be arranged.			Not only personnel for emergency response consisting of employees (200 employees) but also substantially almost all employees (approximately 400 employees) and many of the subcontractors' employees (approximately 1,900 employees) remained at the power station for emergency response. Therefore, there was a greater shortage of rations for personnel than expected.	No skill for the works	No.	• According to the manual for emergency disaster preventive activities, food for 250 personnel for three (3) days and drinking water for 50 days. In addition, food for shift operators for 40 days and food for 60% of office personnel for two (2) weeks had been stocked as countermeasures against influenza A (H, N). This food was distributed to personnel at the power station at the time of the earthquake disaster, and as a result, demand was filled for three (3) days. On March 13, support goods from the other branch offices arrived at the power station. • Preparedness of on-site subcontractors stationed at the power station • Maintenance of each piece of equipment had been continuously ordered from the same company.	• Necessity to stock appropriate amounts of food and drinking water • Importance of establishing a routine relationship with on-site subcontractors who provide cooperation in case of emergency

Table 5.3-1 result of Analysis of accident response (10/11)

Date and Time		(1) Event occurred	(2) Response	(3) Anticipated errors related to response		(4) Factors of occurrence of anticipated errors						(5) Reasons why factors of occurrence of errors could be prevented or overcome	(6) Lesson
						Category							
Date	Time			Description of errors	Events caused by occurrence of anticipated errors	Management	Software	Hardware	Environment	Liveware	Occurrence of supposed secondary cause	Description	
March 13	20:17		Residual heat removal component cooling seawater pump (B) was manually started (page 127 of Attachment 2).										
	21:03		Residual heat removal component cooling seawater pump (D) was manually started (page 127 of Attachment 2).										
March 14	1:24		Residual heat removal (RHR) system pump (B) was manually started (S/C cooling mode was started). Residual heat removal component cooling seawater pump (B) was manually started. It was judged that the occurrence of the specified event pursuant to the Act on Special Measures Concerning Nuclear Emergency Preparedness should be called off (page 127 of Attachment 2).										
	1:44		Emergency diesel generator facility cooling system pump (b) was manually started. Residual heat removal component cooling seawater pump (B) was manually started (page 127 of Attachment 2).										
	3:39		RHR (B) spray mode was started. Residual heat removal component cooling seawater pump (B) was manually started (page 128 of Attachment 2).										
	10:05		Water injection to reactors by RHR (B) low pressure water injection mode was conducted (page 128 of Attachment 2) While injection of water in suppression chambers to reactors via low pressure water injection line by RHR pump (B) was started in order to perform early cooling of reactor water in addition to cooling of suppression chambers, reactor water was made to flow into suppression chambers via main steam safety relief valves, and emergency cooling measures were taken using the line where water in suppression chambers was cooled by RHR heat exchanger (B) and was injected to reactors again via a low pressure water injection line (S/C → RHR pump (B) → RHR heat exchanger (B) → low pressure water injection line→ reactor → SRV → S/C).										
	10:15		Since the temperature of S/C dropped to less than 100°C, it was judged that the specified event pursuant to Article 15 of the Act on Special Measures Concerning Nuclear Emergency Preparedness could be cancelled. Accordingly, it was reported to authorities, etc. at 10:35 (page 128 of Attachment 2).										
	17:00		Reactor water temperature dropped to less than 100°C and reactor cold shutdown was achieved (page 128 of Attachment 2).										
March 16	5:12		As containment vessel atmosphere monitoring showed a trend of Hydrogen concentration increase (Hydrogen approximately 5%, Oxygen approximately 2%), the flammable gas concentration control system was operated. The concentration of Hydrogen and Oxygen was controlled well to prevent them entering into the flammable range (page 128 of Attachment 2).										

