IV. Occurrence and Development of the Accident at the Fukushima Nuclear Power Stations

1. Outline of Fukushima Nuclear Power Stations

(1) Fukushima Daiichi Nuclear Power Station

Fukushima Daiichi Nuclear Power Station (hereinafter referred to as NPS) is located in Okuma Town and Futaba Town, Futaba County, Fukushima Prefecture, facing the Pacific Ocean on the east side. The site has a half oval shape with the long axis along the coastline and the site area is approx. 3.5 million square meters. This is the first nuclear power station constructed and operated by the Tokyo Electric Power Company, Incorporated (hereinafter referred to as TEPCO). Since the commissioning of Unit 1 in March 1971, additional reactors have been constructed in sequence and there are six reactors now. The total power generating capacity of the facilities is 4.696 million kilowatts.

Table IV-1-1 Power Generating Facilities of Fukushima Daiichi NPS

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Electric output (10,000 kW)	46.0	78.4	78.4	78.4	78.4	110.0
Start of construction	Sep. 1967	May 1969	Oct. 1970	Sep. 1972	Dec. 1971	May 1973
Commissioning	Mar. 1971	Jul. 1974	Mar. 1976	Oct. 1978	Apr. 1978	Oct. 1979
Reactor type	BWR-3	BWR-4				BWR-5
Containment type	Mark I					Mark II
Number of fuel assemblies	400	548	548	548	548	764
Number of control rods	97	137	137	137	137	185

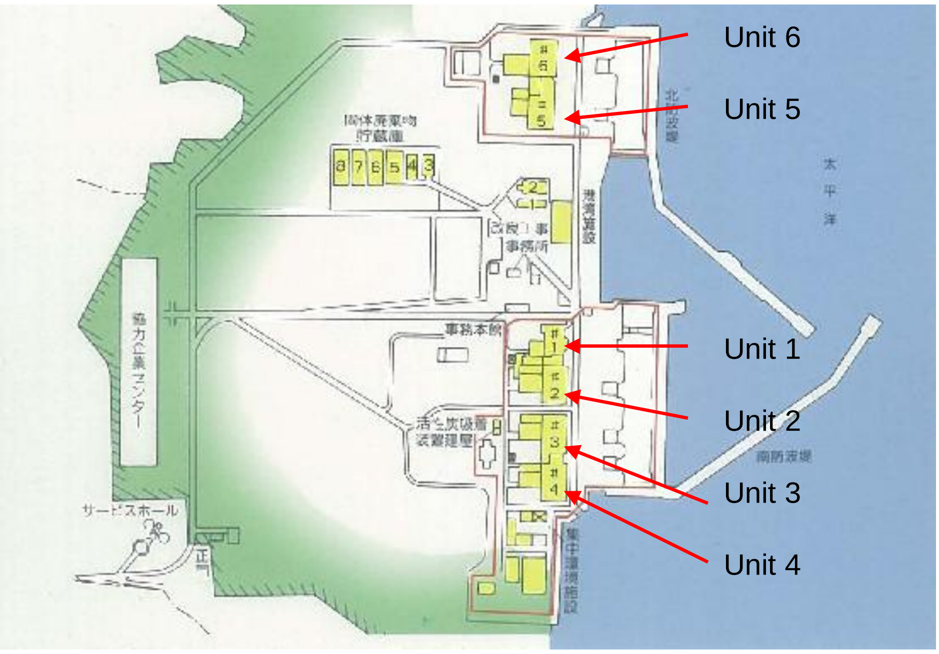

Figure IV-1-1 General Layout of Fukushima Daiichi NPS

(2) Fukushima Daini NPS

Fukushima Daini NPS is located in Tomioka Town and Naraha Town, Futaba County, Fukushima Prefecture, approx. 12 km south of Fukushima Daiichi NPS, and faces the Pacific Ocean on the east side. The site has a nearly square shape and the site area is approx. 1.47 million square meters. Since the commissioning of Unit 1 in April 1982, additional reactors have been constructed in sequence and there are four reactors now. The total power generating capacity of the facilities is 4.4 million kilowatts.

Table IV-1-2 Power Generating Facilities of Fukushima Daini NPS

	Unit 1	Unit 2	Unit 3	Unit 4
Electric output (10,000 kW)	110.0	110.0	110.0	110.0
Start of Construction	Nov. 1975	Feb. 1979	Dec. 1980	Dec. 1980
Commissioning	Apr. 1982	Feb. 1984	Jun. 1985	Aug. 1987
Reactor type	BWR-5			
Containment type	Mark II	Improved Mark II		
Number of fuel assemblies	764	764	764	764
Number of control rods	185	185	185	185

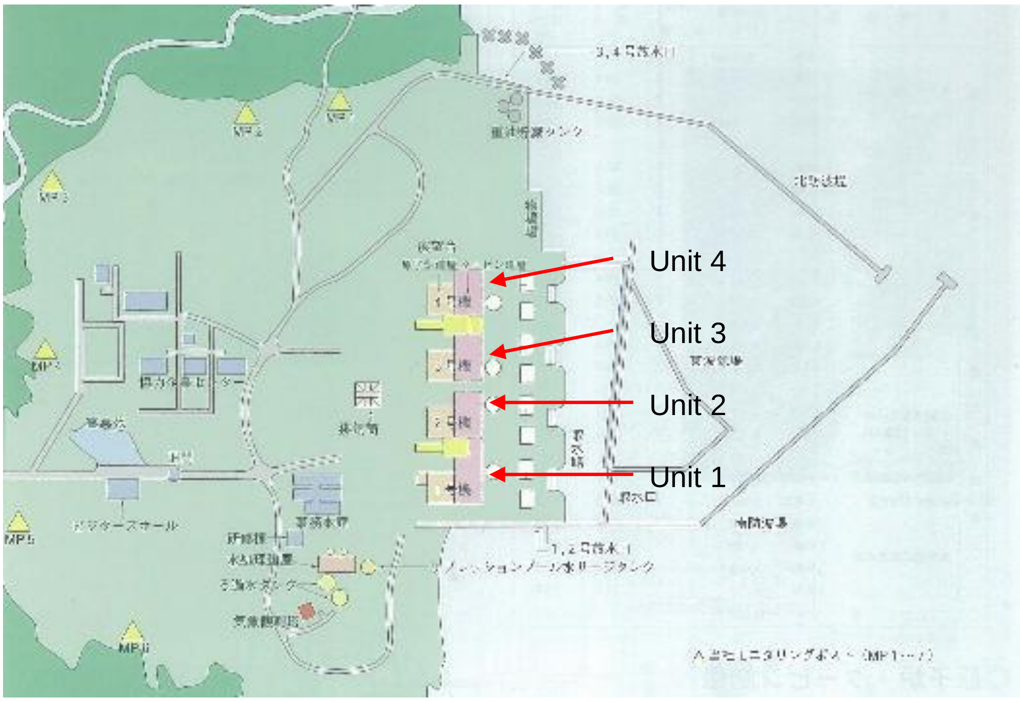

Figure IV-1-2 General Layout of Fukushima Daini NPS

2. Safety Assurance and Other Situations in Fukushima NPSs

(1) Design requirements of nuclear power stations

As described in Chapter II, nuclear power stations must satisfy legal requirements specified in the Reactor Regulation Act, the Electricity Business Act and other relevant laws and regulations.

When receiving an application for installing a nuclear power station from an applicant, Nuclear and Industrial Safety Agency (hereinafter referred to as NISA) conducts the primary safety review, should consult the Nuclear Safety Commission (hereinafter referred to as the NSC Japan) and shall receive their opinion based on the result of their secondary safety review. After NISA considers the opinions of the NSC Japan and examines the results of the safety reviews, the Minister of Economy, Trade and Industry gives the applicant permission to install individually for each reactor. In these safety reviews, NISA and the NSC Japan check that the basic design or the basic design policy of the nuclear power station conforms to the permission criteria specified in the Reactor Regulation Act, for example, in Article 24, "The location, structure, and equipment of the nuclear reactor facility shall not impair prevention of disasters caused by the nuclear reactor, its nuclear fuel material, or objects contaminated with the nuclear fuel material." The NISA Japan conducts safety reviews based on the most recent knowledge and by referring to regulatory guides established by the NSC Japan as specific judgment criteria.

Regulatory guides are roughly divided into four types: siting, design, safety evaluation, and dose target values. One of the regulatory guides for design, the "Regulatory Guide for Reviewing Safety Design of Light Water Nuclear Power Reactor Facilities,"[IV2-1] (hereinafter referred to as Regulatory Guide for Reviewing Safety Design) specifies the basic design requirements for nuclear power stations. It contains a provision about design considerations against natural phenomena, which specifies that structures, systems, and components (SSCs) with safety functions shall be designed to sufficiently withstand appropriate design seismic forces and shall be designed such that the safety of the nuclear reactor facilities will not be impaired by postulated natural phenomena other than earthquakes, such as floods and tsunami.

It also specifies requirements for safety design against external human induced events, such as collapse of a dam, and fires and others.

Basic Judgment criteria for validation of design policies against earthquakes and tsunami are specified in the “Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities”[IV2-2] (the latest version established by the NSC Japan in September 2006, hereinafter referred as Regulatory Guide for Reviewing Seismic Design), which supplements the Regulatory Guide for Reviewing Safety Design.

The Regulatory Guide specifies the basic policy, “Those Facilities designated as important from a seismic design standpoint shall be designed to bear even those seismic forces exerted as a result of the earthquake ground motion, which could be appropriately postulated as having only a very low possibility of occurring within the service period of the Facilities and could have serious affects to the Facilities from seismological and earthquake engineering standpoints, considering the geological features, geological structures, seismicity, etc. in the vicinity of the proposed site, and such Facilities shall be designed to maintain their safety functions in the event of said seismic forces.” It also specifies that uncertainties (dispersion) in formulating the Design Basis Ground Motion Ss shall be considered by appropriate methods and that the probabilities of exceedence should be referred to.

The Regulatory Guide also contains consideration of tsunami as accompanying events of earthquakes, “Safety functions of the Facilities shall not be significantly impaired by tsunami of such magnitude that they could only be reasonably postulated to have a very low probability of occurring and hitting the Facilities within the service period of the Facilities.” A commentary in this Regulatory Guide describes that at the design of the Facilities, appropriate attention should be paid, to possibility of occurrence of the exceeding ground motion to the determined one and, recognizing the existence of this “residual risk”, every effort should be made to minimize it as low as practically possible.
The NSC Japan requests that government agencies ask licensees to conduct backchecks of seismic safety based on specifications in this Regulatory Guide, along with quantitative assessment of “residual risks” by positively introducing the probabilistic safety assessment (hereinafter referred to as PSA), and review the results. In response to this request, NISA issued “Implementation of seismic safety assessment on existing nuclear power reactor facilities and other facilities to reflect the revisions of the ‘Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities’ and other safety assessment regulatory guides”[IV2-3] and requested licensees to carry out backchecks of seismic safety and assess “residual risks”.

(2) Design basis events to be considered in safety assessment

1) Defining design basis events in safety assessment

As described in Chapter II, the Regulatory Guide for Evaluating Safety Assessment of Light Water Reactor Facilities identifies events to be considered in the safety design and assessment of nuclear facilities and defines them as design basis events.

Design basis events regarding loss of external power supply, total AC power loss, and systems for transporting heat to the ultimate heat sink (hereinafter referred to as the ultimate heat sink), which occurred as part of this accident, are described below.

The Regulatory Guide for Evaluating Safety Assessment of Light Water Reactor Facilities takes loss of external power supply as an abnormal transient during operation and requires check of appropriateness of relevant safety equipment. On the contrary, the Regulatory Guide for Reviewing Safety Design does not take total AC power loss as a design basis event. This is because it requires emergency power supply systems to be designed with a high degree of reliability as AC power supplies. Specifically, the “Regulatory Guide for Reviewing Classification of Importance of Safety Functions for Light Water Nuclear Power Reactor Facilities”[IV2-4] (established by the NSC Japan in August 1990, hereinafter referred as Regulatory Guide for Reviewing Classification of Importance of Safety Functions) classifies emergency power supply systems as systems with safety functions of especially high importance. The Regulatory Guide for Reviewing Safety Design specifies in its guidelines, such as Guideline 9 (Design Considerations for Reliability) and Guideline 48 (Electrical Systems), that systems with safety functions of especially high importance shall be designed with redundancy or diversity and independence and shall be designed such that adequately high reliability will be ensured. As described above, the Regulatory Guide for Reviewing Seismic Design specifies that safety functions shall be maintained in the event of an earthquake. Based on this prerequisite, the Regulatory Guide for Reviewing Safety Design specifies that the nuclear reactor facilities shall be designed such that safe shutdown and proper cooling of the reactor after shutting down can be ensured in case of a short-term total AC power loss, in Guideline 27 (Design Considerations against Loss of Power). However, the commentary for Guideline 27 states that no particular considerations are necessary against a long-term total AC power loss because the repair of interrupted power transmission lines or an emergency AC power system can be depended upon in such a case, and that the assumption of a total AC power loss is not necessary if the emergency AC power system is reliable enough by means of system arrangement or management. Accordingly, licensees are to install two independent emergency diesel generator systems (hereinafter referred to as emergency DG), which are designed such that one emergency DG is activated if the other emergency DG is failed, and that the reactor is shut down if a failure persists for a long time.

Loss of all seawater cooling system functions is not taken as a design basis event. This is because the Regulatory Guide for Reviewing Classification of Importance of Safety Functions classifies seawater pumps as systems with safety functions of especially high importance, just like emergency power supply systems. The Regulatory Guide for Reviewing Safety Design specifies that systems with safety functions of especially high importance shall be designed with redundancy or diversity and independence, in Guideline 9 (Design Considerations for Reliability), Guideline 26 (Systems for Transporting Heat to Ultimate Heat Sink) and other guidelines. Also, the Regulatory Guide for Reviewing Seismic Design specifies that safety functions shall be maintained in the event of an earthquake.

The generation of flammable gas inside the primary containment vessel (hereinafter referred to as PCV) when reactor coolant is lost is postulated in the design basis events as a cause of hydrogen explosion accidents. To prevent this event, a flammability control system (hereinafter referred to as FCS) that suppresses hydrogen combustion inside the PCV is installed in compliance with Guideline 33 of the Regulatory Guide for Reviewing Safety (the system controlling the atmosphere in the reactor containment facility). Additionally, keeping the atmosphere inside the PCV inert further reduces the possibility of hydrogen combustion. These designs are aimed at preventing hydrogen combustion in the PCV from the viewpoint of PCV integrity, and are not aimed at preventing hydrogen combustion inside the reactor building.

2) Safety design for the design standard events at Fukushima NPSs

The safety designs for the design basis events of offsite power supplies, emergency power supply systems, and reactor cooling functions related to the accidents at Fukushima NPSs are the following:

The power sources are connected to offsite power supply grids via two or more power lines. Multiple emergency diesel generators are installed independently with redundant design as the emergency power supplies for a loss of external power supply. Also, to cope with a short-period loss of all AC power sources, emergency DC power sources (batteries) are installed maintaining redundancy and independence.

Unit 1 of Fukushima Daiichi NPS is equipped with isolation condensers[1] (hereinafter referred to as IC) and a high pressure core injection system (hereinafter referred to as HPCI), and Unit 2 and Unit 3 of Fukushima Daiichi NPS are equipped with HPCI and a reactor core isolation cooling system[2] (hereinafter referred to as RCIC) to cool the reactors when they are under high pressure and the condenser does not work. Unit 1 of Fukushima Daiichi NPS is equipped with a core spray system (hereinafter referred to as CS) and a reactor shut-down cooling system (hereinafter referred to as SHC), and Unit 2 and Unit 3 of Fukushima Daiichi NPS are equipped with a residual heat removal system (hereinafter referred to as RHR) and a low pressure CS to cool the reactors when they are under low pressure.

Additionally, in the main steam line that leads to the reactor pressure vessel (hereinafter referred to as RPV) are installed main steam safety relief valves (hereinafter referred to as SRV) that discharge steam in the reactor to the suppression chamber (hereinafter referred to as S/C) and safety valves that discharge steam in the reactor to the dry well (hereinafter referred to as D/W) of the PCV. The SRV functions as an automatic decompression system. Table IV-2-1 shows a comparison between these safety systems. Their system structures are shown in Figures IV-2-1 to IV-2-7.

As shown in Figure IV-2-8 and Figure IV-2-9, the heat exchanger in the SHC for Unit 1 or RHR for Units 2 and 3 of Fukushima Daiichi NPS transfers heat using seawater supplied by the seawater cooling system to the sea, as the ultimate heat sink.

To prevent hydrogen explosion in the PCV, it is filled with nitrogen gas and a flammability control system FCS is installed.

1 This facility condenses steam in the RPV and returns the condensed water to the RPV by natural circulation (driving pumps not needed), when the RPV is isolated due to loss of external power supplies, for example, (when the main condenser cannot work to cool the reactor). The IC cools steam that is led to a heat transfer tube with water stored in the condenser (in the shell side).

2 This system cools the reactor core when the RPV is isolated from the condensate system due to loss of external power supplies, for example. It can use water either in the condensate storage tank or in the suppression chamber. The turbine that uses part of the reactor steam drives the pump of this system.

(3) Measures against severe accidents

1) Basis of measures against severe accidents

a. Consideration of measures against severe accidents

Severe accidents [3] has drawn attention since "The Reactor Safety Study" (WASH-1400)[IV2-5], which assessed the safety of nuclear power stations by a probabilistic method, was published in the United States in 1975.

Severe accidents, which are beyond design basis events on which nuclear facilities are designed, are considered to be at defense depth level 4 in multiple protection as described in IAEA's Basic Safety Principles for Nuclear Power Plants, 75-INSAG-3, Rev.1, INSAG-12 (1999)[IV2-6]. Multiple protection generally refers to a system that comprises multi-layered safety measures through ensuring design margin at each level of defense, and these levels include: preventing occurrence of abnormalities (level 1); preventing progression of abnormalities into accidents (level 2); and mitigating impact of accidents (level 3). The design basis events are usually for setting safety measures up to level 3. Measures against severe accidents belong to actions at level 4, and they provide additional means to prevent events from progression into severe accidents and mitigate impacts of severe accidents, and also provide measures effectively using existing facilities or based on procedures. They are stipulated as actions to control severe accidents or actions to protect the function of confining radioactive materials to prevent events from worsening.

In Japan, following the 1986 Chernobyl accident in the former Soviet Union, the NSC in Japan set up the Round-table Conference for Common Problems under its Special Committee on Safety Standards of Reactors in July 1987 to study measures against severe accidents. The Round-table Conference members did research on the definition of severe accidents, PSA methods, and maintaining the functions of the PCV after a severe accident, and they put together the "Report on Study of Accident Management as a Measure against Severe Accidents—Focused on the PCV"[IV2-7] in March 1992.

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[3] These events significantly exceed design basis events causing the system to become incapable of appropriately cooling the reactor core or controlling reactivity by any methods covered by the safety design, and consequently will lead to serious reactor core damage.

This report says, “Nuclear facility safety is secured through safety ensuring activities that deal with design basis events, and the risk of radioactive exposure of the general public in the vicinity is sufficiently low. Even if a severe accident or events that may lead to a severe accident occurred at a nuclear facility, appropriate accident management[4] based on the PSA would reduce the possibility of it becoming a severe accident or mitigate the impact of a severe accident on the general public, further lowering the risk of exposure.”

Following this report, the NSC Japan made a decision called “Accident Management as a Measure against Severe Accidents at Power Generating Light Water Reactors”[IV2-8] (herein after called the “Accident Management Guidelines”) in May 1992. Based on this decision, licensees have taken voluntary actions (not included in regulatory requirements), such as measures to prevent accidents from becoming severe accidents (phase I) and measures to mitigate the impact of severe accidents (phase II).

The (former) Ministry of International Trade and Industry, based on these Accident Management Guidelines, issued the “Implementation of Accident Management”[IV2-9] to request licensees to carry out PSA on each of their light water nuclear power reactor facilities, introduce accident management measures based on PSA, and submit result reports on these actions, the content of which MITI was to confirm.