Table 5.3-1 result of Analysis of accident response (11/11)

Date and Time		(1) Event occurred	(2) Response	(3) Anticipated errors related to response		(4) Factors of occurrence of anticipated errors						(5) Reasons why factors of occurrence of errors could be prevented or overcome	(6) Lesson
Date	Time			Description of errors	Events caused by occurrence of anticipated errors	Category							
						Management	Software	Hardware	Environment	Liveware	Occurrence of supposed secondary cause	Description	
			The increase of Hydrogen concentration is considered as follows: It is possible that before cold shutdown, an oxidization reaction of zinc (paint, etc.) and so on in the containment vessel could have occurred under conditions of radiolysis and high temperature and humidity. It is also considered to be possible that after the cold shutdown, an oxidization reaction of zinc and so on could have continued partially even though the temperature of the containment vessel dropped. In addition, it is estimated that under pre-cold shutdown conditions, the dehumidifier for containment vessel atmosphere monitoring could not have functioned due to the loss of cooling sources, and since sample gas temperature and humidity exceeded service conditions, it deviated from the measurements. After cold shutdown, however, sample gas dehumidifier function was recovered. It should be remarked, however, that the reliability of the Hydrogen concentration meter needs investigation (page 220 of Main Text).										A method of monitoring Hydrogen concentration is being developed based on the experiences in Fukushima Daiichi.
Others													
March 11			The main administration office evacuated to the parking area that had been designated as an evacuation site, and conducted confirmation of employee safety. Emergency response personnel then moved to the important anti-seismic building while other employees evacuated to a field (page 136 of Attachment 2).	The safety of some employees could not be confirmed.	It is required to conduct confirmation of missing employees in addition to restoration works, which has an adverse impact on the restoration works.	Failure to direct evacuation to the designated place and confirm personnel safety					No.	• There were provisions in the manual for emergency events. • Training was conducted.	

5.4 Important lessons obtained from the analysis

As a result of the analysis, the following points were obtained as important lessons. It is desirable that the contents of these lessons are also applied in other power plants as preparations for large-scale accidents.

① Appropriate governance of the response headquarters at the power plant.

Important features required in the on-site headquarters are as follows:

- An accurate understanding of the circumstances of the accident (plant parameters, status of damage of equipment).
- Each team of the headquarters shall fulfill the assigned tasks as shared among the teams.
- The conductor of the headquarters shall accurately pick up the opinions/information from each group and ensure that they are shared.
- Develop appropriate response strategy. (Example: making decisions on the recovery plan priority, appropriate routing of cable laying)
- For the implementation of individual response, create appropriate ad hoc measures in line with the situation at hand, and establish a proper framework for implementation. (Example: Establishing a reliable channel for communication with the patrolling team for the contingency of a tsunami warning.)
- Not only respond to the development of the event, but prepare proactive measures. (Example: line configuration in preparation for the containment vessel vent.)

② Establishment of a system to receive immediate assistance, supply of materials from external organizations.

For the restoration works of the residual heat removal system, equipment and materials such as motors usable for the residual heat removal system pump and a large amount of cables spanning 9 km were quickly procured from outside, and large number of personnel, including workers skilled in cable laying, were dispatched to help.

These quick arrangements can be attributed to following factors.

- The power company is vertically integrated to handle power generation and transmission, so the human resources for cable laying and equipments/materials such as cables were all available in the same company, making rapid procurement possible.
- The cooperating companies are stationed in the plant site, and a close relationship with them has been established on a day-to-day basis to facilitate cooperation in emergency situations. To ensure quick procurement of materials and equipment, development of the following is desirable:
- Maintaining a list of suppliers for a variety of equipment.
- Secure a driver with a license for large vehicles for carrying large and heavy equipment (for receiving the supply of cargo from companies which are not allowed to let their staff enter a nuclear disaster evacuation zone.)
- Support by government agencies including transportation of heavy and large cargo by SDF helicopters.

③ It is desirable to foster a culture of safety among all related personnel, including not only TEPCO employees but also the workers of cooperating companies, for the purpose of strong determination and a sense of mission to achieve convergence in the event of an emergency, even in a hazardous environment such as high radiation dosing from the nuclear disaster caused by the tsunami due to the aftershocks.

④ Seismic design proved effective.
As intended, equipment in the safety systems that have been installed with state-of-the-art seismic design worked without failure, even in ground motion. In addition, the equipment used for the conventional AM system (MUWC) also withstood ground motion beyond the design standard by its own margin and kept functioning without failure.

⑤ Maintenance of procedure and staff training in advance worked well.
Among other factors, the most notable ones which enabled a variety of smooth and swift responses were that procedure manuals were prepared in advance and all the operating personnel and workers, being familiar with the procedures, responded appropriately according to the procedures as prescribed in the manuals.

⑥ The importance of the back-up structure to allow the operating staff of the central control room to concentrate on the operation of the reactor.
The operating personnel of the central control room received overall support from the plant so as to be able to concentrate on the operation of the reactor. This included maintaining normal shifts, increasing the number of patrollers, dispatching liaisons for better communication, and centrally controlling contact with off-site entities by the emergency headquarters. Successful convergence of the accident can be attributed to these support systems.

⑦ Peripheral earthquake preparedness other than seismic design of facilities and equipment or emergency operating procedures was also effective.
The plant already had variety of earthquake preparations in place from the Chuetsu-oki Earthquake, and these proved effective this time. Example: Fastening and fixing loose furniture in the main control room and offices, preparing temporary lighting and handheld microphones, etc.

6. Emergency response as seen from the viewpoint of the human factor

With respect to the emergency response at Fukushima Daini, some situations that actually occurred were not described in the manual or handled in the usual training drills, and so the capabilities of plant organizations and individuals to handle the situation were tested. In these difficult circumstances, their response was generally adequate and under good leadership, and it successfully prevented the spread of the accident, leading to convergence.

We have analyzed the background from the viewpoint of the human factor. Table 6-1 shows the results of analysis by the m-SHEL model. We also made analysis based on a method of analyzing the resilience of the organization. The results are shown in Table 6-2.

In terms of human factors, there were considered to be two major factors that contributed to the successful convergence of the accident: the appropriate management of the accident response, and the effectiveness of the various measures that had been prepared in advance.

In order to ensure the effectiveness of management, it is necessary that the senior management perform good leadership with sufficient knowledge, and the organization should be well disciplined, which requires ongoing efforts to establish a good work environment under normal circumstances.

Important areas that require advance preparation may be: establishment of an emergency system (including an external support system), maintenance of manuals, cultivation of a culture of safety, education and training, stockpiling of food, and installation of a seismic isolation building. These requirements also call for ongoing efforts under normal circumstances.

Some fortunate circumstances were observed in this accident, such as a single line of the external power supply remaining online by chance, there being relatively insignificant tsunami damage to some of the vital facilities, or accident convergence being achieved in a relatively short time. However, in preparing for future accidents, we must assume that we cannot expect these fortunate circumstances.

We also performed analysis focusing on the resilience of Fukushima Daini as an organization. We identified the good practices of the organization from four perspectives and concluded that the organization as a whole is well-balanced. Finding these good practices also indicated that the strength of the organization comes from ongoing efforts under normal circumstances (development of manuals and training). In addition, it is necessary that each and every member of personnel hold a strong sense of mission for safety. This serves as the foundation to support the strength of these organizations. We have been reminded once more that fostering a culture of safety is truly important.