After that, the Basic Safety Policy Subcommittee of the Nuclear and Industrial Safety Subcommittee studied overall safety regulations in Japan, and it put together a report “Issues on Nuclear Safety Regulations”[IV2-10] in 2010. This report says that based on moves overseas such as introducing severe accident measures as a regulatory requirement in some countries, it is appropriate to consider dealing with safety regulations on severe accidents measures in terms of their position in the regulation system and legislation. In response to this, NISA has been considering how to deal with severe accidents.

b. Utilization of risk information

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4 Appropriate severe management is measures taken to make effective use of not only safety margin allowed in the current design and original functions provided in safety design but also other functions expected to work for safety as well as newly installed components and equipment so that any situation which exceeds design basis events and may cause serious damage to core will not progress to a severe accident, and, even if the situation progresses to a severe accident, its influences will be mitigated.

The NSC Japan started a study of periodic safety reviews[5] (hereinafter referred to as PSR) in order to consider using PSA, and it worked out a basic policy on PSR including implementation of PSA in 1993.

This policy requested implementation of PSA as part of PSR activities to effectively improve the current level of safety even further, because PSA comprehensively and quantitatively assesses and helps get the whole picture of the safety of a nuclear power station by postulating a wide range of abnormal events that may occur at a nuclear power station. As a result, the (former) MITI has requested that licensees implement PSR since 1994, and has reported to the NSC Japan on licensees' assessment results including PSA.

Later in 2003, PSR was included in regulatory requirements as part of the measures for aging management, while PSA was left as voluntary measures taken by licensees. Then it was decided that PSR results would be confirmed by NISA and reports to the NSC Japan were discontinued. Meanwhile, licensees have been taking severe accidents measures using PSA.

In Japan, civil standards on PSA related to internal events are established. For external events, a civil standard on seismic PSA is also established, while study of PSA related to other external events such as flooding has only started.

The Study Group on Use of Risk Information of Nuclear and Industrial Safety Subcommittee studied utilization of risk information to put together "the basic policy of utilization of risk information in nuclear regulation"[IV2-11] in 2005. However, later the activity had been temporarily suspended. In 2010, this study group was resumed, and it has been considering measures for further utilization of risk information.

On the other hand, the safety goals associated with the use of risk information have been being examined by the Special Committee on Safety Goals of the NSC Japan since 2000, and the "Interim Report on Investigation and Examination"[IV2-12] was issued in 2003. In addition, the "Performance Goals of Commercial Light Water

5 It conducts comprehensive re-evaluation of the safety of nuclear power stations approximately once every ten years based on the latest technological knowledge in order to improve the safety of existing nuclear power plants. Specifically, it re-evaluates comprehensive evaluation of operating experience, reflection of the latest technological knowledge, conduction of technical evaluations for aging, and PSA results.

Reactor Facilities: Performance Goals Corresponding to Safety Goal Proposal"[IV2-13] was issued in 2006. However, the use of risk information based on the safety goals has not progressed because the safety goals of Japan have not been determined.

Accordingly, compared to other countries, Japan has not been sufficiently promoting the use of risk information.

c. Examination of total AC power loss and cooling functions, etc.

The following are the status of the severe accidents associated with the current accident.

According to the “Interim Report on the Conference on Common Issues”[IV2-14] issued by the NSC Japan ((the Special Committee on Nuclear Safety Standards of on February 27, 1989, hereinafter referred to as the "Common Issue Interim Report"), accident management during total AC power loss includes efforts such as core cooling by using RCIC powered by direct current (from batteries), recovery of offsite power systems or emergency DGs, bringing in portable diesel generators or batteries, and power interchange between emergency DGs in adjacent plants. The Common Issue Interim Report states that an accident has a high chance of being settled before it results in core damage if preparation has been made for such management.

In addition, if RHR lose its functionality, the inner pressure and temperature of the PCV increase with decrease in the pressure of the reactor. Accordingly, the Common Issue Interim Report additionally states that to prevent the PCV from being damaged, facilities for depressurization of the PCV to vent pressure in order to prevent PCV rupture (hereinafter referred to as “PCV vent”) should be built and that the procedures for the operation of the individual facilities should be prepared.

The accident management guidelines mention alternative coolant injection into the reactor by using a fire extinguishing line and the PCV vent as the Phase I (core damage prevention) accident management of BWR plants. The accident management guidelines also state that PCV vent facilities with a filtering function installed in combination with other measures, such as coolant injection into the PCV, may be an effective measure for Phase II (after core damage) accident management. The accident management guidelines additionally state that coolant injection into the PCV should be included in the Phase I (core damage prevention) and Phase II (after core damage) accident management of BWR plants. In the PSA that is the basis of this guideline, it was concluded that injecting an alternative coolant into the PCV would suppress increases in the temperature and pressure of the atmosphere in the PCV and prevent debris-concrete reaction[7] and melt shell attack[8].

2) Status of preparation for accident management by TEPCO

TEPCO issued the "Report on Accident Management Examination" [IV2-15] in March 1994, and has been preparing for accident management and establishing procedures, education, etc. associated with the application of the accident management based on the report. TEPCO presented the "Report on Preparation for Accident Management"[IV2-16] describing the status of the preparation for accident management to the Ministry of Economy, Trade and Industry in May 2002.

TEPCO has prepared accident management for the reactor shutdown function, coolant injection into reactors and PCVs function, heat removal from PCVs function, and support function for safety functions. The main measures of accident management are shown in Table IV-2-2. In addition, the system structures of accident management facilities of Units 1 to 3 are shown in Figs. IV-2-10 to IV-2-17.

With regard to alternative coolant injection in the Fukushima NPSs, TEPCO has built the following lines for injecting coolant into reactors: lines via condensate water makeup systems from the condensate storage tanks as the water sources; and lines via fire extinguishing systems and condensate water makeup systems from the filtrate tanks as the water sources. TEPCO has also developed "procedures for coolant injection using these lines during accidents (severe accidents)" (hereinafter referred to as "procedures for operation in severe accidents").

In addition, TEPCO has built a switching facility in Unit 3 for injecting seawater into the reactor via the residual heat removal sea water system (hereinafter referred to as RHRS)

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7 When core melt drops down through the bottom of RPV, it causes thermal decomposition of floor concrete as well as erosion with concrete constituents.

8 When core melt drops down through the bottom of RPV, it drops into and spreads over the cavity area at the bottom of RPV. Then debris spreads over the dry well floor through a pedestal opening and causes damage to walls of PCV.

as shown in Fig. IV-2-12 and has developed a procedure for switching operation of the relevant facilities. However, Units 1 and 2 are not provided with such the facility because no seawater lines lead into the reactor buildings of Units 1 and 2.

TEPCO built new vent pipes extending from the S/C and D/W to the stacks from 1999 to 2001 as PCV vent facilities during severe accidents as shown in Figs. IV-2-13 and IV-2-14. These facilities were installed to bypass the standby gas treatment system (hereinafter referred to as SGTS) so that they can vent the PCV when the pressure is high. The facilities are also provided with a rupture disk in order to prevent malfunction.

The procedures for operation in severe accidents define the PCV vent conditions and the PCV vent operation during severe accidents as follows: PCV vent from the S/C (hereinafter referred to as “wet vent”) shall be given priority; and when the PCV pressure reaches the maximum operating pressure before core damage, when the pressure is expected to reach about twice as high as the maximum operating pressure after core damage and if RHR is not expected to be recovered, wet vent shall be conducted if the total coolant injection from the external water source is equal to or less than the submergence level of the vent line in the S/C or PCV vent from the D/W (hereinafter referred to as “dry vent”) shall be conducted if the vent line of the S/C is submerged. The procedures for operation in severe accidents specify that the chief of emergency response headquarters shall determine whether PCV vent operation should be conducted after core damage.

For accident management associated with the function of heat removal from the PCV, alternative coolant injection to a PCV spray (D/W and S/C) (hereinafter referred to as the alternative spray function) has also been provided as shown in Figs. IV-2-15 and IV-2-16. PCV sprays (D/W and S/C) are installed to reduce the pressure and temperature generated due to energy released within the PCV if reactor coolant is lost, according to guideline 32 (containment heat removal system) of the Regulatory Guide for Reviewing Safety Design. The procedures for operation in severe accidents specify criteria such as the standard for starting and terminating coolant injection from RHR by using this modified line and the criteria for starting and terminating coolant injection from the condensate water makeup system and the fire extinguishing system.

Power interchange facilities have been installed such that the power supply of the alternating current source for power machinery (6.9 kV) and the low voltage alternating current source (480 V) can be interchanged between adjacent reactor facilities (between Units 1 and 2, between Units 3 and 4, and between Units 5 and 6) as shown in Fig IV-2-17. The procedures for operation in severe accidents specify procedures for the relevant facilities.

In order to recover emergency DGs, the procedures for operation in severe accidents specify procedures for recognition of failures, detection of the location of failures, and recovery work for faulty devices by maintenance workers.

Table IV-2-1 Comparison between Engineering Safety Equipment and Reactor Auxiliary Equipment

Fukushima-Daiichi Nuclear Power Station		Unit 1	Unit 2	Unit 3
Core spray system (CS)	No. of systems	2	2	2
	Flow (T/hr per system)	550	1020	1141
	No. of pumps (per system)	2	1	1
	Pump discharge pressure (kg/cm2g)	20	35.2	35.2
Containment cooling system (CCS)	No. of systems	2	2	2
	Design flow (T/hr per system)	705	2960	2600
	No. of pumps (per system)	2	2	2
	No. of heat exchangers (per system)	1	1	1
High pressure coolant injection system (HPCI)	No. of systems	1	1	1
	Flow (T/hr)	682	965	965
	No. of pumps	1	1	1
Low pressure coolant injection system (LPCI)	No. of systems		2	2
	Flow (T/hr per pump)		1750	1820
	No. of pumps (per system)		2	2
Residual heat removal system (RHR)	Pump			
	No. of pumps		4	4
	Flow (t/h)		1750	1820
	Total pump head (m)		128	128
	Seawater pump			
	No. of seawater pumps		4	4
	Flow (m3/h)		978	978
	Total pump head (m)		232	232
	Heat exchanger			
	No. of units		2	2
	Heat transfer capacity (kcal/h)		7.76E+06	7.76E+06
Reactor shut-down cooling system (SHC)	Pump			
	No. of pumps	2		
	Flow (m3/h per unit)	465.5		
	Pump head (m)	45.7		
	Heat exchanger			
	No. of heat exchangers	2		
	Heat exchanging capacity (kcal/h)	3.8E+06		
Reactor core isolation cooling system (RCIC)	Steam turbine			
	No. of steam turbines		1	1
	Reactor pressure (kg/cm2g)		79-10.6	79-10.6
	Output (HP)		500-80	500-80
	Speed of rotation (rpm)		5000-2000	4500-2000
	Pump			
	No. of pumps		1	1
	Flow (t/h)		95	97
	Total pump head (m)		850-160	850-160
	Speed of rotation (rpm)		Variable	Variable
Isolation condenser (IC)	No. of systems	2		
	Effective water retention capacity of the tank (m3 per tank)	106		
	Steam flow (T/hr per tank)	100.6		
Standby gas treatment system (SGTS)	No. of systems	2	2	2
	No. of fans (per system)	1	1	1
	Exhaust capacity (m3/hr per unit)	1870	2700	2700
	Iodine filtration efficiency of the system (%)	≥ 97	≥ 99.9	≥ 99.9
Safety valve	No. of valves	3	3	3
	Total capacity (T/hr)	900	900	900
	Blowout pressure (kg/cm2g)	86.8 (two valves) 87.9 (one valve)	87.2	87.2
	Blowoff area	Drywell	Drywell	Drywell
Main steam safety relief valve	No. of valves	4	8	8
	Total capacity (T/hr)	1090	2900	2900
	Relief valve function	74.2 kg/cm2g (1 valve)	75.9 kg/cm2g (1 valve)	75.9 kg/cm2g (1 valve)
		74.9 kg/cm2g (2 valves)	76.6 kg/cm2g (3 valves)	76.6 kg/cm2g (3 valves)
		75.6 kg/cm2g (1 valve)	77.3 kg/cm2g (4 valves)	77.3 kg/cm2g (4 valves)
	Safety valve function	78.0 kg/cm2g (2 valves)	78.0 kg/cm2g (2 valves)	
		78.7 kg/cm2g (2 valves)	78.7 kg/cm2g (3 valves)	
			79.4 kg/cm2g (3 valves)	
	Blowoff area	Suppression Chamber	Suppression Chamber	Suppression Chamber

Table IV-2-2 Accident Management Measures at Fukushima Daiichi and Daini NPSs

	Fukushima Daiichi			Fukushima Daini
	Unit 1 (BWR-3)	Units 2 to 5 (BWR-4)	Unit 6 (BWR-5)	Units 1 to 4 (BWR-5)
1. Accident Management Associated with Reactor Shutdown Function				
(1) Recirculation Pump Trip (RPT) RPT is a function inducing an automatic trip of the recirculation pump to reduce the reactor power by using an instrumentation and control system that has been installed separate from the emergency reactor shutdown system.	○	○	○	○
(2) Alternative Control Rod Insertion ARI is a function for automatically opening a newly installed valve and inserting control rods to shut down the reactor upon detecting an abnormality by using an instrumentation and control system that has been installed separate from the emergency reactor shutdown system.	○	○	○	○
2. Accident Management Associated with Coolant Injection into Reactor and PCV				
(1) Alternative Means of Coolant Injection In order to effectively utilize the existing condensate water make-up systems, fire extinguishing systems, and PCV cooling systems, the destination of the piping is modified so that coolant injection into reactors is possible from these existing systems via systems such as core spray systems, so that they can be used as alternative means of coolant injection facilities.	○	○	○	○
(2) Automatic Reactor Depressurization (Reactor depressurization is already automatic. Therefore, it should be regarded as improvement in the reliability of ADS.) In the event where only the reactor water level is decreasing due to insufficient high pressure coolant injection during a abnormal transient signals indicating high D/W pressure are not generated, and the automatic depressurization system is not automatically activated in the conventional facilities. Accordingly, the reactor has been modified to be automatically depressurized by using safety relief valves after the occurrence of a signal indicating a low reactor water level, which makes it possible for systems, such as emergency low pressure core cooling systems, to inject coolant into the reactor even in such an event.	—	○	○	○
3. Accident Management Associated with Heat Removal Functions in PCV				
(1) Alternative Heat Removal with D/W coolers and Reactor Coolant Cleanup System D/W coolers and reactor coolant cleanup systems are manually activated to remove heat from PCV. The procedure is defined in the accident operation standard.	○	○	○	○
(2) Recovery of PCV Cooling System (Residual Heat Removal System) Recognition of failures of the PCV cooling system (residual heat removal system), detection of the locations of failures, and recovery work for the failures by maintenance workers are defined in the recovery procedure guidelines as basic procedures.	○	○	○	○
(3) Compressive Strengthening Vent Reactor containment vent lines with strengthened pressure resistance are installed to be directly connected to stacks from inert gas systems without passing through standby gas treatment systems, so that the applicability of depressurization operation as a means of prevention of over-pressurization in the PCV is extended to improve the heat removal function in PCV.	○	○	○	○
4. Accident Management Associated with Support Function for Safety Functions				
(1) Interchange of Power Supplies Power supply capacity is improved by constructing tie lines of low-voltage AC power supplies between adjacent reactor facilities.	○	○	○	○
(2) Recovery of Emergency DGs Recognition of failures of emergency DGs, detection of the location of failures, and recovery work for the failures by maintenance workers are defined in the recovery procedure guidelines as basic procedures.	○	○	○	○
(3) Dedicated Use of Emergency DGs One of the two emergency DGs was commonly used between adjacent Units. However, new emergency DGs have been installed at Units 2, 4, and 5, so that each DG is used for only one Unit.	○	○	○	○