Table 6-1 Human factors that contributed to the convergence of the accident

Management	Software	Hardware	Environment	Live ware
● The pre- determined emergency system clearly defined role assignment. System established as soon as the earthquake hit and utilized effectively. ● Senior management exercised strong and unperturbed leadership when making analysis for accurate instructions. ● Intent of instructions clearly understood by all personnel through information sharing. ● Action plans were prepared not only in response to actual event development but in the sense of proactive strategy. ● A system to receive quick support from off- site was in place. Procurement of equipment and materials was reasonably quick. ● A system was established so that operators in the central control room could concentrate on the operation of reactor.	● Procedures prepared in anticipation of the main condenser being unusable as a heat sink. ● Root contact was in place for mobilizing emergency response personnel. ● Instructions were effective. ● Restoration team dispatched patrol team after determining evacuation procedures in advance. ● A video conference system was available with the head office and Kashiwazaki-Kari-wa. Multiple communication channels were available.	● Important seismic isolation building functioned. ● Power source remained functional. ● RCIC was available thanks to only minor inundation by the tsunami. ● Radiation management equipment was free of earthquake and tsunami damage, and was secured. ● AM equipment was functional without failure, even for ground motion beyond the design intensity.	● Outside disturbance was minimal and plant was mostly able to handle the situation at its discretion. ● Earthquake occurred on a weekday afternoon and the emergency response system was smoothly established. (Necessary personnel swiftly secured) ● Sufficient stockpile of drinking water and food was available. ● Emergency response headquarters able to carry out operations at the important seismic isolation building. ● A grip bar was available on the operation panel of the central operation room for operators to hold on to. ● Cabinets were fastened and secured to prevent tripping. ● Instruments remained functional, so the situation could be confirmed. ● Proper lighting and communications were maintained, so the work environment was not significantly adverse. ● Prospect of accident convergence foreseen in relatively short time.	● Sufficient knowledge to predict the progress of events to plan effective countermeasures. ● Operators performed adequate operations without mistakes. ● In the event of an emergency, all personnel maintained a strong sense of mission to achieve convergence even in a hazardous environment. (Such psychological culture of safety was fostered at the plant.) ● All personnel were well educated and trained to execute duties properly in accordance with instructions. ● Some TEPCO employees had professional expertise in driving large vehicles.

Table 6-2 Analysis of the resilience of Fukushima Daini

Responding	Monitoring	Anticipating	Learning
• Equipment still in operating condition after the earthquake could be confirmed at the central operating room. • Personnel with operator experience were dispatched to the central operating room so that operating personnel could concentrate on operating the reactor. • An emergency system was immediately established after the earthquake. • A patrol team was quickly organized and dispatched to check conditions at site. • Recovery procedures were quickly prepared and each team began work after confirming tasks. • Dry well spray was conducted to cool the containment vessel. • Early arrangements for procurement of equipment and support of workers were initiated.	• Operation of equipment was confirmed by the lamps in the central operating room. • Site patrol was conducted to check damage to equipment. • The main parameters of the plant were continuously monitored at the headquarters. • Information from each group was visually displayed on a white board to ensure sharing among all staff. • Smooth communication between each group and headquarters for close instructions and progress reports maintained through frequent and mutual reports, advice and consultations. • The integrity of the instruments was confirmed by monitoring the continuity of parameter variations.	• Power source recovered quickly for the worst contingency of total loss of external power. • Recovery procedures were prepared based on plant situation and site patrol findings. • Prioritized recovery plan of units from the changes in parameter and executed in sequence. • Confirmed function of MUWC while RCIC was in operation. • A patrol team was dispatched to the scene only after evacuation procedures were established. • Procurement of equipment and material was arranged as far in advance as possible. • Daily rations of water and food were adjusted for possible prolongation of the situation. • Assuming the worst, containment vessel vent was prepared in advance.	• A video conference system was available with the head office and Kashiwazaki-Kariwa. Multiple communication channels were available. • Based on the experience of the Chuetsu-oki earthquake, a variety of preparations were in place: installation of the important seismic isolation building, a grip bar on the operating panel of the central operation room, and securing of cabinets to prevent tripping. • A system was in place to receive quick support from off- site. • After examination based on the manual, a temporary cooling system configuration of RPV and S/C using one unit of RHR was devised as the operation to be applied.

Resilience: Capability of organization to ensure continuous success in the ever-changing circumstances.

- Responding: Response to incident
- Monitoring: Monitoring of development of incident
- Anticipating: Anticipation of threats and opportunities
- Learning: Learning from past success and failure

7. Lessons

Fukushima Daini's accident response includes a variety of best practices in many aspects from which we can learn valuable lessons. In addition, since the impact of the tsunami at Fukushima Daini was limited compared with Fukushima Daiichi, the parameters and function of equipment were not lost like Fukushima Daiichi and the plant did not suffer such extreme conditions of high pollution or high-dose exposure. Therefore, the lessons taken therefrom should be applicable to many other power plants as practical lessons.

We compiled this section by combining these lessons and the lessons that were found through the analysis in Section 5. We hope that our findings will be used in the future as reference material when introducing accident countermeasures.

7.1 Organization, management, communication

- The basic aspects of accident response are 1. an adequate grasp of the situation, 2. planning immediate action plans and a complete restoration schedule in the longer term, 3. procuring materials and equipment required for the restoration, 4. executing the plan and schedule while monitoring the situation. In addition, it is also important to allocate the manpower necessary for the purpose and give appropriate instructions in a timely manner when sharing information.

- The results of the analysis of the human factor indicate that management is critically important in the event of an accident and suggest that the education and training of the senior management of the plant is especially important.

- Emergency group organization and role assignment were determined in advance, enabling smooth implementation of accident response. Each team was able to fulfill their respective roles in a flexible manner through appropriate and frequent reporting, informing and consultation. One of the most important factors in accident response is the development of a personnel system and the assignment of human resources.

- An experienced operator was dispatched to the central control room to serve as a dedicated liaison in order to convey a variety of information to headquarters or deliver instructions from the Headquarters. As a result, operators could concentrate on the operation of the reactor. At the same time, the Headquarters built a strong support network for the staff by creating a good work environment, including centralizing all contact with the outside including the head office, dispatching patrollers to grasp the situation, and maintaining normal work shifts so that operators could take rest as appropriate from time to time. It is imperative to establish a system that allows operators to concentrate on the operation.

- All the planning of countermeasures was performed by the plant personnel without resorting to the assistance of the plant manufacturers. When determining the priority of the restoration, the first and foremost factor was the common and shared determination of all the personnel to avoid the containment vent. Also, while the management does not address such a system, the circular loop system for cooling organized after the restoration of the seawater system was a practical way to apply know-how. All these good practices seem to be attributable to the usual day-to-day efforts for education and training at the plant, which resulted in the improvement of the knowledge of plant personnel. Under current circumstances where new plants are very seldom constructed, the necessary field of knowledge for plant personnel is safety-related knowledge. It is hoped that further efforts will be made to improve the knowledge of plant personnel, such as accident mitigation through education on the concept of defense in depth.

- Dry well spray, which may have adverse effects upon the equipment in containment vessels, is prescribed in the manual. Therefore, the plant manager decided to carry it at his discretion. Rather than giving priority to preserving the asset value of the equipment, he made this decision based on the idea of safety first in order to ensure the integrity of the containment vessel and hold the execution of containment vent down as far as possible to avoid releasing radioactive materials into the environment. This shows that the culture of safety has firmly taken root there. It is necessary to make daily efforts to foster this culture among all the personnel in the organization, from the plant manager down to the workers.

- The required equipment was supplied in a short time thanks to the external assistance which contributed to the early recovery. It is necessary to establish a quick support system at the head office in an emergency. The agreements for support and co-operation in case of emergency that had been executed with support companies and manufacturers were effective. It is desirable to develop a system for the procurement of materials and equipment at the time of an accident. It may be a good idea to establish cooperation agreements between power companies to enable the lending or quick supply of equipment and materials.

- The restoration work was carried out through joint efforts together with the work force of cooperating companies, which made the early recovery of equipment possible, contributing to the early convergence of the accident. Subcontractors should be included when accident response preparations are carried out in order to enhance cooperative relationships through training and through fostering a sense ownership.

- Early recovery of external power was achieved with the help of the engineering division. Such support from within the same company was an advantage in terms of the response capabilities. When assuming a situation in a large-scale disaster that requires inter-departmental cooperation within the company, it is desirable to build up a system and mutual understanding for internal cooperation through training etc.

7.2 Advance preparation (equipment, manual, training)

- Because the accident occurred on a weekday afternoon, mobilizing the necessary manpower was easy. But if it had been on a holiday or at night, mobilizing the large number of necessary staff would have taken a long time. In this regard, it is necessary to keep adequate, necessary manpower for initial response stationed at the site, and a response plan shall be prepared based on a realistic scenario in which the workforce gathers gradually over a period of time. For this reason, mobilization drills shall be exercised from time to time to assess the number of personnel to gather and the time at which they should convene. Such advance preparation shall be conducted not only for TEPCO personnel but also for the personnel of partner companies.