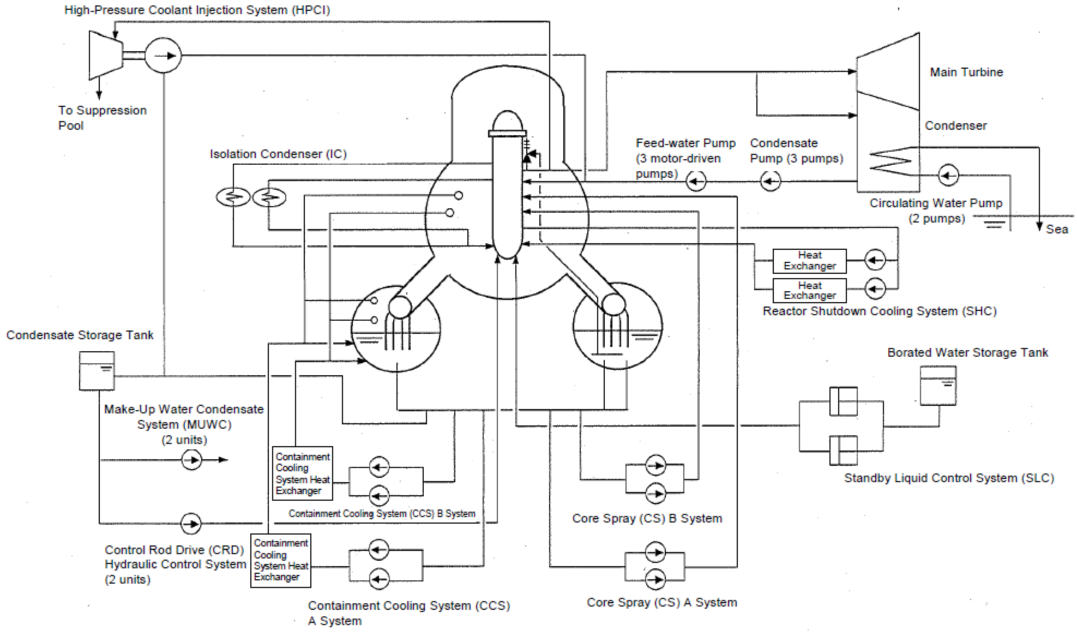


Fig. IV-2-1 System Structure Diagram of Fukushima Daiichi NPS Unit 1

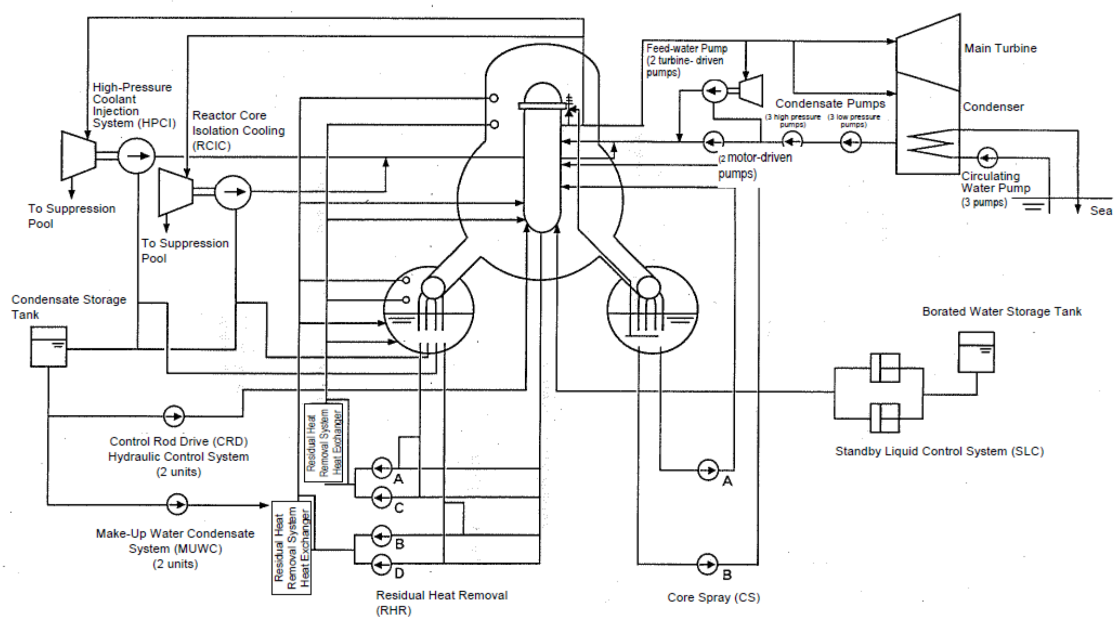
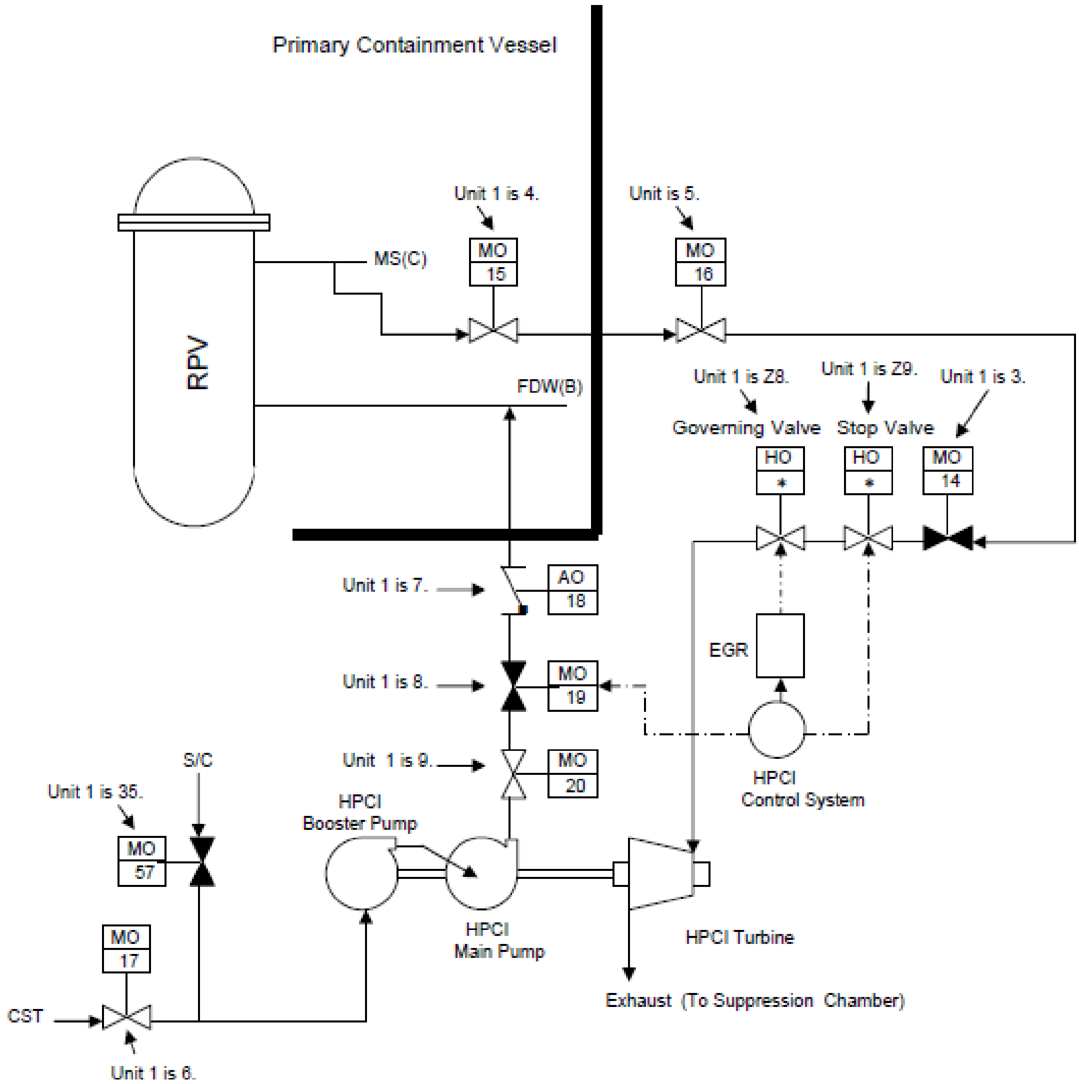
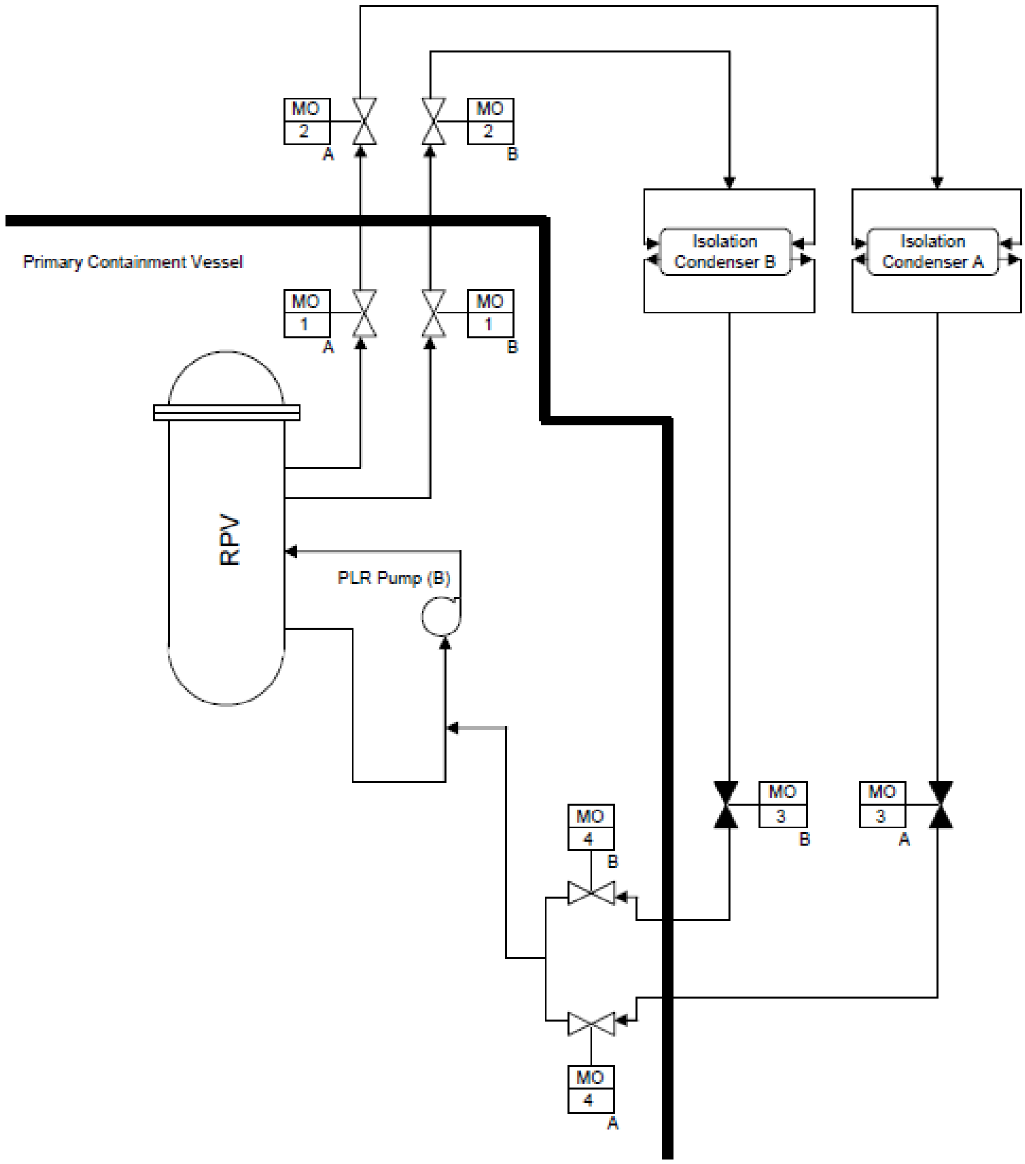


Fig. IV-2-2 System Structure Diagram of Fukushima Daiichi NPS Units 2 and 3



*1: During normal operation, MO-15, 16, 17, 20 and HO valves are "open" and MO-14 and 19 valves are "close".
At startup, 14 and 19 valves are "open".
*2: MO-15 valve is inoperative due to AC power loss. (as-is)
*3: MO-14, 16, 17, 19 and 20 valves are inoperative due to DC power loss (the separate power source from isolation logic circuits). (as-is)
*4: During DC power loss, isolation (close) logic circuits are operative.
At that time, if the drive power of each valve (written in *2 and *3) is activated, each valve is closed. If the drive power of each valve is already lost, the circuits are inoperative. (as-is)

Fig. IV-2-3 System Structure Diagram of High Pressure Coolant Injection System (Units 1 to 3)



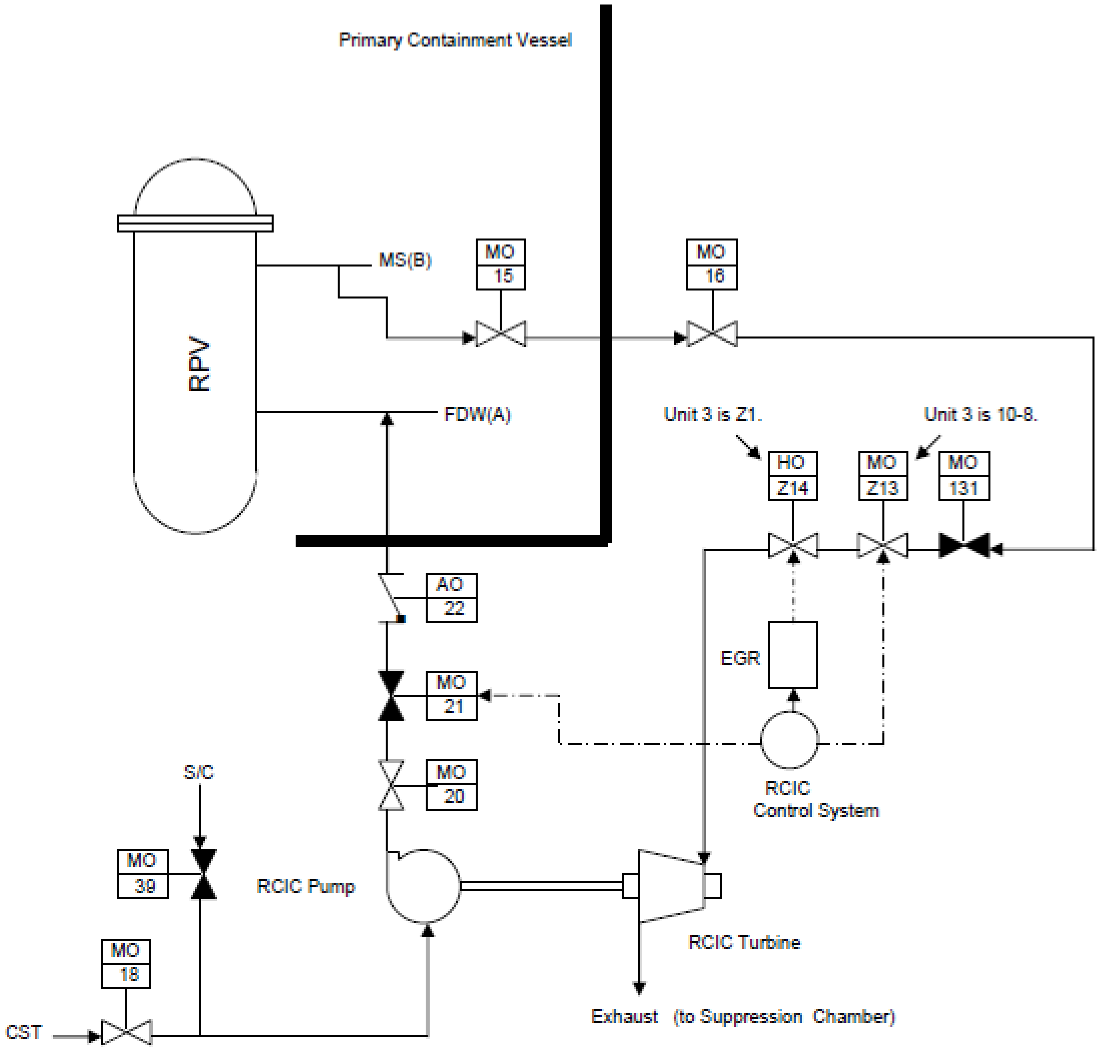
*1: During normal operation (in a standby condition), MO-1, 2 and 4 valves are "open" and MO-3 valve is "close". At startup, MO-3 valve is "open".

*2: MO-1 and 4 valves are inoperative due to AC power loss. (as-is)

*3: MO-2 and 3 valves are inoperative due to DC power loss (the same power source as isolation logic circuits). (as-is)

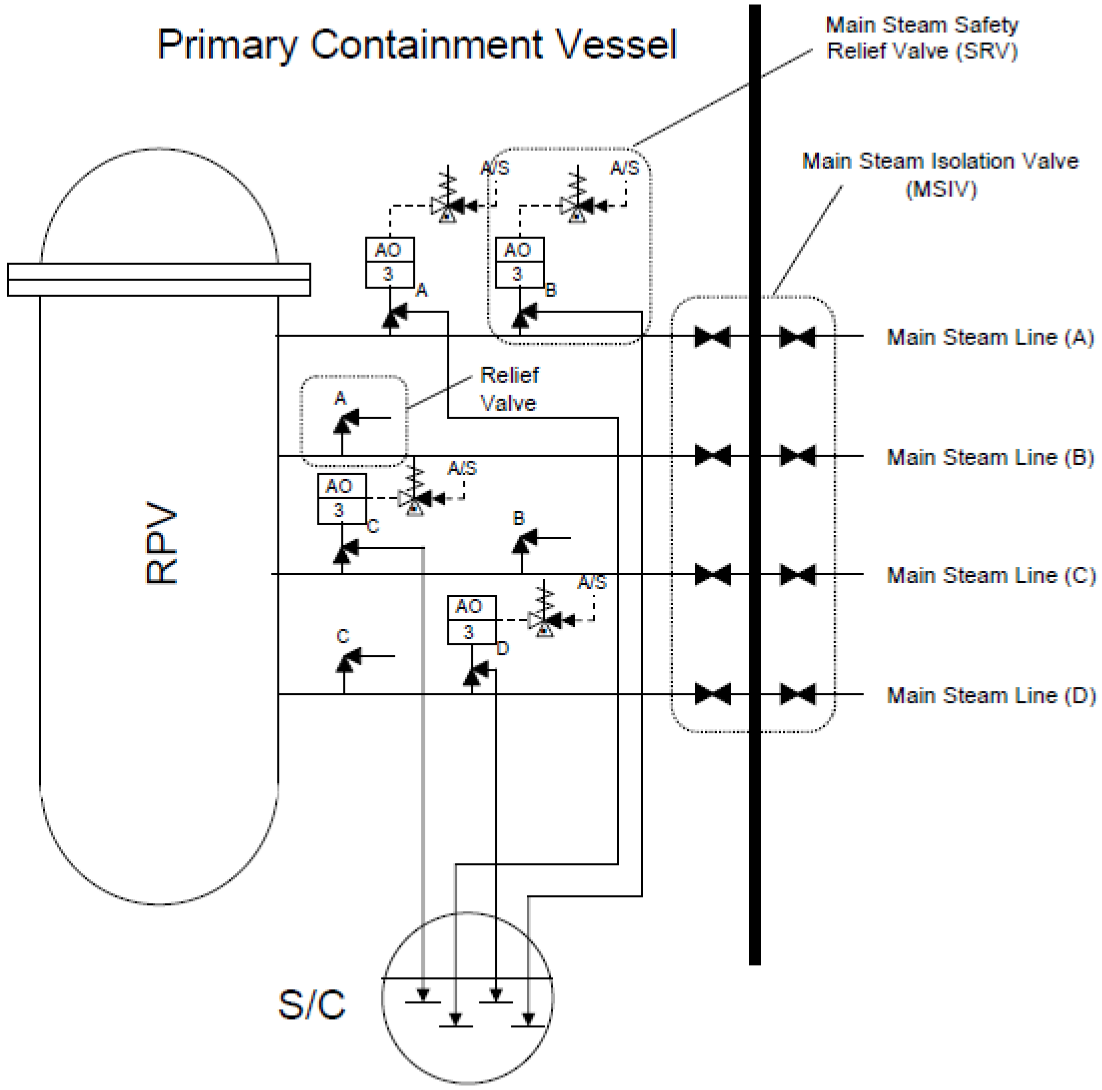
*4: During DC power loss, isolation (close) logic circuits are operative.
At that time, if the drive power of each valve (written in *2 and *3) is activated, each valve is closed. If the drive power of each valve is lost, the valves are inoperative. (as-is)

Fig. IV-2-4 System Structure Diagram of Isolation Condenser (Unit 1)



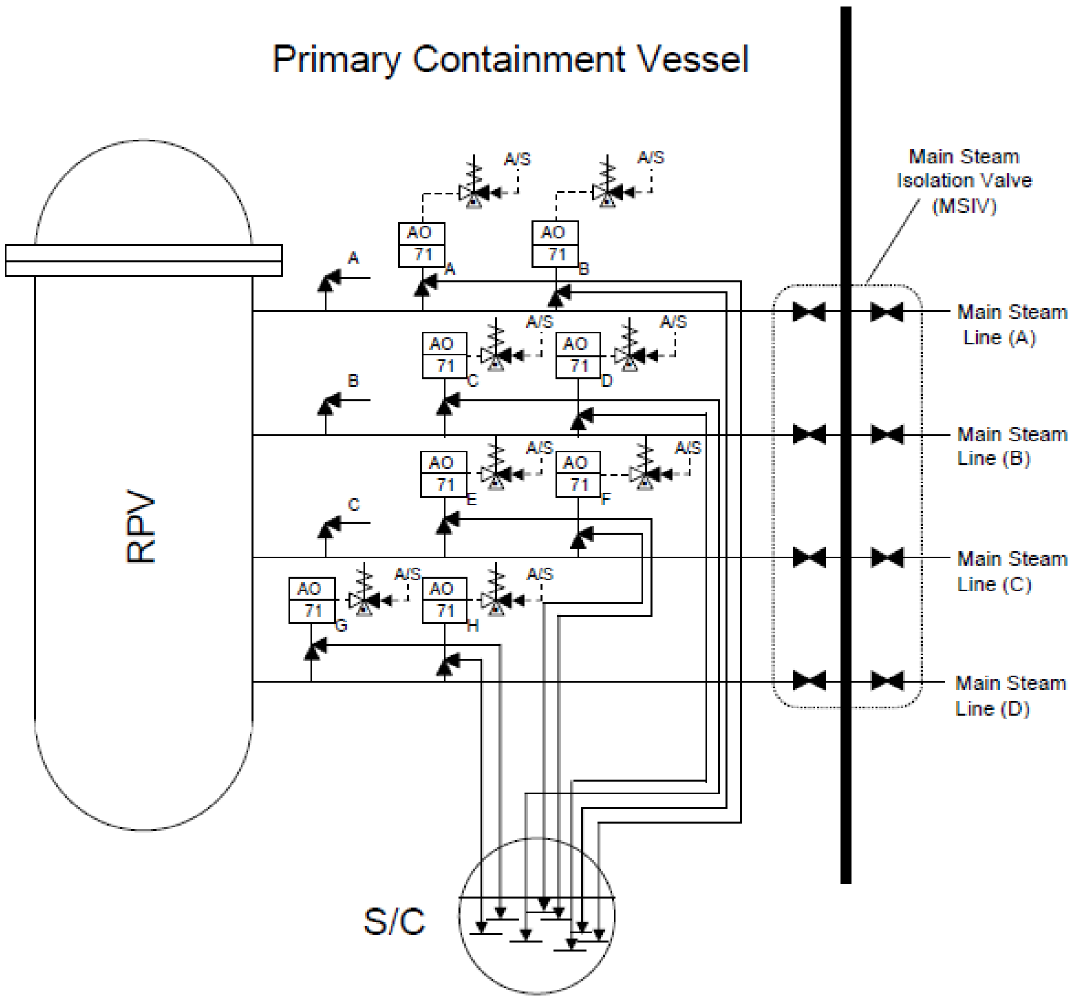
*1: During normal operation (in a standby condition), MO-15, 16, 18, 20 and Z13 valves and HO-Z14 are "open" and MO-131 and 21 valves are "close".
At startup, 131 and 21 valves are "open".
*2: MO-15 valve is inoperative due to AC power loss. (as-is)
*3: MO-16. 18, 20, 21 and 131 valves are inoperative due to DC power loss (the separate power source from isolation logic circuits). (as-is)
*4: During DC power loss, isolation (close) logic circuits are operative.
At that time, the drive power of each valve (written in *2 and *3) is activated, each valve is closed. If the drive power of each valve is already lost, the valves are inoperative. (as-is)

Fig. IV-2-5 System Structure Diagram of Reactor Core Isolation Cooling System (Units 2 and 3)



*1: The main steam safety relief valves (4 valves) are AO valves, and open drive air is supplied by the energized solenoid valves of air supply lines.
During power loss, solenoid valves become deenergized and main steam relief valves are in a closed condition.