- Emergency headquarters were affected by the earthquake and tsunami, and they functioned effectively. At the important seismic isolation building, power was lost because the power distribution panel was flooded. An emergency gas turbine generator was in place but it did not work due to the impact of the tsunami. It is desirable to enhance the reliability of the power source through higher vibration resistance design or watertight equipment design. We can also see that there was the possibility of achieving restoration of the gas turbine generator much earlier if its situation had been checked immediately. On-site surveillance is truly important.

- In the headquarters, plant parameters and other necessary information was displayed on a large display panel and shared by everyone at the headquarters. Thus, planning of effective measures was ensured, and the purpose/intent of instructions was clearly identified. During the power blackout, information and instructions were posted on the whiteboard. In addition, the power plant has a video conference system for sharing information which is connected with the head office and three power plants. This helped get a swift supply of motors for the seawater pump from Kashiwazaki-Kariwa, resulting in a quick recovery. All these cases indicate that the headquarters should establish an effective system to share information between the parties concerned.

- Since AM equipment and its manuals, which prescribe the use of MUWC, were in place, it was possible to utilize these functions to suppress the expansion of the accident. Training carried out ordinarily was also effective. In the future, a variety of equipment to combat severe accidents shall be prepared in addition to the AM equipment. Training for proficiency in the use of these facilities will be necessary, and feedback of the training results shall also be implemented for continuous improvement and to achieve a quicker and more accurate response.

- Special expertise and tools are required in cable laying works. To transport materials and equipment, TEPCO employees were forced to drive large vehicles because of radioactive material fallout. Securing such personnel with special skills, expertise, and tools in advance, for the assumption of various situations that may occur during an accident, is desirable and shall be properly prepared. In addition, the cooperation of the SDF is essential, including the delivery of materials and equipment in the case of a complex accident created by a catastrophic situation outside due to earthquakes and tsunamis. In the future, these issues should be addressed in the study of the entire disaster prevention system.

- The ample amount of food prepared in advance for emergencies was utilized effectively as short-term rations. However, by allocating the stock to all the workforce of the external support teams and staff of cooperative enterprises, the situation became dire and difficult from the second day. It is not practical to keep stock to provide food and water to people in the magnitude of 2,000 over a long period of time. A practical approach may be to keep a stock of food and water for a few days and prepare a system to secure the supply and transportation measures thereafter. It may be a sensible idea to implement cooperation agreements with nearby power plants and adjacent power companies to share and lend their stock of food and water in an emergency.

- The grip bar attached to the control panel of the main control room was useful during the earthquake tremors. Anti-trip precaution measures taken for the cabinet and furniture in the office were effective in preventing human injury. These earthquake tremor countermeasures are desirable.

7.3 Initial response in the accident

- At Fukushima Daini, the lamp display in the central control room allowed loss of function to be confirmed and known at an early stage. In addition, the status of the plant and the reactor core could be observed in real time by monitoring the key parameters, which helped in the appropriate maneuvers of the plant. However, it is desirable to prepare appropriate measures, such as spare batteries, to collect parameters and other information when power has been lost. Specifically, vital parameters such as reactor pressure, reactor water level, primary coolant temperature, containment pressure, and containment temperature should be made available even in the most severe situation.

- In a difficult situation where communication was unreliable, after setting up evacuation procedures, patrollers were dispatched to walk down to the site in order to determine if the damaged equipment could be recovered quickly. The findings of the patrollers made it possible to accurately grasp the status of the equipment, which in turn made it possible to determine a recovery plan in line with the actual situation. It is important to grasp the situation as early as possible while ensuring safety. How to check the status in difficult situations such as loss of external power supply, for example, shall be discussed and appropriate measures shall be prepared in advance. Assuming a walk down patrol to the site when power and lighting are lost may require temporary lighting.

- Countermeasures are considered strategically based on the idea of defense in depth, such as a preparation for the containment vent, for example, which is a proactive countermeasure in planning rather than a reactive action responding to the progress of events. The external power supply was received via one series of transmission systems after the earthquake. However, in anticipation of its failure and loss, the other series were restored in the most urgent manner. The execution of effective response measures based on good foresight is desirable.
- To ensure the safety of patrollers, a contact liaison was stationed in the site with a PHS handset connected at all times to ensure contact, who would go down to the patrollers to deliver evacuation instructions if a tsunami warning was issued. It was reported that at Fukushima Daiichi, they experienced difficulty in the use of transceivers because of signal interference when they tried to use transceivers instead of the PHS, which had stopped functioning. If the transceivers had frequency bands which were different to each other, they could have been used as an effective means of communication. Also, loudspeakers and megaphones may be convenient and effective tools to eliminate the necessity of a messenger running to distant locations of the site.

7.4 Additional measures

- One of the major factors that contributed to the early convergence of the accident at Fukushima Daini is the availability of an online external power supply and that the starting transformer was not affected by the tsunami either. Ingenious effort should be exerted to come up with all possible measures to minimize the possibility that everything will be lost due to an external event such as an earthquake or tsunami. With respect to the external power supply, every power company is trying to improve its reliability under the guidance of the national government by improving the seismic design or installing additional transmission lines so as to enable interchange of power between units. It is important to be prepared for extreme external events such as tsunami or violent winds in order to avoid the total loss of external power.
- Depending on its mode of usage, the emergency power vehicle will use up its fuel within a few hours. Therefore, it is necessary to continuously monitor the fuel to replenish it in a timely manner. When using the temporary equipment, you should confirm in advance appropriate measures for the procurement of fuel and utility in anticipation of using it for a long time.

8. Conclusion

First of all, we would like to express our deepest appreciation to all the TEPCO personnel who participated in the compilation of this report on the accident response at Fukushima Daini by giving us details in various ways.

The report issued by the Accident Investigation Board of the Government in July has high regard for Fukushima Daini for its appropriate accident response, but is critical of that of Fukushima Daiichi.

However, the impact of the earthquake and tsunami at Fukushima Daini was smaller than that of Fukushima Daiichi, and as a result, an external power source was available at Daini. AM equipment and manuals were also available at Daini, which was activated by external power, and were used to bring the plant to convergence.

As we summarized as a lesson, the accident response at Fukushima Daini shows us a number of excellent ways to cope, such as: organization management, appropriate response by well-trained operators, effective use of equipment prepared in advance, and support from outside materials.

It may be meaningless to apply hypothetical hindsight to reviewing past incidents, but if some part of the power source had remained available, then there might have been the possibility that they could lead the plant to convergence in the same manner as Fukushima Daini, although the hard fact is that they lost all power panels due to the tsunami flooding, and the accident expanded.

Currently, stress tests are conducted on all nuclear power plants in Japan to strengthen all of the vulnerable points. For effective improvement, it is important to address not only the aspect of hardware, but also of software. In this respect, a variety of valuable information derived from the response to the accident at Fukushima Daini should be useful as reference material for consideration. We hope that this report will be used in Japan and around the world.

As for enhancing safety measures at nuclear power plants in the future, it has been determined that the Japan Nuclear Safety Institute, which was established in November, will take the helm and leadership. We hope the results of this study will be used by this new organization and contribute to nuclear power plant safety in Japan.

We prepared this report focusing on lessons from the accident response at Fukushima Daini, but there are two more nuclear power plants which were led to accident convergence despite the impact of the earthquake and tsunami: Onagawa Nuclear Power Station of Tohoku Electric and Tokai Daini Power Station of JAPC. We await future analysis and validation of their accident response to find lessons, and we expect that the new organization will address these tasks.

Attachment

Recommended Actions for the Emergency Response by Equipments/Materials Reinforcement

This report provided a wide range of lessons learned in terms of the organization, management structures and preparation of small equipment/materials. Among them, this attachment summarizes specific recommendations for consideration in the chart below, including an arrangement of equipment/materials for emergency response, which may be effective for the same incident.