Fig. IV-2-6 System Structure Diagram of Main Steam Safety Relief Valve (Unit 1)



*1: Main steam safety relief valves (8 valves) are AO valves, and open drive air is supplied by the energized solenoid valves of air supply lines.
During power loss, solenoid valves become deenergized and main steam relief valves are in a closed condition.

Fig. IV-2-7 System Structure Diagram of Main Steam Safety Relief Valve (Units 2 and 3)

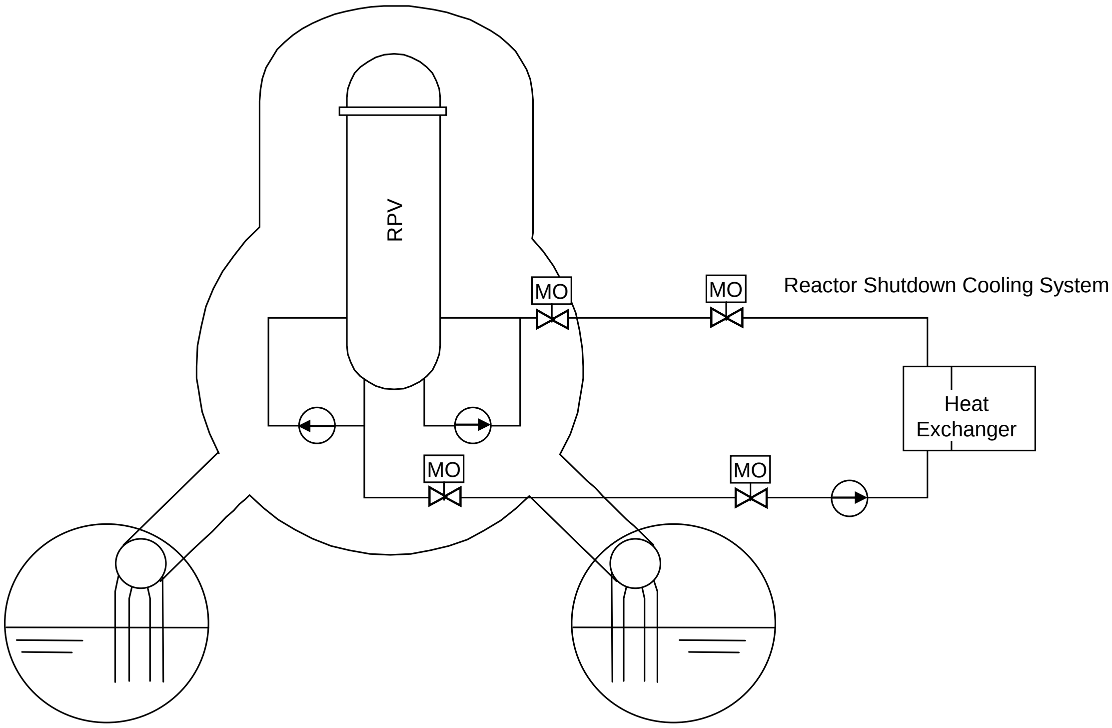


Fig. IV-2-8   System Structure Diagram of Reactor Shutdown Cooling System (Unit 1)

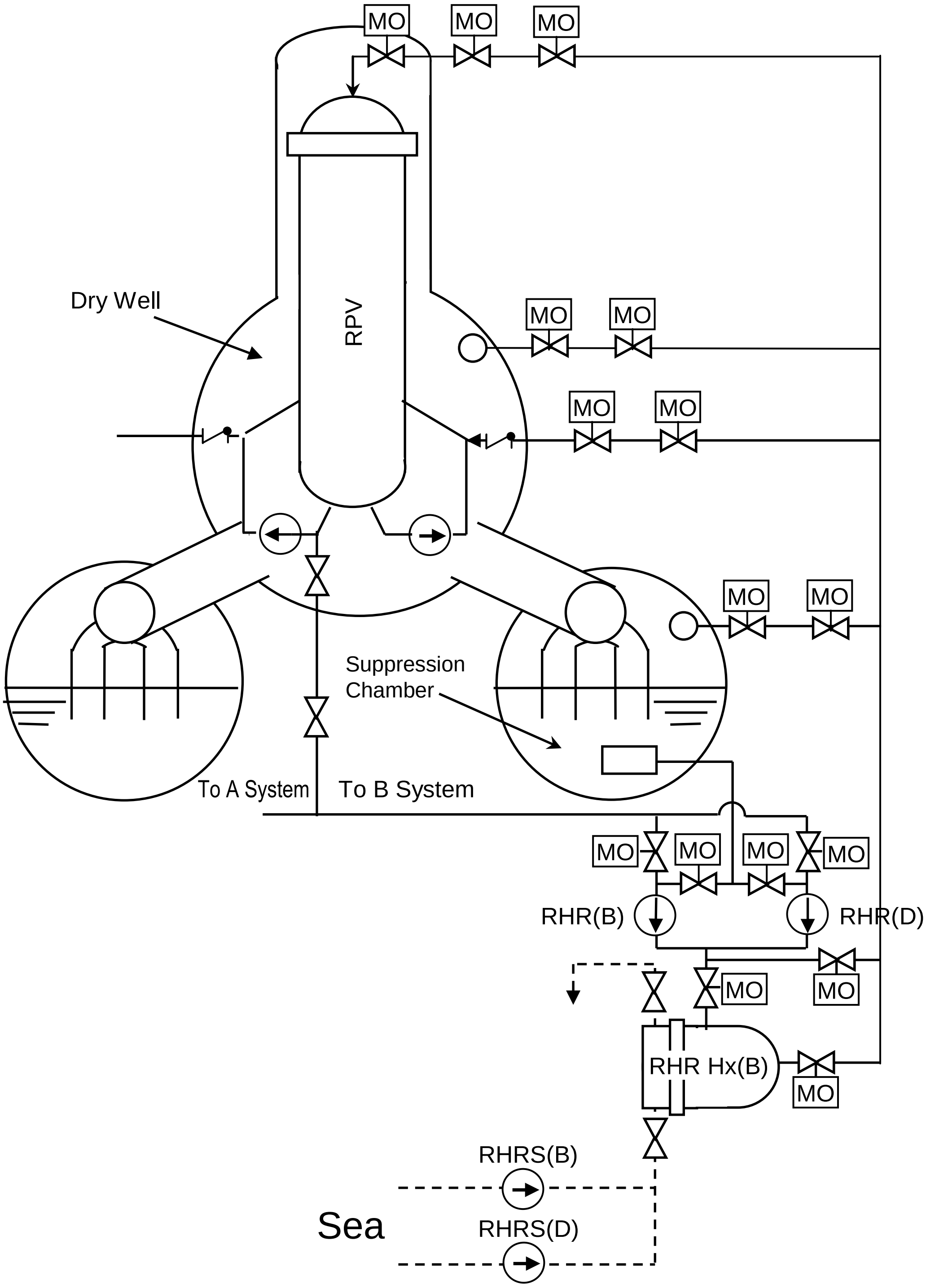


Fig. IV-2-9 System Structure Diagram of Residual Heat Removal System
(Units 2 and 3)

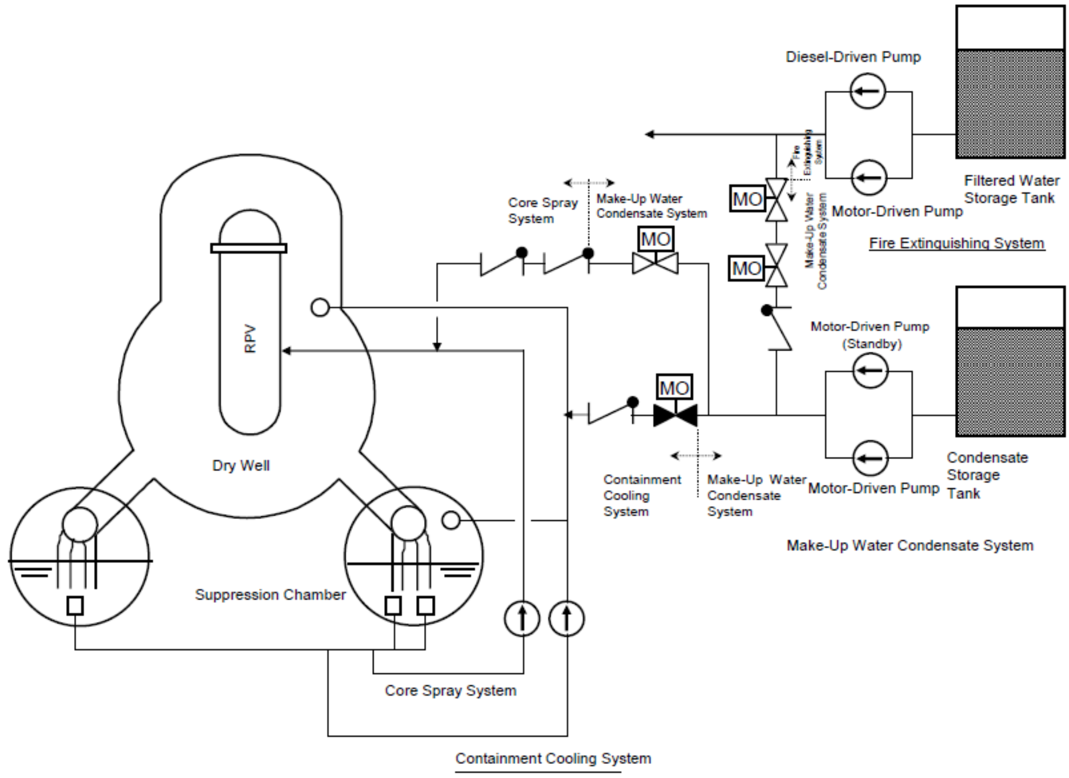


Figure IV-2-10 Overview of the Alternate Water Injection Facility for Unit 1 (by Fresh Water)

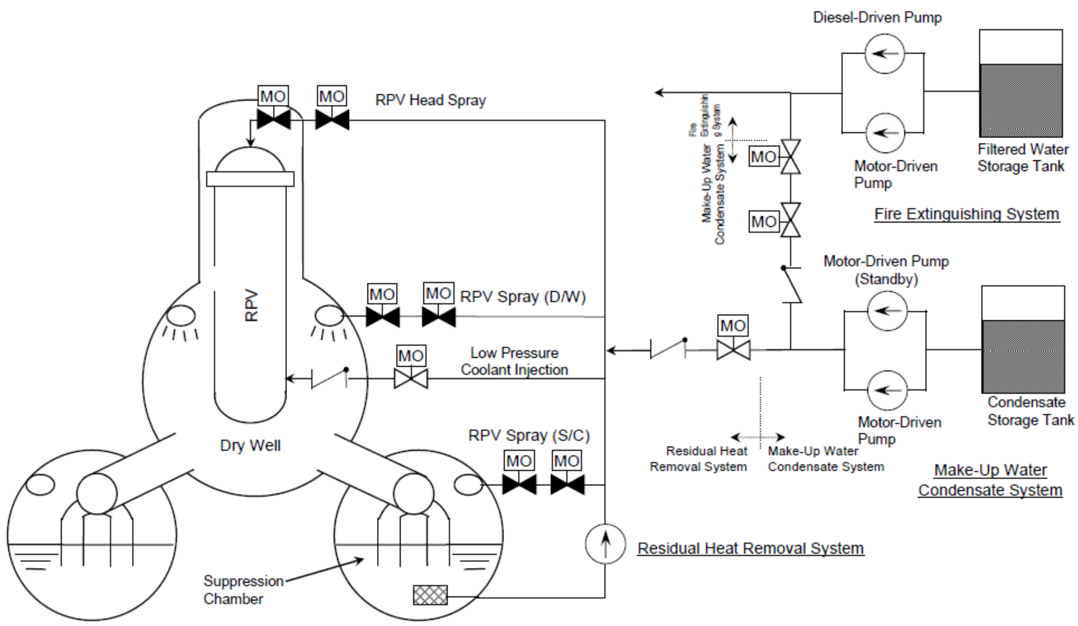


Figure IV-2-11 Overview of the Alternative Water Injection Facility for Units 2 and 3 (by Fresh Water)

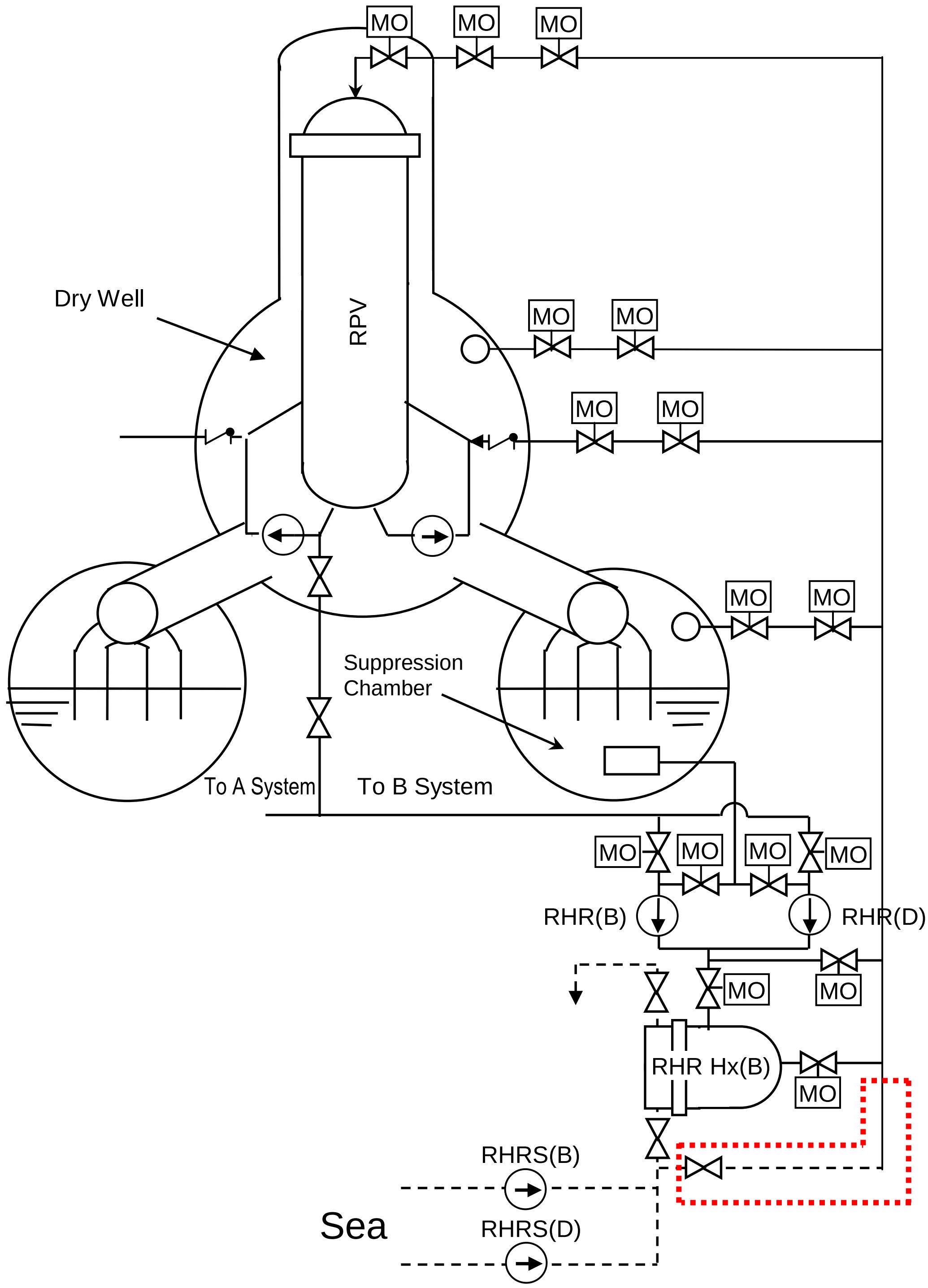


Figure IV-2-12 Overview of the Alternative Water Injection Facility for Unit 3 (by Seawater)

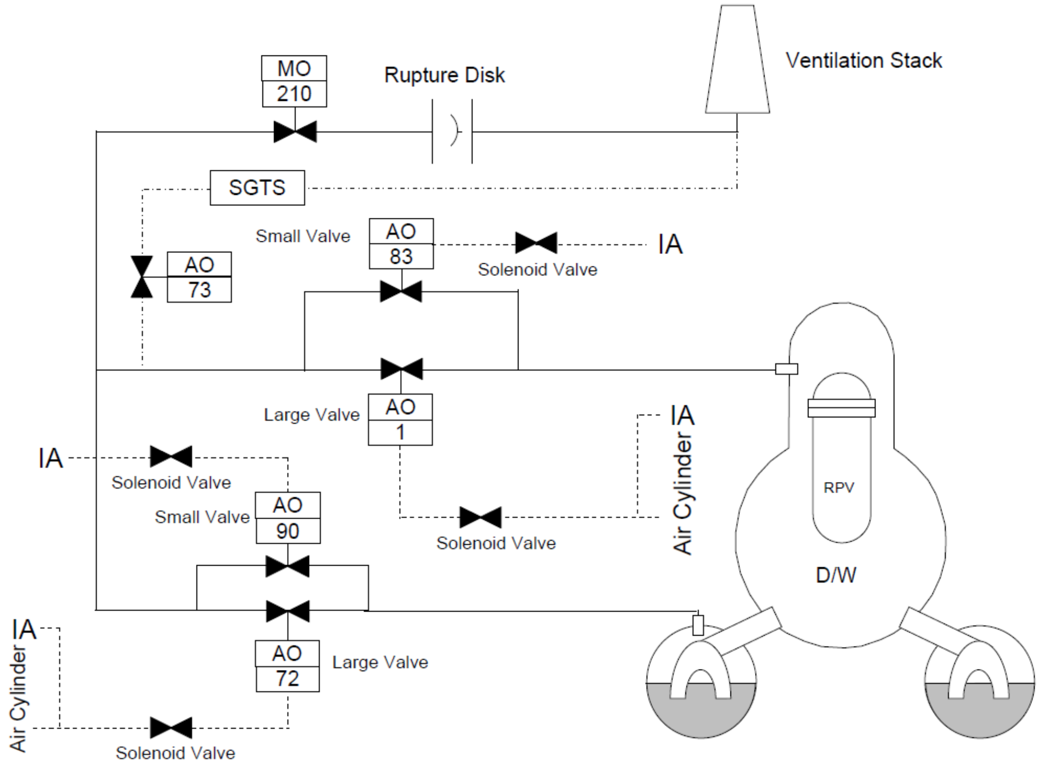


Figure IV-2-13　Overview of PCV Venting Facility (Unit 1)