Please note that the following is based on the measures taken at Fukushima Daini and keep in mind that plenty of room is left for other kinds of possible efforts.

Operation

Item	Details
(1) Installing a bar at the central operating panel	Operators can grip the bar and stand by, keeping low, for the reactor scram operation after the earthquake. In addition, such stand-by position should be included in training to ensure that operators can keep low in the event of the earthquake.
(2) Fixing cabinets in the central operating room	Fix cabinets and other equipments to prevent them from falling so as not to hurt operators or adversely affect the environment at the central operating room. Also fix meeting tables and whiteboard, etc.
(3) Handheld microphone	Handheld microphones are effective to make sure directions from the shift supervisor can be clearly communicated in a situation with loud noise due to a fire alarm malfunction during the earthquake. This should be included in training.
(4) On-site surveillance camera (to grasp the situation visually)	The surveillance camera allowed the central operating room to see the tsunami onslaught. Be sure that the surveillance footage can be checked at the central operating room, which will be effective in observing the situation.
(5) Support staff for the central operating room	Prepare to dispatch support staff to the central operating room as a procedure during an accident.

Recovery efforts

Item	Details
(1) Secure storage of equipment structural drawings	Equipment structural drawings required for considering recovery actions could not taken from the main office building due to damage, and digital libraries were not available due to the blackout. Make preparations so that they can be used in the event of an earthquake, fire, or blackout. (Strengthen the seismic resistance of the document storage room, entrance, and rack, and store documents in separate places assuming that fire will spread to the main office building)
(2) List of suppliers of necessary equipment/materials	Seawater pump motors were procured from outside the plant because they were flooded by the tsunami seawater. Preparing the list of necessary equipment/material suppliers in advance is effective for quick procurement.
(3) Prior consideration for transportation of equipment/materials for recovery	The major earthquake caused confusion in transportation (blockages of national roads, insufficient detours, and traffic jams) and transport companies refused to deliver to the evacuation area. Consequently, TEPCO employees had to deliver materials on their own. However, pick-up meetings were difficult due to mobile phones being disconnected. Therefore, prior consideration for equipment/material transportation is required assuming such

	conditions.
(4) Securing heavy machinery operators	Since transport companies refused to deliver to the evacuation area, directly managed transport was required. Thus, drivers for heavy trucks should be secured (a list of such drivers; training personnel with licenses for heavy vehicles).
(5) Securing personnel with special skills	TEPCO employees not only drove heavy trucks but also operated cranes and connected cables on their own. Secure employees with the capability to handle such operations in the event of an accident.
(6) Preparing temporary lighting, handheld microphones, and transceivers	For recovery, small equipment such as temporary lighting and handheld microphones were useful. Transceivers might be effective as a means of communication. Secure a certain quantity of such equipment/materials.
(7) Prior arrangement of support from cooperating companies	Support from cooperating companies was essential for recovery. Consider strengthening the following approaches to prepare for an accident. ・Conclude a contract on emergencies with on-site cooperating companies ・Recovery training involving on-site cooperating companies ・Prior consideration for arranging support staff from cooperating companies in an emergency
(8) Measures for unavailability of cooperating company buildings due to the earthquake	A cooperating company's building could not be used for a while due to earthquake damage. Check items in that building which are essential for recovery but may be unavailable due to damage.
(9) Strengthening medical/health care	Because many staff work and live in small places, strengthen medical and health care such as health management and continuous physical support for the late-onset de-conditioning due to stress.

Information sharing method

Item	Details
(1) Plant parameter indications at the emergency headquarters	Indicate plant parameters at the emergency headquarters to understand plant conditions.
(2) Video conference system with the head office	Simultaneous video conference among the head office, other TEPCO plants, and the Tokyo branch to make immediate support possible.

Logistics

Item	Details
(1) Food and water stock	In reality, a larger number of the necessary employees and cooperating company staff were engaged in recovery efforts under the predetermined emergency procedure. Based on this achievement, stock the proper volume of food and water and consider the method of procurement from outside suppliers.
(2) Fuel procurement	Ensure a method to procure fuel for power supply cars in the event of a major earthquake.