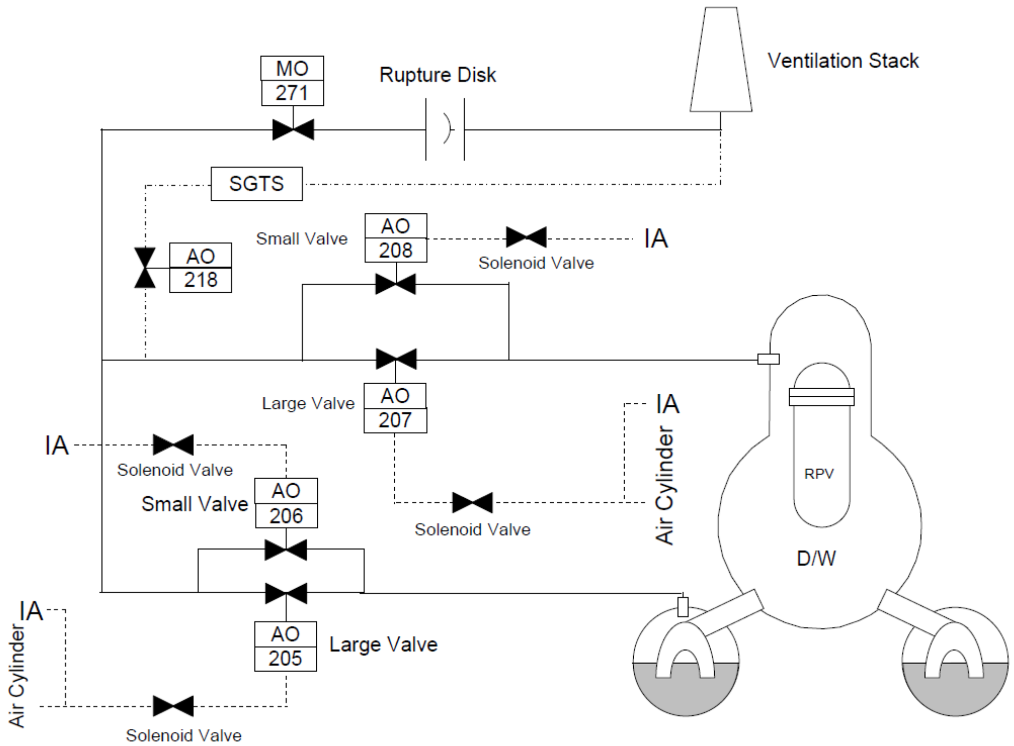


Figure IV-2-14　Overview of PCV Venting Facility (Units 2 and 3)

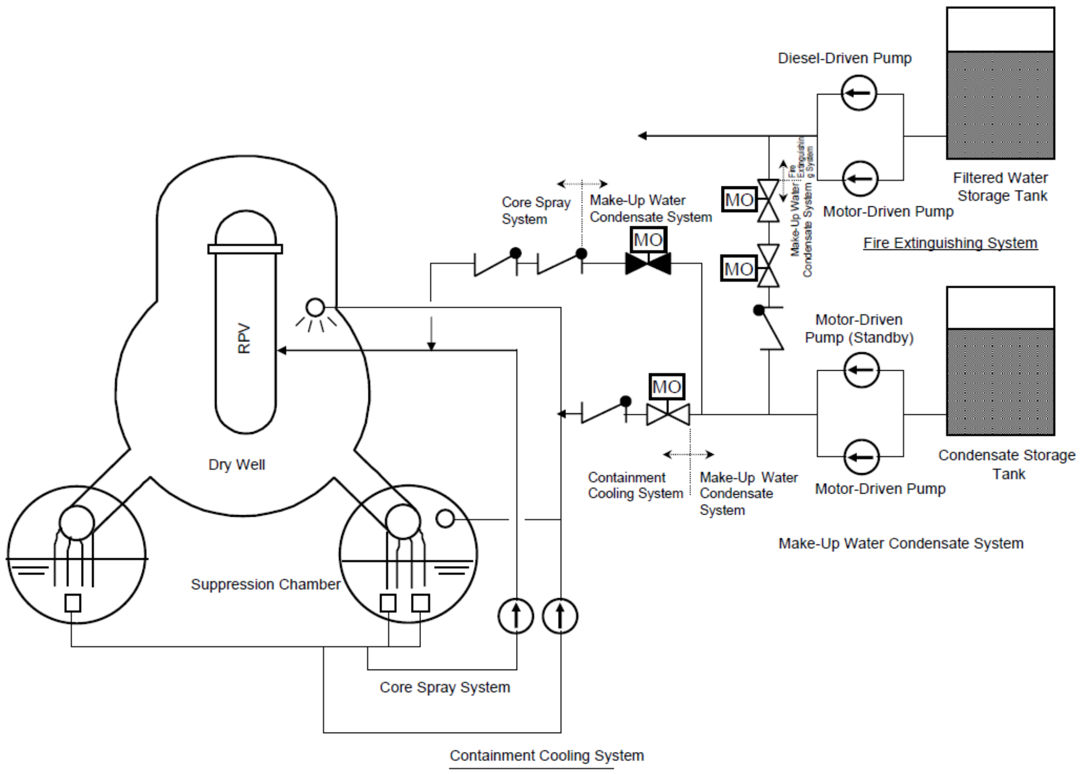


Figure IV-2-15　Overview of PCV Spray (D/W and S/C) Facility (Unit 1)

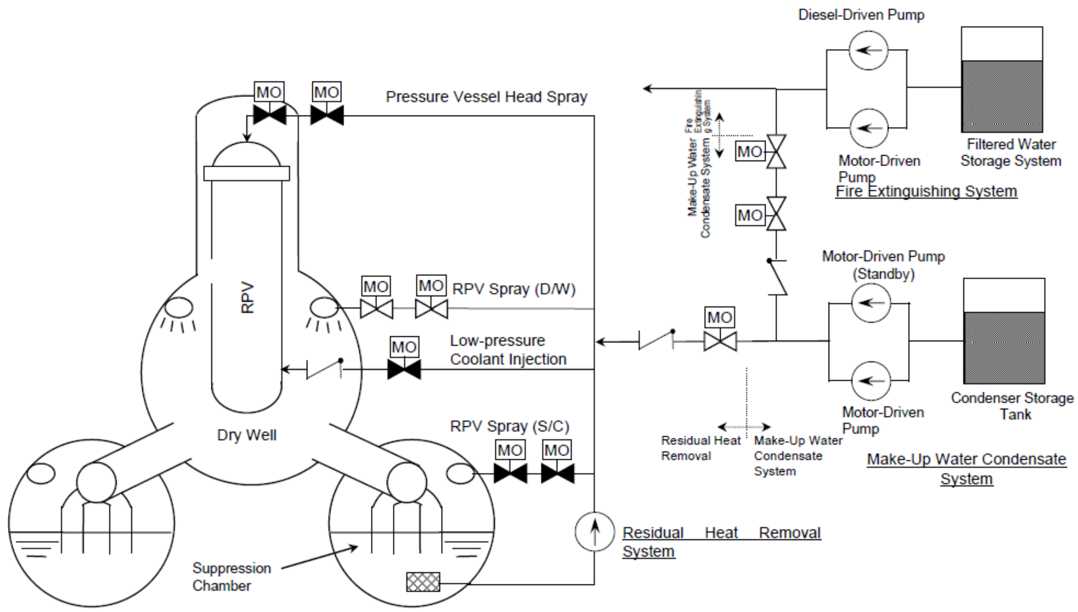
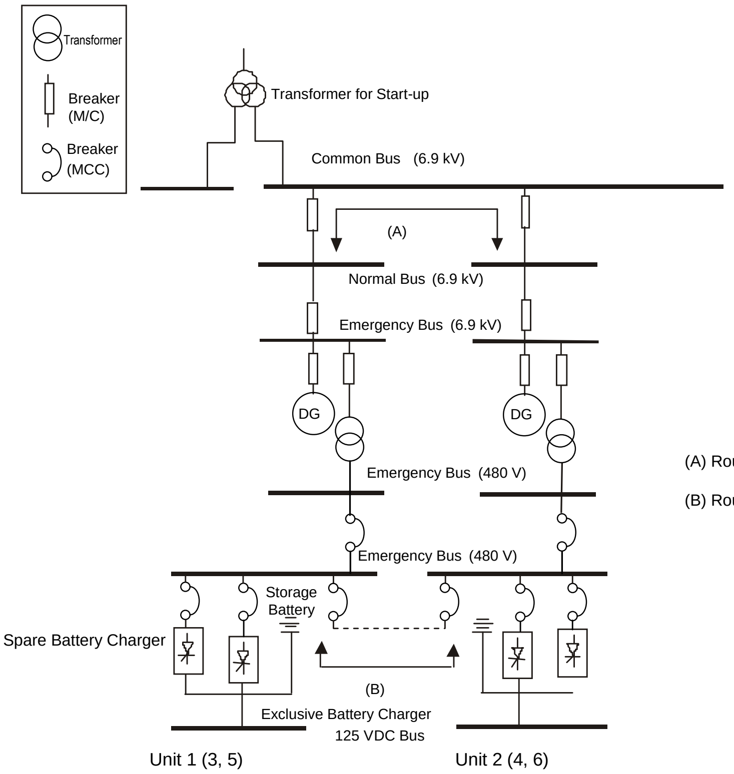


Figure IV-2-16　Overview of PCV Spray (D/W and S/C) Facility (Units 2 and 3)



(A) Route: Accommodating AC power of 6.9 kV (M/C can control only when DC power is usable.)
(B) Route: Accommodating AC power of 480 V (MCC is manual operation, and also during normal operation, MCC is open and locked.)

Figure IV-2-17 Conceptual Diagram of Power Supply Interchange among Units

3. Condition of the Fukushima NPSs before the earthquake

(1) Operation

On the day when the earthquake occurred, Unit 1 of the Fukushima Daiichi NPS was in operation at the constant rated electric power, and Units 2 and 3 of the Fukushima Daiichi NPS and all units of the Fukushima Daini NPS were in operation at the constant rated thermal power. The condition of the Fukushima NPSs before the occurrence of the earthquake is indicated in Table IV-3-1.

Fukushima Daiichi NPS Unit 4 was in periodic inspection outage. Large-scale repair work was under way to replace the core shroud, and all fuel assemblies had been transferred to the spent fuel pool from the reactor core with the reactor well filled with water and the pool gate closed.

Fukushima Daiichi NPS Unit 5 was in periodic inspection outage, all fuel assemblies were loaded in the reactor core and the pressure leak test for RPV was being conducted.

Fukushima Daiichi NPS Unit 6 was in periodic inspection outage, and all fuel assemblies were loaded in the reactor core that was in cold shutdown condition.

Table IV-3-1 The Condition of the Fukushima NPSs before the Earthquake

Power stations and reactor units			Condition before the occurrence of the earthquake
Fukushima Daiichi	Unit 1	Reactor	In operation (400 fuel assemblies)
		Spent fuel pool	392 fuel assemblies (including 100 new ones)
	Unit 2	Reactor	In operation (548 fuel assemblies)
		Spent fuel pool	615 fuel assemblies (including 28 new ones)
	Unit 3	Reactor	In operation (548 fuel assemblies, including 32 MOX fuel assemblies)
		Spent fuel pool	566 fuel assemblies (including 52 new ones; no MOX fuel assembly)
	Unit 4	Reactor	Undergoing a periodic inspection (disconnection from the grid on November 29, 2010; all fuel assemblies were removed; the pool gate closed; and the reactor well filled with water)
		Spent fuel pool	1,535 fuel assemblies (including 204 new ones)
	Unit 5	Reactor	Undergoing a periodic inspection (disconnection from the grid on January 2, 2011; RPV pressure tests under way; and the RPV head put in place)
		Spent fuel pool	994 fuel assemblies (including 48 new ones)
	Unit 6	Reactor	Undergoing a periodic inspection (disconnection from the grid on August 13, 2010 and the RPV head put in place)
		Spent fuel pool	940 fuel assemblies (including 64 new ones)
	Common pool		6,375 fuel assemblies (stored in each Unit's pool for 19 months or more)
Fukushima Daini	Unit 1	Reactor	In operation (764 fuel assemblies)
		Spent fuel pool	1,570 fuel assemblies (including 200 new ones)
	Unit 2	Reactor	In operation (764 fuel assemblies)
		Spent fuel pool	1,638 fuel assemblies (including 80 new ones)
	Unit 3	Reactor	In operation (764 fuel assemblies)
		Spent fuel pool	1,596 fuel assemblies (including 184 new ones)
	Unit 4	Reactor	In operation (764 fuel assemblies)
		Spent fuel pool	1,672 fuel assemblies (including 80 new ones)

(2) Connection of offsite power supply

1) Fukushima Daiichi NPS

Connection of an offsite power supply to the NPS were as follows: Okuma Lines No. 1 and No. 2 (275 kV) of the Shin-Fukushima Substation were connected to the switchyard for Units 1 and 2, Okuma Lines No. 3 and No. 4 (275 kV) were connected to the switchyard for Units 3 and 4, and Yonomori Lines No. 1 and No. 2 (66 kV) were connected to the switching yard for Units 5 and 6. In addition, the TEPCO Nuclear Line (66 kV) from Tomioka Substation of the Tohoku Electric Power was connected to Unit 1 as the spare line.

The three regular high voltage switchboards (6.6 kV) are used for Unit 1, for Unit 2, and for Units 3 and 4, respectively. The regular high voltage switchboards for Unit 1 and for Unit 2 were interconnected, and the regular high voltage switchboards for Unit 2 and for Units 3 and 4 were interconnected in a condition that enabled the electricity fed each other. When the earthquake occurred, the switching facilities for Okuma Line No. 3 in the switchyard for Units 3 and 4 were under construction, so that six lines were available for power of the NPS from offsite power supply.

2) Fukushima Daini NPS

A total of four lines of offsite power supply from the Shin-Fukushima Substation were connected to the Fukushima Daini NPS: Tomioka Lines No. 1 and No. 2 (500 kV) and Iwaido Lines No. 1 and No. 2 (66 kV).

When the earthquake occurred, Iwaido Line No. 1 was under construction, so that three lines were available for power of the NPS from offsite power supply.

4. Occurrence and progression of the accident at the Fukushima NPSs

(1) Overview of the chronology from the occurrence of the accident to the emergency measures taken

1) Fukushima Daiichi NPS

The earthquake which occurred at 14:46 on March 11, 2011 brought all of the Fukushima Daiichi NPS Units 1 through 3, which were in operation, to an automatic shutdown due to the high earthquake acceleration.

Due to the trip of the power generators that followed the automatic shutdown of the reactors, the station power supply was switched to the offsite power supply. As described in Chapter III, the NPS was unable to receive electricity from offsite power transmission lines mainly because some of the steel towers for power transmission outside the NPS site collapsed due to the earthquake. For this reason, the emergency DGs for each Unit were automatically started up to maintain the function for cooling the reactors and the spent fuel pools.

Later, all the emergency DGs except one for Unit 6 stopped because the emergency DGs, seawater systems that cooled the emergency DGs, and metal-clad switchgears were submerged due to the tsunami that followed the earthquake, and the result was that all AC power supply was lost at Units 1 to 5.

At 15:42 on March 11, TEPCO determined that this condition fell under the category of specific initial events defined in Article 10 of the Act on Special Measures Concerning Nuclear Emergency Preparedness (hereinafter referred to as Nuclear Emergency Preparedness Act) and notified the national government, local governments, and other parties concerned.

At 16:36 on the same day, TEPCO found the inability to monitor the water level in the reactors of Units 1 and 2, and determined that the conditions of Unit 1 and 2 fell under the category of an event that is “unable to inject water by the emergency core cooling system” as defined in Article 15 of the Nuclear Emergency Preparedness Act, and at 16:45 on the same day, the company notified NISA and other parties concerned of this information.

TEPCO opened the valve of the IC System A of Unit 1 IC, and in an effort to maintain the functions of the IC, it continued to operate it mainly by injecting fresh water into its shell side. Immediately after the tsunami, TEPCO could not

confirm the operation of the RCIC system of Unit 2, but confirmed about 3:00 on March 12 that it was operating properly. Unit 3 was cooled using its RCIC system, and as a result, the PCV pressure and water levels remained stable.
In order to recover the power supply, TEPCO took emergency measures such as making arrangements for power supply vehicles while working with the government, but its efforts were going rough.

Later, it was confirmed around 23:00 on March 11 that the radiation level in the turbine building of Unit 1 was increasing. In addition, at 0:49 on March 12, TEPCO confirmed that there was a possibility that the PCV pressure of the Unit 1 had exceeded the maximum operating pressure and determined that the event corresponded to the event ‘abnormal increase in the pressure in the primary containment vessel’ as defined in the provisions of Article 15 of the Nuclear Emergency Preparedness Act. For this reason, in accordance with Article 64, Paragraph 3 of the Reactor Regulation Act, the Minister of Economy, Trade and Industry ordered TEPCO to reduce the PCV pressure of Units 1 and 2.

At 5:46 on March 12, the company began alternative water injection (fresh water) for Unit 1 using fire engines. (The conceptual diagram of alternative water injection using fire engines is shown in Figure IV-4-1.) In addition, TEPCO began preparations for PCV venting because the PCV pressure was high, but the work ran into trouble because the radiation level in the reactor building was already high. It was around 14:30 on the same day that a decrease in the PCV pressure level was actually confirmed. Subsequently, at 15:36 on the same day, an explosion considered as a hydrogen explosion occurred in the upper part of the Unit 1 reactor building.

Meanwhile, the RCIC system of Unit 3 stopped at 11:36 on March 12, but later, the HPCI system was automatically activated, which continued to maintain the water level in the reactor at a certain level. It was confirmed at 2:42 on March 13 that the HPCI system had stopped. After the HPCI system stopped, TEPCO performed wet venting to decrease the PCV pressure, and fire engines began alternative water injection (fresh water) into the reactor around 9:25 on March 13. In addition, PCV venting was performed several times. As the PCV pressure increased, PCV venting was performed several times. As a result, the PCV pressure was decreased. Subsequently, at 11:01 on March 14, an explosion that was considered as a hydrogen explosion occurred in the upper part of the reactor building.

At 13:25 on March 14, TEPCO determined that the RCIC system of Unit 2 had stopped because the reactor water level was decreasing, and began to reduce the

RPV pressure and inject seawater into the reactor using fire-extinguishing system lines. TEPCO continued to cool the reactor core using the fire pumps loaned by a fire department. The wet venting line configuration had been completed by 11:00 on March 13, but the PCV pressure exceeded the maximum operating pressure. At 6:00 on March 15, an impulsive sound that could be attributed to a hydrogen explosion was confirmed near the suppression chamber (hereinafter referred to as S/C), and later, the S/C pressure decreased sharply.

The total AC power supply for Unit 4 was also lost due to the earthquake and tsunami, and therefore, the functions of cooling and supplying water to the spent fuel pool were lost. Around 6:00 on March 15, an explosion that was considered as a hydrogen explosion occurred in the reactor building, damaging part of the building severely.

At 22:00 on March 15, in accordance with Article 64, Paragraph 3 of the Reactor Regulation Act, the Minister of Economy, Trade and Industry ordered TEPCO to inject water into the spent fuel pool of Unit 4. On March 20 and 21, fresh water was sprayed into the spent fuel pool of Unit 4. On March 22, a concrete pump truck started to spray seawater onto the pool, followed by the spraying of fresh water instead of seawater, which began on March 30.

On March 17, a Self-Defense Forces helicopter sprayed seawater into the spent fuel pool of Unit 3 from the air. Later, seawater was sprayed into the pool using high-pressure water-cannon trucks of the National Police Agency’s riot police and fire engines of the Self-Defense Forces. From March 19 to March 25, Tokyo Fire Department, Osaka City Fire Bureau and Kawasaki City Fire Bureau, that were dispatched as Emergency Fire Response Teams, sprayed seawater for five times by using seawater supply system against fire and squirt fire engines. In addition, Yokohama City Fire Bureau, Nagoya City Fire Bureau, Kyoto City Fire Bureau and Kobe City Fire Bureau dispatched their fire engines to Fukushima Daiichi NPS or in readiness. Niigata City Fire Bureau and Hamamatsu City Fire Bureau assisted to set up large-scale decontamination system. Later, the concrete pump truck started to spray seawater into the spent fuel pool of Unit 3 on March 27 and into the spent fuel pool of Unit 1 on March 31.

The total AC power supply for Unit 5 was also lost due to the earthquake and tsunami, resulting in a loss of the ultimate heat sink. As a result, the reactor pressure continued to increase, but TEPCO managed to maintain the water level and pressure by injecting water into the reactor by injecting water into the reactor by operating Make-Up Condensing Water Pump after the power was supplied from Unit 6. Later, the company activated a temporary seawater pump, bringing the reactor to a cold shutdown condition at 14:30 on March 20.

One of the emergency DGs for Unit 6 had been installed at a relative high location, and as a result, its functions were not lost even when the NPS was hit by the tsunami, but the seawater pump lost all functionality. TEPCO installed a temporary seawater pump while controlling the reactor water level and pressure by injecting water into the reactor and reducing the reactor pressure on a continuous basis. By doing this, the company recovered the cooling functions of the reactor, thus bringing the reactor to a cold shutdown condition at 19:27 on March 20.

After the accident, seawater was used for cooling the reactors and the spent fuel pools for a certain period of time, but the coolant has been switched from seawater to fresh water with consideration given to the influence of salinity.

2) Fukushima Daini NPS

Units 1 through 4 of the Fukushima Daini NPS were all in operation but automatically shutdown due to the earthquake. Even after the occurrence of the earthquake, the power supply needed for the NPS was maintained through one of the three external power transmission lines that had been connected before the disaster. (Incidentally, the restoration work for another line was completed at 13:38 on March 12, enabling the NPS to receive electricity through two external power transmission lines.) Later, the tsunami triggered by the earthquake hit the NPS, making it impossible to maintain reactor cooling functions because the seawater system pumps for Units 1, 2, and 4 could not be operated.

For this reason, at 18:33 on March 11, TEPCO determined that a condition had occurred that fell under the category of events specified in Article 10 of the Nuclear Emergency Preparedness Act and notified the national government, local governments, and other parties concerned of this information. Later, since the temperature of the suppression chamber exceeded 100°C, and the reactor lost its pressure suppression functions, the company determined that an event where "pressure suppression functions are lost" defined in Article 15 of the Nuclear Emergency Preparedness Act had occurred at Unit 1 at 5:22 on March 12, at Unit 2 at 5:32 on the same day, and at Unit 4 at 6:07 on the same day, and notified the Nuclear and Industrial Safety Agency and other parties concerned of this information.

Units 1, 2 and 4 of the Fukushima Daini NPS recovered their cooling functions due to the restoration work that followed the earthquake because the offsite power supply was maintained, and the metal-clad switchgears, DC power supply, and other facilities were not submerged. As a result, Unit 1 was brought to a cold shutdown condition, in which the temperature for reactor coolants goes down below 100°C, at 17:00 on March 14, Unit 2 at 18:00 on the same day, and Unit 4 at 7:15 on March 15. Unit 3 was brought to a cold shutdown condition at 12:15 on March 12 without losing reactor cooling functions and suffering other kinds of damage.

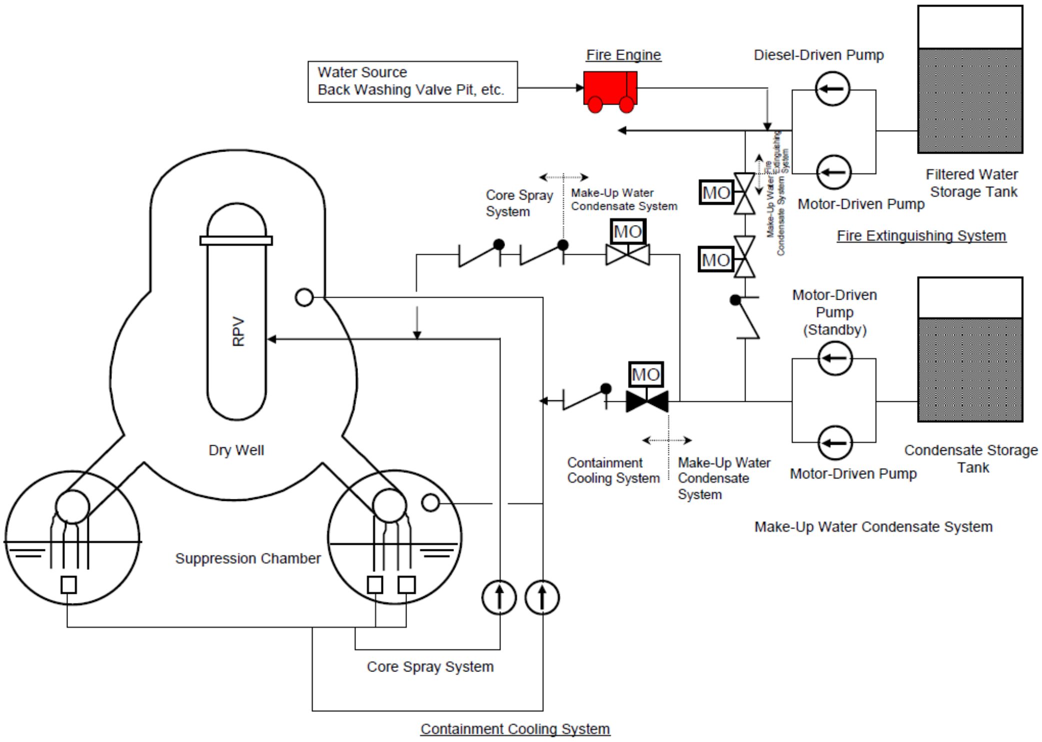


Figure IV-4-1　Conceptual Diagram of Alternative Water Injection Using Fire Engines

5. Situation of Each Unit etc. at Fukushima NPS

The outline of the accident at Fukushima NPS has been given in Chapter 4. This accident involved a total loss of the AC power supply, so after the tsunami invasion, we were only able to get extremely limited parameter information.

This section covers the parameter information we have been able to get to this point, under these very difficult conditions.

In addition, in order to supplement this limited information, TEPCO carried out analysis and evaluation of reactor situation of Unit 1, Unit 2 and Unit 3 using MAAP, which is a Severe Accident Analysis Code, based on gained operating records and parameters. The results were reported to NISA on May 23. NISA carried out a cross-check by using another severe Accident Analysis Code, MELCOR in order to conduct a cross-check for validation of TEPCO's analysis with the assistance of Incorporated Administrative Agency Japan Nuclear Energy Safety Organization in order to confirm the adequacy of the analysis and evaluation. The report of analysis and evaluation conducted by Tokyo Electric Power Company is shown in Appended Reference IV-1, and analytic results by cross-check are shown in Appended Reference IV-2.

Note that this parameter information was left behind in the Main Control Room and other areas after the accident and took some time to recover, so TEPCO made it public on May 16, along with reporting it to NISA.

In addition, based on these analysis results, we have evaluated the event progress of this accident and made some estimates in areas such as the RPV, PCV, etc. situation regarding their relationship with changes over time and the events that occurred.

Our evaluation of the development of events regarding the nuclear reactors for each unit at Fukushima NPS is written up as shown below.

(1)We sorted out the plant information we have obtained as of the current moment and summarized it in chronological order.

(2)We need to check the reliability of the parameter information etc. we obtained in order to evaluate the accident event progress, so this was considered based on the relationships with the performance of each plant operation, the overall behavior, the parameter information, and so on.

(3)Based on the conditions we considered in (2), we carried out a Severe Accident analysis, and analyzed the event development of the reactor accidents.

(4)In order to evaluate RPV, PCV, etc., we first estimated the RPV, PVC, etc. situation when they were relatively stable. Then we used the estimated event progress to estimate the RPV, PCV, etc. situation as it changed with time.

(5)We carried out a comparative consideration from the analysis in (3) and the RPV, PCV, etc. estimate results in (4). Then we evaluated how the series of events of accident progressed.

In terms of events outside the reactor, in our summary in (1) we sorted out the related situations. In addition, we also analyzed the explosion damage to the reactor building in Unit 4 of the Fukushima Daiichi NPS. We then went on to sort out and sum up separately from the listings for each unit the fuel cooling work being done in the spent fuel pool and the situation (and treatment situation) for the pool water that has been confirmed in the trenches and other areas outside the building, and in the turbine building of each unit.

Note that the estimates shown here are estimates of the possible situation based on the plant information we have been able to get at the present stage. We will need to update our deliberations as appropriate based on any supplemental information, such as details of parameter information or event information, and severe accident analysis results that reflect these.

(1) Fukushima Daiichi NPS, Unit 1

1) Chronological arrangement of accident event progress and emergency measures

a From the earthquake to the invasion of the tsunami

As shown in Chapter 3, before the earthquake the power station was operating steadily at its rated power. Immediately after the earthquake struck, at 14:16 on March 11, the reactor of Unit 1 scrammed due to the excessive earthquake acceleration, and at 14:47 the control rods were fully inserted and the reactor became subcritical, and it was shutdown normally. In addition, the earthquake damaged the power reception breakers on the NPS side of the Okuma No. 1 and No. 2 Power Transmission Lines and other areas, so there was a loss of external power. This meant that two emergency diesel generators automatically started up.

At 14:47, the loss of the power supply to the instruments due to the loss of external power caused the failsafe to send a signal to close the Main Steam Isolation Valve (hereinafter referred to as MSIV), and the MSIV was closed down. Regarding this point, since the increase in the main steam flow volume that would be measured if the main steam piping was broken, was not confirmed in the Past Event Records Device, TEPCO judged that there were no breaks in the main steam piping and NISA considers that is a logical reason to make that judgment.

The shutoff of the MSIV increased the RPV pressure, and at 14:52 the IC automatically started up. Next, in accordance with the operating manual for the IC, at 15:03 the IC was manually shut down. The manual notes that the temperature decrease rate for the RPV should be adjusted to not exceed 55°C/h. Moreover, the reactor pressure varied three times between 15:10 and 15:30, and TEPCO performed manual operations using only the A-system of the IC. Note that when the IC is operated, the steam is condensed and cooled, and is returned into the reactor as cold water through the reactor recirculation system. The records of the temperatures at the entrance to the reactor recirculation pump show three drops in temperature, so this is assumed to be the effects of the manual operation of the IC.

Meanwhile, in order to cool the S/C, at approx. 15:07 and 15:10 the B and A systems of PCV spray system were activated.

For the one hour that they remained following the earthwork, the HPCI records show no indications of any drop to the automatic activation water level (L-L) or any records of the HPCI being activated.

b Effects from the tsunami

At 15:37, the effects of the tsunami were felt, and the water, meaning that two emergency diesel generators stopped operation, and the emergency bus distribution panel was submerged, leading to all AC power being lost, affected both the seawater pump and the metal-clad switchgear of Unit 1. Unit 2 also suffered a loss of all AC power, so it was not possible to supply power from Unit 2.

In addition, the loss of DC power functions meant that it was not possible to check the parameter information. With the reactor water level no longer able to be monitored, and the water injection situation unclear, there was the possibility that no water was being injected, so at 16:36 TEPCO judged that this condition fell under the category of an event that is "unable to inject water by the emergency core cooling system as defined in Article 15 of the NEPA. Additionally, the loss of function of the component cooling system seawater pump meant that function of the component cooling system was lost, and the SHC was not able to be used, so it was not possible to relocate the decay heat of the PCV to the sea, the ultimate heat sink.

c Emergency measures

TEPCO opened the A system valve on the IC and used the diesel-driven fire pump (hereinafter referred to as D/D FP) to pump fresh water into the body of the IC etc., in an attempt to maintain the IC functions. However, according to the results from the valve circuit investigation TEPCO carried out in April, the degree the valve was open is not clear, so it is not possible to judge the extent to which the IC was functioning at this point in time (end of May). In addition, it has been confirmed that the radiation level inside the turbine building increased at around 23:00 on March 11.

TEPCO confirmed that there was the possibility that the PCV pressure had exceeded the maximum operating pressure at 00:49 on March 12, and judged that this condition fell under the category of an event that is "unable to inject water by the emergency core cooling system as defined in Article 15 of the NEPA and informed NISA. As a result, at 6:50 on March 12, the Minister of Economy, Trade and Industry ordered the suppression of the PCV pressure in Units 1 and 2, in accordance with the provisions in Article 64, Paragraph 3 of the Reactor Regulation Act.

TEPCO started pumping alternative water injection (fresh water) through fire pumps at 5:46 on March 12. Therefore, since cooling using the IC had stopped due to the failure of all AC power at 15:37 on March 11, that meant that there was a 14-hour-and-9-minute period when cooling using pumped water had stopped.

TEPCO worked to vent the PCV in order to lower its pressure. However, since radiation inside the reactor building was already at the high radiation environment level, the work proceeded with difficulty. The motor-operated valve (MO valve) in the PCV vent line was manually opened to 25% at about 9:15 on March 12. In addition, workers headed to the site to open the air-operated valve (AO valve) manually but the radiation levels were too high. As a result, a temporary air pressurization machine was set up to drive the AO valve and the PCV vent was operated. TEPCO judged that the PCV vent had succeeded since the PCV pressure had been reduced by 14:30.

d The building explosion and measures taken subsequently

At 15:36 on March 12, an explosion, thought to be a hydrogen explosion, occurred in the upper part of the reactor building. The roof, and the outer wall of the operation floor as well as the waste processing building roof, were destroyed. Radioactive materials were released into the environment during these processes, thereby increasing the radiation dose in the area surrounding the site.

According to TEPCO, the supply of 80,000 liters of fresh water ran out at around 14:53 on March 12, however it was unclear when the water injection stopped. At 17:55, in accordance with the provisions in Article 64, Paragraph 3 of the Reactor Regulation Act the Minister of Economy, Trade and Industry ordered TEPCO to take action to inject seawater to fill up the RPV. TEPCO started pumping in seawater using the fire-fighting lines at 19:04 on March 12. There was confusion in the lines of communication and command between the government and TEPCO regarding this injection of seawater. Initially, it was considered that it was suspended, but TEPCO announced on May 26 that it had not been stopped and injection had in fact continued based on a decision by the Power Station Director (in order to prevent the accident from escalating, the most important thing was to keep injecting water into the reactor).

Later, on March 25, injection returned to using fresh water from the pure water tank. As of the end of May, the total amount injected was around 10,787 m^3 of fresh water, and around 2,842 m^3 of seawater, for a total of around 13,630 m^3. In addition, water was injected using the temporary electric pump from March 29, and on April 3 it was shifted to a stable water injection system by changing the power supply for this pump from a temporary supply to a permanent supply, and by other measures.

On April 6, the Minister of Economy, Trade and Industry directed that TEPCO provide reports on the necessity of injecting nitrogen, how it would be done, and an evaluation of effects regarding safety, based on Article 67, Paragraph 1 of the Reactor Regulation Act. This was done as there was the possibility of hydrogen gas accumulating inside the

PCV. NISA accepted TEPCO's report, dated the same day, and directed them on three points, including ensuring safety through appropriate management of parameters, etc. when carrying out the nitrogen injection. TEPCO started nitrogen injection operations on April 7 and as of the end of May is still continuing them.

To restore and enhance the power supply, TEPCO completed inspections and trial charging of the power receivers from Tohoku Electric Power Co.'s Toden Genshiryoku Line on March 16, and as of March 20 had completed electricity access at the power center, ensuring an external power supply. As of March 23, cables were laid from the power center for the load needed. The connections are being established.

Main time lines are shown in Table IV-5-1. In addition, parameters for the RPV pressure etc. are shown in Figs. IV-5-1 through IV-5-3.

2) Evaluation using the Severe Accident Analysis Code

a Analysis and evaluation by TEPCO

As a result of the analysis, while it was shown that the RPV had been damaged by melted fuel, when the results of temperature measurements for the RPV were taken into account, TEPCO considered that the most of the fuel was in fact being cooled at the bottom of the RPV.

TEPCO estimated in this progress, the IC was not assumed to function following the tsunami and it was estimated that the fuel was uncovered for about three hours after the earthquake, with reactor damage starting one hour after that.

Since then there was no water being injected into the reactor, the fuel had undergone core melting, due to its decay heat, and flowed to the lower plenum, then about 15 hours after the earthquake it started to damage the RPV.

The radioactive materials contained in the fuel just before the accident were released into the RPV as the fuel was damaged and melted, and the analysis was carried out for the leakage assumed from PCV with the increase of PCV pressure, and almost all the noble gases were vented out into the environment. The ratio of released radioactive iodine to the total iodine contained (hereinafter referred to as release ratio) was approximately 1% from the analysis result, and the release of other nuclides was less than 1%.

b NISA's cross-check

In the cross-check analysis, along with carrying out an analysis using the MELCOR code with the same conditions (basic conditions) as TEPCO used, an analysis was also performed using different conditions to those TEPCO assumed. A sensitivity analysis was carried out, such that the amount of alternative water injection was estimated by the relation of the pump discharge pressure with the RPV pressure.

The cross-check of basic conditions showed largely the same trends. At around 17:00 on March 11 (two hours after the shock), the fuel began uncovered, and the core damage started within one hour. The PCV was damaged five hours after the shock, which is earlier than that of TEPCO's analysis, and the behavior of the RPV pressure was coherent with the pressure actually measured.

As for release ratio of radioactive nuclides, the analytical results show about 1% of tellurium, about 0.7% of iodine and about 0.3% of cesium. However the release ratios are affected by the infection flow rates of seawater, the results may be changed by operation condition because the operation condition was not clear.

3) Evaluation of the Status of RPV, PCV, and the Equipment

a Checking plant information

Based on the plant information during the period between March 23 and May 31, when the plant was relatively stable, the status of the RPV and PCV was evaluated. Handling of the plant data during this period was considered as shown below.

The standard water level is determined by the water level in the instrumentation piping and condensation tank in the PCV. While PCV pressure was high, there was a possibility that the reactor water level around the fuel was indicated higher than actual level, because high PCV temperature vaporize the water in the instrumentation piping and condensation tank in the PCV, hence those water level was indicated lower than actual level. This suggests that the reactor water level was indicating higher than normal. As a result of recovering and correcting the standard water level for the reactor water level gauge on May 11, the water level was confirmed to have dropped below the fuel level, so it was not possible to measure the water level inside the RPV during this period either.

The RPV pressure was considered as generally showing the actual pressure as the A and B system measurements matched until around March 26. However, after that the B system showed a rising trend, and so due to the condition estimates shown in the next section the B system was removed from evaluation consideration as it was no longer matching the D/W pressure.

The RPV temperature showed different figures for each of the two water nozzle systems, but the system that was hovering around 120°C, matching the RPV pressure, was referenced as the temperature of the atmosphere in the RPV, and the data showing the higher temperatures was referenced as the metal temperature of the RPV itself.

The plant data until March 22 was handled as follows.

The reactor water levels around the fuel may have been indicating higher reactor water levels, as noted above. It was decided that water levels would not be referenced as it was not possible to judge the point at which the indications became inaccurate.

The RPV pressure was referenced as generally showing the actual pressure for the A system, as, although both the A and B system figures matched after March 17, prior to that date the A system had also been changing continuously.

It was difficult to confirm the actual changes in the D/W pressure in the PCV as the information from TEPCO was sporadic, but it was decided to assume it based on event information such as equipment operation, etc.

b Estimates of the RPV, PCV, etc. status during the relatively stable period

-Status of the RPV boundary

The amount of water injected into the RPV by May 31 was estimated at approx. 13,700 tons based on information from TEPCO, but the total amount of steam generated from the start of water injection was approx. 5,100 tons, as the water was evaluated with a larger estimate of decay heat using the evaluation formula for decay heat. If the pressure boundary could be ensured, then at minimum there would remain a difference of approx. 8,600 tons. The capacity of the RPV, even in the larger estimates, is about 350 m^3, so it is thought that the injected water is evaporated in the RPV and that there was not only leakage of steam, but of liquid as well. The injection of water into the RPV was done using a feed water nozzle, and initially pooled up outside the shroud, then flowed into the bottom of the RPV through the jet pump diffusers. The fuel has been considered as cooled, and at the present moment it is estimated that the injected cooling water is that which has leaked to the RPV bottom.

In the present state, it is thought that steam continues to escape from the gas phase part of the RPV, but the RPV pressure is higher than the D/W pressure, so it is assumed that the opening is not large. However, the pressure changes after March 23 are changing in parallel with the changes in PCV pressure, so the possibility cannot be denied that there is a problem with the measurements.

-Status of the RPV interior (reactor status, water level)

As a result of increasing the amount of water injected when the injection was changed from the feed water line on March 23 the temperature of the RPV bottom dropped from being higher than the measurable maximum (greater than 400°C), but after the injection water amount was dropped, temperatures in some areas increased, so it is thought that the fuel is inside the RPV. As a result of recovering and correcting the standard water level for the water level gauge in the reactor on May 11, it was confirmed that the water level was lower than the fuel. Therefore, at the present moment it is estimated that the fuel has melted and an considerable amount of it is lying at the bottom of the RPV. However, there is a possibility that the bottom of the RPV was damaged and some of the fuel might have dropped and accumulated on the D/W floor (lower pedestal).

The temperature of part of the RPV (the feed water nozzles, etc.) is higher than the saturation temperature for the PRV pressure, so at the present stage it is estimated that part of the fuel is not submerged in water, but is being cooled by steam.

-PCV status

On March 12 the D/W pressure reached its highest level of approx. 0.7 MPag, exceeding the PCV maximum working pressure (0.427 MPag), and on March 23 the D/W temperature exceeded the measurable maximum (greater than 400°C). From these and other issues it is estimated at the present stage that the functions of the gasket on the flange section and the seal on the penetrating section have weakened. The inclusion of nitrogen, which started on April 7, was measured to increase the pressure by approx. 0.05 MPa, so at that stage it was estimated that the leakage rate from the D/W was approx. 4%/h. No major changes have been confirmed in the PCV status since then.

Up until the inclusion of nitrogen on April 7, the D/W pressure and the S/C pressure were almost the same, and the S/C pressure dropped from being 5 kPa higher than the D/W pressure to being the same pressure several times up until April 3.Therefore, at the present stage it is estimated that the vent pipes and the vacuum breakers between the D/W and the S/C were not submerged. At present, TEPCO is continuing with its considerations in order to estimate the water level in the D/W.

While the S/C pressure dropped after March 23, once it briefly reached approx. 0.3 MPag, a positive pressure state was measured for some time, and at the present stage it is estimated that there is no major damage to the S/C.

4) Estimation of the conditions of the RPV, PCV, and other components during times that variation with time was apparent

The basic means of cooling the reactor after the MSIV is closed are cooling via the IC and water injection via the HPCI. However, there were few records of the operating conditions of these systems following arrival of the tsunami. Furthermore, the radiation dose rose in the turbine building at around 23:00 on March 11 and there was an unusual rise in pressure in the PCV at around 0:49 on March 12. Therefore, these conditions suggest that the RPV had been damaged before 23:00 on March 11 to increase the pressure and temperature of the PCV significantly, which led to the leakage from the PCV. Similarly, the information, written on the whiteboard in the central control room, of the increased indication of the radiation monitor when the outer air lock was put on at 17:50 on March 11 suggest that core damage was then starting. Analysis is required from here on to confirm the degree to which IC and HPCI were functioning that includes detailed investigation and analysis of the conditions of each component.

Although alternative water injection was commenced at 5:46 on March 12, the RPV water level reading dropped at around 7:00 and has yet to recover. Due to poor reliability of the water gauge, analysis is required from here on by detailed investigation and analysis that covers the relationship between the water injection operations and the following pressure behavior.

As the D/W pressure in the PCV showed a tendency towards dropping slightly at around 6:00 on March 12 prior to wet vent operations, it is possible that there was a leak in the PCV. A drop in D/W pressure was also likely to have occurred after a temporary air compressor was installed to drive the pneumatic valves (AO valves) and wet vent operations were carried out at around 14:00 on March 12. However, when D/W pressure measurement recommenced at around 14:00 on March 13, the pressure has risen to 0.6 MPag and the PCV vent line had closed due to an unknown cause. Emissions may have restarted at 18:00 when pressure started dropping again.

On March 13, RPV pressure dropped to 0.5 MPag and reversed position with D/W pressure. However, detailed examinations cannot be conducted due to lack in data of both pressures.

5) Evaluation of accident event development

Regarding development of the Unit 1 accident event, from analyses conducted to date, it is likely that the IC stopped working when the tsunami hit, causing damage to the reactor from early on, and that by the time when the injection of sea water started into the reactor, the core had melted and moved to the bottom of the RPV.

From the balance of the amount of water injected and the volume of vapor generated from decay heat, it is likely that the water injected into the RPV was leaking.

Considering the results of RPV temperature measurements, it is likely that a considerable amount of the fuel cooled in the bottom of the RPV.

Concrete details of the explosion in the reactor building are unclear due to constraints in checking conditions inside the building. In addition to severe accident analysis, numerical fluid dynamics analysis was also carried out. Results of these analyses showed likelihood that gasses including hydrogen produced from a reaction inside the reactor between water and zirconium of the fuel cladding were released via leaks in the RPV and PCV, so that only hydrogen that reached the detonation zone accumulated in the space in the top of the reactor building and caused the explosion. In the waste processing building, in addition to damage caused by the blast, it is possible that there was an inflow of hydrogen via the part through which the piping runs.

At this point, the degree to which individual equipment was actually functioning is unclear, so that it is also impossible to determine the status of progress of the event. However, the results of the severe accident analysis suggests that the radioactive materials emitted to the environment by the leakage and the subsequent wet vent from the PCV on the dawn of March 12. It is currently estimated that at that time, most of the noble gases in the content within the reactors, about 0.7% of the total radioactive iodine, and about 0.3% of the total cesium were emitted.

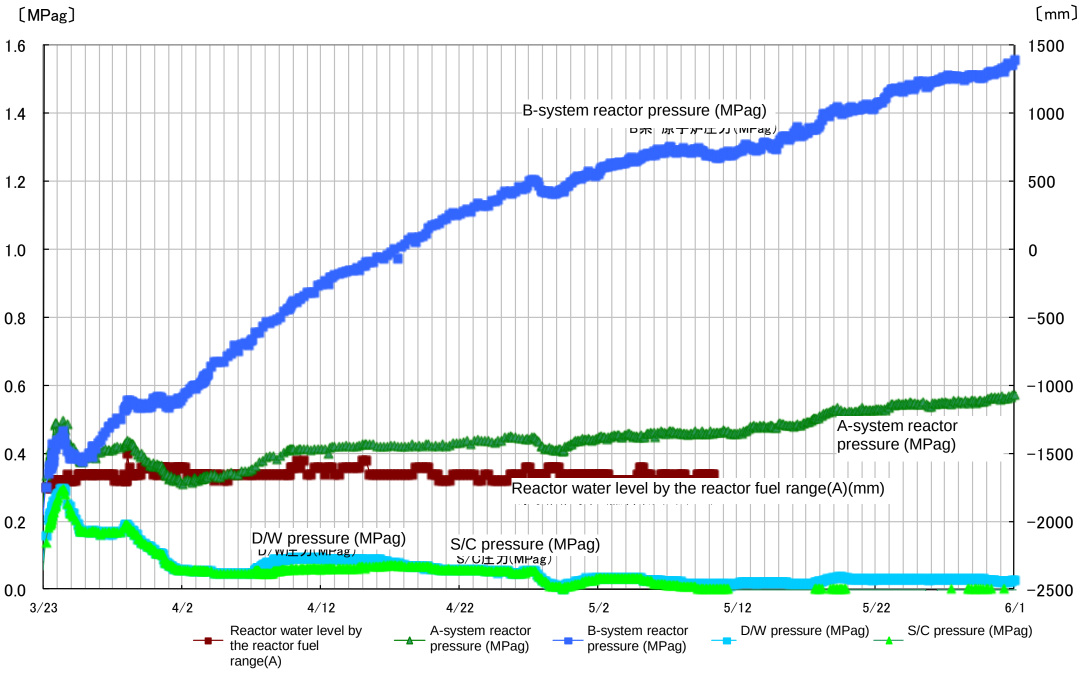
Table IV-5-1 Fukushima Daiichi NPS, Unit 1 – Main Chronology (Provisional)

* The information included in the table is subject to modifications following later verification. The table was established based on the information provided by TEPCO, but it may include unreliable information due to tangled process of collecting information amid the emergency response. As for the view of the Government of Japan, it is expressed in the body text of the report.

		Unit 1
	Situation before the earthquake: operating	
3/11	14:46	Reactor SCRAM (large earthquake acceleration)
	14:47	All control rods were fully inserted. turbine trip loss of external power supply emergency diesel generator (emergency DG) start-up main steam isolation valve (MSIV) close
	14:52	emergency condenser (IC) automatic start-up
	around 15:03	IC shutdown and repeatedly reactuated until around 15:30 (reactor pressure was controlled by IC)
	15:07 - 15:10	reactor containment spray system pumps were started up to cool the suppression chamber (S/C).
	15:37	all AC power supplies lost
	15:42	TEPCO determined that notification event according to NEPA Article 10 (loss of all AC power supplies) had occurred.
	16:36	TEPCO, believing that it became impossible to inject water using the emergency core cooling system, determined that the event according to NEPA Article 15 had occurred.
	18:18	Opening operation was performed on IC (A) system supplying piping isolation valve MO-2A and return piping isolation valve MO-3A/steam generation was observed.
	18:25	IC (A) system MO-3A valve was closed.
	20:30	Main control room was lit (temporary facility secured)
	21:19	Line-up from diesel-driven fire pump (D/D FP) to IC was performed.
	21:30	IC 3A valve was opened/steam generation was observed.
	21:35	being supplied from D/D FP to IC.
	22:00	reactor water level: effective fuel top (TAF)+550 mm
	23:00	Radiation dosage is rising in the turbine building. (North side of the ground floor of turbine building 1.2 mSv/h. South side of the ground floor of turbine building 0.5 mSv/h.)
3/12	0:30	Water is being supplied to IC (A) body side by fire extinguishing system.
	0:49	Since there was a possibility that dry well (D/W) pressure level (maximum operating pressure in terms of design: 427 kPa gage) exceeded 600 kPa, TEPCO determined that the event according to NEPA Article 15 (abnormal rise in containment vessel pressure level) had occurred.
	1:48	D/D FP is checked and it is found that supply is shut down by pump trouble, not by running out of fuel.
	2:30	D/W pressure 0.84 MPa (840 kPa) reactor water level TAF+1,300 mm (fuel region A), reactor water level TAF+530 mm (fuel region B)
	4:15	D/W pressure 840 KPa
	5:09	D/W pressure 770 KPa
	5:14	From the rise of radiation level on site and also from a decreasing tendency of D/W pressure, TEPCO determined that radioactive material is leaking.
	5:46	Fresh water injection by fire pumps was started.
	6:30	2000 litters of fresh water had been injected. By (1000 litters/injection) fire engine, water was injected from the core spray (CS) system through the D/D FP line.
	7:55	Reactor water level decreased to 200 mm from TAF-100 (fuel region level instrument A) and 200 mm from TAF-100 (fuel region level instrument B).
	7:55	3000 litters of water (cumulative) had been injected through the FP line by fire engines.
	8:30	5000 litters of water (cumulative) had been injected through the FP line by fire engines.
	9:04	Workers left for the site for pressure venting.
	9:15	6000 litters of water (cumulative) had been injected through the FP line by fire engines.
	around 9:15	Suppression chamber vent line motor-operated (MO) valve was manually opened (25%).
	around 9:30	On site operation on the suppression chamber vent line air-operated (AO; second valve) valve was attempted but given up because of its too high radioactive dosage.
	9:40	21000 litters of water (cumulative) had been injected through the FP line by fire engines.
	10:17	Operation to open the second valve (AO valve) was performed in the main control room through remote control.
	12:55	Reactor water level: fuel region A-1700 mm, fuel region B-1500 mm, D/W pressure: 750 KPa
	around 14:00	Additional operation for the second valve (AO valve) (using air compressor).
	14:30	Pressure decrease in the containment by venting was observed.
	14:53	Fire engines completed injection of 80,000 liters of water (cumulative) using FP lines.
	around 15:36:	What was considered as a hydrogen explosion occurred in the upper part of the reactor building (Relatively strong "shake" was sensed, and around 15:40, smoke rising was observed near Unit 1).
	19:04	Injection of sea water (without boric acid) into the reactor was started.
	20:45	Injection of boric acid was started to prevent the reactor from going critical again.
3/13	3:38	Sea water was being injected by using the fire extinguishing line.

	Unit 1	
	Situation before the earthquake: operating	
3/14	1:10	Sea water injection was suspended because the remaining amount of sea water being supplied to the reactor became small. (As of 23:30, sea water was being injected into the reactor.)
3/15		
3/16		
3/17		
3/18		
3/19		
3/20	15:46	480 V emergency low-voltage switchboard (power center (P/C) 2C) received power. A temporary power supply was supplied from Tohoku nuclear power line.
3/21		
3/22		
3/23	1:40 2:33	Main bus panel for measuring received power 120 VAC In addition to the sea water injection from fire pumps using fire-extinguishing systems, water (sea water) injection from outside through the water supply system was started to add to the injection water.
3/24	around 11:30 17:10	Main control room lighting recovered. Transfer of the accumulated water from the turbine building (T/B) basement to the hot well (H/W) began.
3/25	15:37	The water injected into the reactor by fire pumps was switched from sea water to fresh water.
3/26		
3/27		
3/28		
3/29	8:32 17:30 (22:03)	For water injection into the reactor, the fire pumps were replaced with temporary motor pump. Transfer of the accumulated water from T/B to H/W was completed. Residual water in a trench was analyzed and radioactivity was detected.
3/30		
3/31	9:20 11:25 12:00 13:03 14:24 15:25 16:04	Transfer of the accumulated water from the trench to the central radioactive waste treatment facility (central R/W) pellet pool began. Transfer of the accumulated water from the trench to central R/W pellet pool was completed. Transfer of the accumulated water from condensate storage tank (CST) to the suppression pool water surge tank (SPT) began. For cooling spent fuel pool, spraying (fresh water) by using Tokyo Electric Company's concrete pump truck was started. Transfer of the accumulated water from CST to SPT was completed. Transfer of the accumulated water from CST to SPT was started. For cooling spent fuel pool, spraying (fresh water) by using Tokyo Electric Company's concrete pump truck was finished. About 90 t of water was injected.
4/1		
4/2	15:26 17:16 17:19	Transfer of the accumulated water from CST to SPT was completed. For cooling spent fuel pool, spraying was started by using Tokyo Electric Company's concrete pump truck to check the spraying position. For cooling spent fuel pool, spraying was completed by using Tokyo Electric Company's concrete pump truck to check the spraying position.
4/3	11:50 13:55	For water injection into the reactor, the power supply to the temporary motor pump was switched from the temporary power supply to the permanent power supply. Transfer of the accumulated water from H/W to CST was started.
4/4		
4/5		
4/6		
4/7	1:31	Nitrogen gas injection was started.
4/8		
4/9	3:29	For the nitrogen gas injection, all valves were temporarily closed and the operation to switch to the high purity nitrogen gas generator was started. →03:59 operation to open the injection valve was started. →04:10 Nitrogen injection to the containment vessel was switched to the high purity nitrogen generating measures (all valves were opened).
4/10	9:30	Transfer of the accumulated water from H/W to CST was completed.
4/11	around 17:16 around 17:16 17:56 18:04 23:34	Due to the earthquake, external power supplies to Unit 1 and Unit 2 (Tohoku Electric Power Line) was shut down, and the reactor injection pump was shut down. Due to the earthquake, nitrogen injection suspended. External power supply recovered. The reactor injection pump was reactivated. Nitrogen injection into the reactor containment was resumed.
4/12	14:51	It was confirmed that the nitrogen gas injection device had been working without any problem after the earthquake.
4/13		
4/14	7:45 12:20	Installation of silt fences to the front surface and curtain wall of Unit 1 and Unit 2 was started to prevent the diffusion of contaminated water. Installation of silt fences to the front surface and curtain wall of Unit 1 and Unit 2 was completed to prevent the diffusion of contaminated water.

	Unit 1	
	Situation before the earthquake: operating	
4/15	10:19	Transfer of power distribution panels and the like for injection pump of the reactor to upland as measures against tsunami was started.
		Transfer of power distribution panels and the like for injection pump of the reactor to upland as measures against tsunami was completed.
4/16		
4/17	11:30 around 17:30	In the reactor building, atmosphere investigation by using an unmanned robot was started. In the reactor building, atmosphere investigation by using an unmanned robot was completed.
4/18	11:50 12:12	Replacement of the hoses used for reactor injection with new ones was started. The injection pumps were stopped. Replacement of the hoses used for reactor injection with new ones was finished. Injection pump operation.
4/19	10:23	Nos. 1,2 - 3,4 power tie line had been laid. (both Tohoku Electric Power Line - Okuma Line can be used to each other.)
4/20		
4/21		
4/22		
4/23		
4/24		
4/25	14:10 14:44 17:38 18:25 19:10	For power supply enhancement, the nitrogen injection device was shut down. In association with the power supply enhancement (tie up Nos. 1, 2 - 5, 6 with each other), shutdown operation of Nos. 1, 2 power supply panel for 6,9 kV was started. In association with the power supply enhancement (tie up Nos. 1, 2 - 5, 6 with each other), shutdown operation of Nos. 1, 2 power supply panel for 6,9 kV was finished. The reactor injection pump recovered its state of using external power supply. The shut down nitrogen injection device was restarted.
4/26	11:35 around 13:24	Atmosphere investigation (for radiation dosage, leakage, and the like) by using an unmanned robot was started on the reactor building. Atmosphere investigation (for radiation dosage, leakage, and the like) by using an unmanned robot was finished on the reactor building.
4/27	10:02	In order to examine the injection volume sufficient to flood the fuel in the reactor, operation of gradually changing the reactor injection volume from about 6 m^3/h to the maximum about 14 m^3/h was started.
4/28		
4/29	10:14	Injection into the reactor was kept from 4/27 by the volume of 10 m^3/h, but the volume was returned to the originally planned 6 m^3/h.
4/30		
5/1		
5/2	12:58 14:53	In association with installation of an alarm device to the core injection pump, the core injection pump was switched to fire pumps. As the installation of the alarm device to the core injection pump was finished, the fire pumps were switched back to the core injection pump.
5/3		
5/4		
5/5	16:36	In order to improve the environment of the reactor building, local exhausters were installed, and then the operation of all exhausters was started.
5/6	10:01	In order to flood the reactor vessel, the injection volume to the reactor was increased from about 6 m^3/h to about 8 m^3/h.
5/7		
5/8	20:08	A duct built through the double-entry door of the reactor building was cut.
5/9	4:17	The double-entry door of the reactor building was fully opened.
5/10		
5/11	8:47 8:50 15:55 15:58	The power supply to the reactor injection pump was switched to a temporary diesel generator, and injection was performed. As Okuma line No. 2 line was restored, part of the reactor power supply was shut down and the nitrogen gas supplying equipment was shut down. The power supply to the reactor injection pump was switched from the temporary diesel generator to the reactor power supply. In association with the restoration of Okuma line No. 2 line, the shutdown operation of part of the reactor power supply finished, and then the nitrogen gas supplying equipment was reactivated.
5/12		
5/13	16:04 19:04	Spraying (fresh water) on the spent fuel pool by Tokyo Electric Company's concrete pump truck and the checking the spraying position were started. Spraying (fresh water) on the spent fuel pool by Tokyo Electric Company's concrete pump truck and the checking the spraying position were completed.
5/14	15:07	Spraying (fresh water) was started on the spent fuel pool by Tokyo Electric Company's concrete pump truck.
	15:18	Spraying (fresh water) was finished on the spent fuel pool by Tokyo Electric Company's concrete pump truck.
5/15		
5/16		



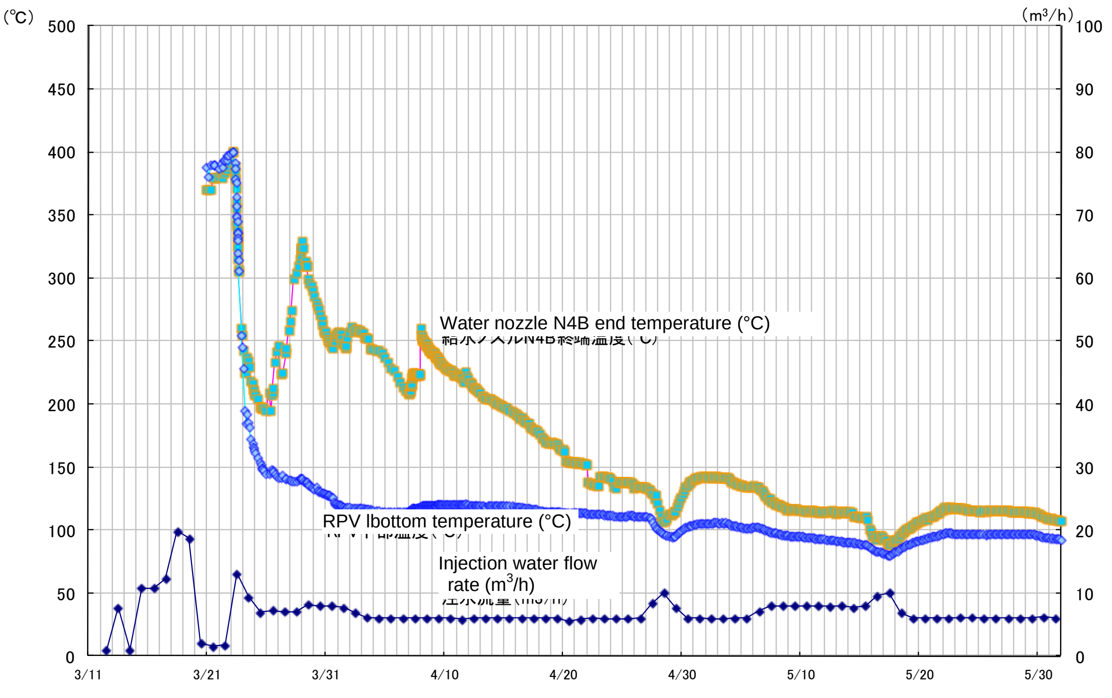
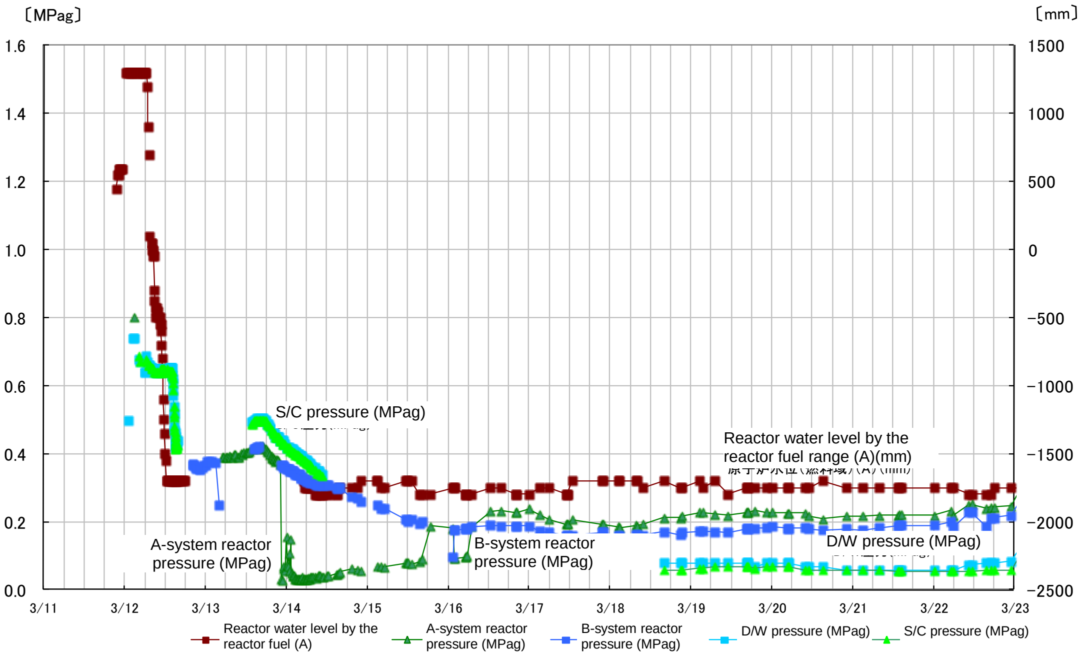


Figure IV-5-1 Changes in major parameters [1F-1] (From March 11 to May 31)



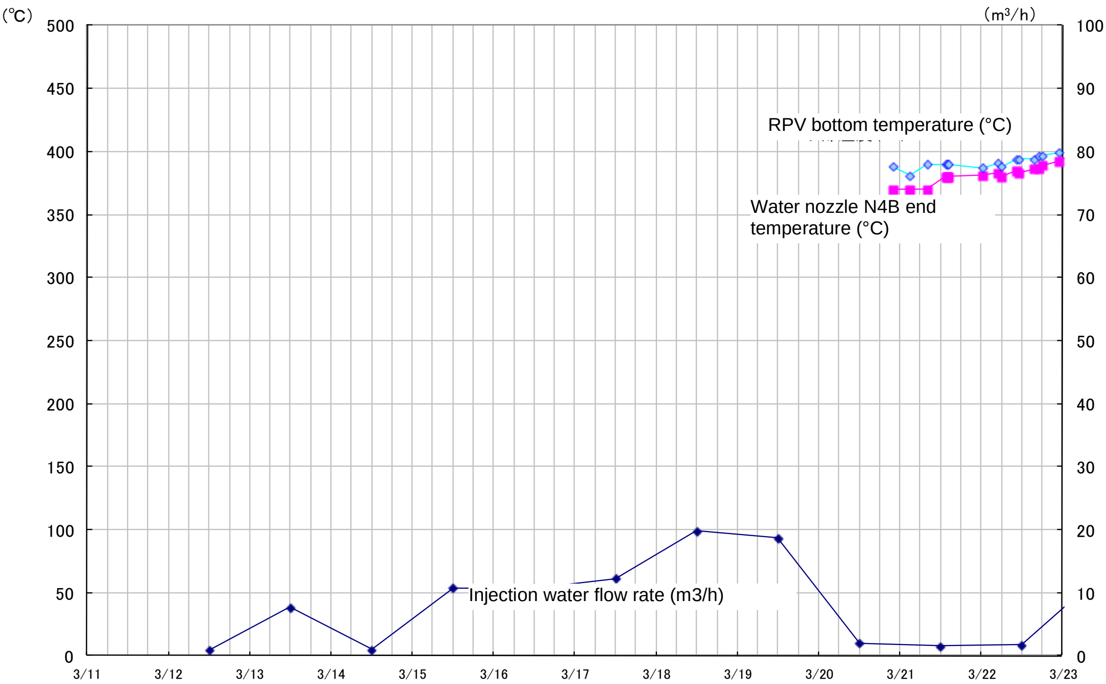
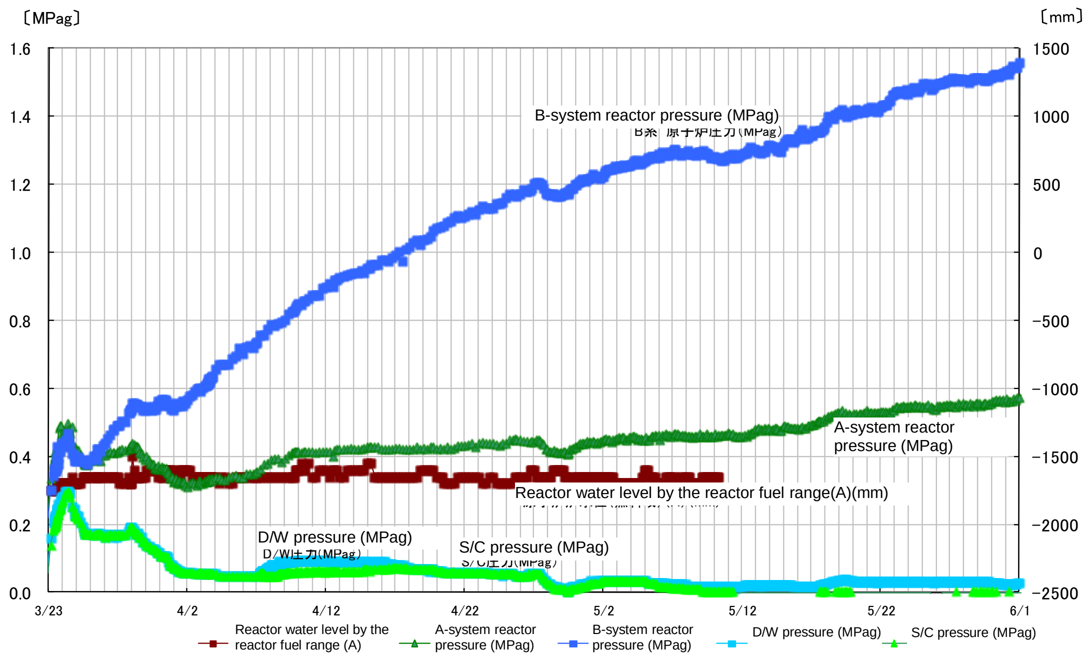


Figure IV-5-2 Changes in major parameters [1F-1] (From March 11 to March 23)



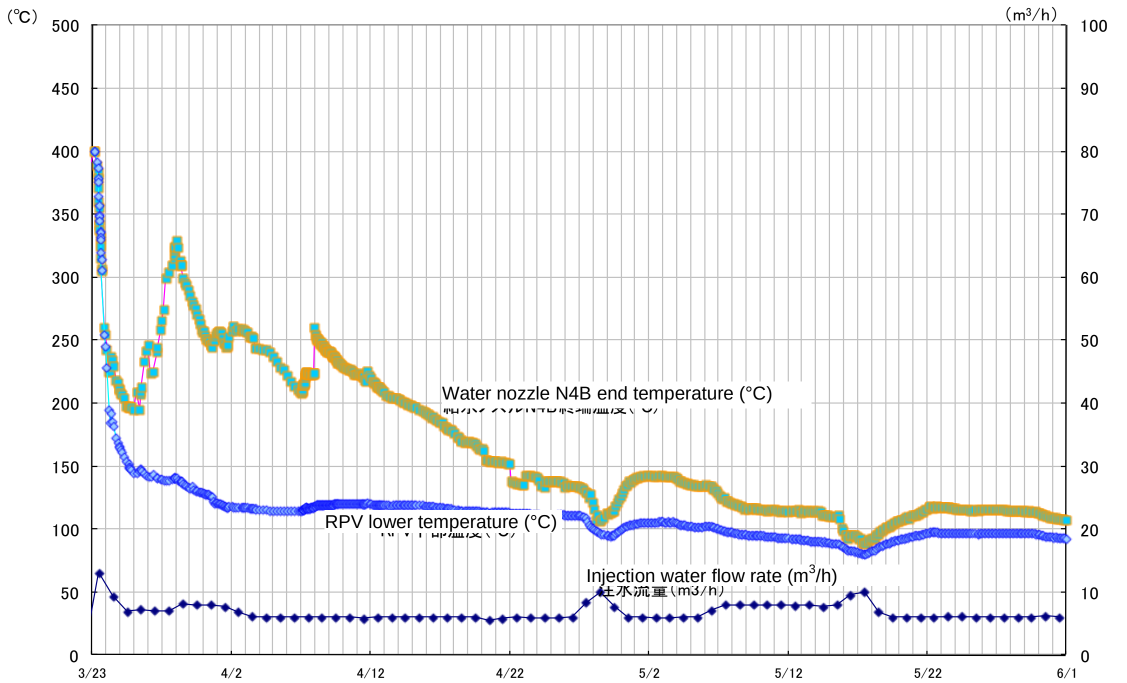


Figure IV-5-3　Changes in major parameters [1F-1] (From March 23 to May 31)

(2) Fukushima Daiichi NPS Unit 2

1) Chronological arrangement of accident event progress and emergency measures

a Between the earthquake occurrence and invasion of the tsunami

As noted in number 3 of this chapter, steady operation of rated thermal power was being carried out prior to the earthquake. At 14:47 on March 11 following the earthquake occurrence, scram (automatic shutdown) was achieved due to large earthquake acceleration. At the same time, all control rods were fully inserted, the reactor became sub-critical and normal automatic shut down was achieved. The external power supply was lost as a result of the earthquake, due to damage incurred to the receiving circuit breakers of the station at the Okuma No. 1 and No. 2 power transmission line. This resulted in automatic startup of the two emergency DGs.

At 14:47, the instrumentation lost power as a result of loss of external power supply, activating the MSIV closure signal as a fail-safe and causing the MSIV to close. Regarding closure of the MSIV, TEPCO determined that there was no rupture of the main steam piping, as we could not verify an increase in steam flow from the transient recorder records that would be have been observed if the main steam piping had ruptured. NISA considered this judgment reasonable.

Closure of the MSIV led to a rise in RPV pressure. In accordance with the Procedures, the RCIC was activated manually at 14:50, but shut down at 14:51 due to a high reactor water level. This led to a drop in the water level, but the RCIC was again manually activated at 15:02 causing a rise in the water level. A high reactor water level was achieved at 15:28 causing the reactor RCIC to shut down automatically. The RCIC was again manually activated at 15:39.

Between 22:00 on March 11 and 12:00 on March 14, the reactor water level reading (fuel range) remained stable at a level (+3000 mm or more) which maintained sufficient depth from the Top of Active Fuel (hereinafter referred to as TAF).

Reactor pressure was controlled by closing and opening of the SRV.

As operation of the SRV and RCIC led to a rise in the S/C temperature, the RHR pumps were started in succession from 15:00 to 15:07 to cool the S/C water. This is verified by suppression of the temperature rise from around 15:00 to around 15:20 on the same day as shown in the temperature chart of the S/C.

There are no records of operation of any emergency core cooling equipment aside from the activation of the RHR pumps to cool the S/C until the occurrence of the station blackout. This was likely because the reactor water level did not drop to the point (l-2) at which other equipment is automatically activated, and TEPCO state that they did not activate such equipment manually.

b Impact from the tsunami

The abovementioned S/C then showed a tendency towards a rise in temperature from 15:30, and the RHR pumps were successively shut down from around 15:36. This is thought to be due to a loss in functioning caused by the tsunami. At this time, the Unit was affected by the tsunami, the two emergency DGs stopped operating due to flooding and submergence of the seawater pump for cooling, the power distribution panel, and the emergency bus bar, and a station blackout was resulted.

Furthermore, information on parameters could not be verified due to a loss in direct electrical current functionality.

Loss in functionality of the RHR sea water pump led to a loss in RHR functionality, and the decay heat could not be transferred to the sea water that acted as the final heat sink.

c Emergency measures

At 22:00 on March 11, observation of the reactor water level was achieved. As of the day, it is presumed that the water injection was achieved by the RCIC since the water level was observed stable. However, reactor pressure is slightly lower than rated, at 6 MPa.

From 4:20 to 5:00 on March 12, as condensate storage tank water level decreased and in order to control the S/C water level increase, the water source for the RCIC was switched from the condensate storage tank to the S/C so that the RCIC could continue injecting water. The reactor water level remained stable at a level which maintained sufficient depth from the TAF by 11:30 on March 14. From that point until 13:25 on

March 14, the reactor water level began to drop, at which point the RCIC was judged to have shut down. The level dropped to 0 mm (TAF) at 16:20 on the same day. In relation to this, TEPCO verified on-site that the RCIC was operating at 02:55 on March 12, and that the RCIC water source had switched from the condensate storage tank to the S/C, and through such measures among others, the RCIC was functioning by around 12:00 on March 14 to stabilize the reactor water level. TEPCO determined that there may have been a loss in reactor cooling functionality at 13:25 on the same day and made a notification pursuant to the provisions of Article 15 of NEPA.

The RCIC is steam-driven, but the valves were operated through direct electrical currents. Although the time of RCIC functionality loss determined by TEPCO is more than 30 hours after operation start-up, given the actual constraints of battery capacity, it follows that functionality was maintained even after the battery run out.

SRV opening operations and alternative water injection operations commenced at 16:34 on March 14, and a drop in reactor pressure was confirmed at around 18:00. At this time, the reactor water level also dropped. After that point, reactor pressure began to show a tendency towards rising, which is presumed to have caused the SRV to close due to problems in the air pressure used to drive the air operated valves (AOVs) and other problems. At 19:54 on March 14, the seawater injection into the reactor using fire engines was started. Water injection was therefore suspended for six hours and 29 minutes since 13:25 when the RCIC lost functionality.

With regard to PCV vent operations to reduce pressure in the PCV, at 06:50 on March 12, TEPCO was ordered by the Minister of Economy, Trade and Industry in accordance with Article 64, Paragraph 3 of the Reactor Regulation Act to contain the PCV pressure. Based on this order, TEPCO began PCV vent operations, carrying out operations at 11:00 on March 13 and 00:00 on March 15, but a decrease in D/W pressure could not be verified.

d Explosion and actions taken afterword

At around 6:00 on March 15, the sound of an impact was heard which was considered to have resulted from a hydrogen explosion. No visible damage was observed at the reactor building, but it was confirmed that the roof of the waste processing building which is neighboring to the reactor building was damaged. During these processes, radioactive material to be released into the environment, and as a result, the radiation dosage around the premises increased.

At 10:30 on March 15, based on Article 64, Paragraph 3 of the Reactor Regulation Act, the Minister of Economy, Trade and Industry directed TEPCO to inject water into the reactor of Unit 2 as soon as possible and carry out a dry vent as it necessitates.

With regard to the alternate water injection system, until March 26, sea water was injected into the reactor, but from March 26, fresh water was injected from a temporary tank. From March 27, the fire pumps were replaced by temporary motor-driven pumps, and from April 3, the temporary power source was replaced by an external power source to ensure the stable injection of water. The total amount of water injected as of May end was approx. 20,991 m^3 (fresh water; approx. 11,793 m^3, sea water: approx. 9,197 m^3).

With regard to recovery and reinforcement of the power supply, TEPCO completed checking and the trial energizing of the facilities to receive power from the nuclear power line of Tohoku Electric Power Co., Inc. on March 16. From March 20, the Power Center received power to ensure the power supply from an external power source. On March 26, lighting in the Main Control Room was restored, and power was connected while the load soundness was being checked.

In Table IV-5-2, these major events are arranged in a time-sequences with more details. Figs. IV-5-4 to 5-6 show the plant data such as RPV pressure.

2) Assessment using severe accident analysis codes

a Analysis by TEPCO

Results of the analysis by TEPCO show that when alternate injection water flow is small, RPV will be damaged due to the fuel melting. TEPCO assessed that considering the above results and the measured RPV temperature data obtained to date, that most of the fuel actually cooled at the RPV bottom.

TEPCO judged that during this time, although RCIC operation was continued, water leakage from RPV was presumed to have occurred, based on PCV pressure behavior, that this leakage caused the RCIC to shut down. TEPCO supposed that the fuel was uncovered for five hours from 13:25 on March 14 (75 hours after the Earthquake began) and that the core damage started two hours later. After that, assuming there was an outflow of alternate injection water due to insufficient maintenance of the reactor water level in the fuel region, the core likely melted, and the melted fuel moved to the lower plenum so that the RPV was damaged 109 hours after the Earthquake began.

The leakage of radioactivity was analyzed assuming that the radioactivity contained in the fuel was released to RPV after fuel collapse and melting and that it leaked to the PCV. It is estimated that nearly all the noble gas was released to environment, and the release rates of iodine and other nuclides are less than about 1%.

b Cross check analysis by NISA

In the cross check analysis, NISA conducted analysis using MELCOR codes with the conditions that TEPCO analyzed (base case) and sensitivity analysis as a function of the injected water volume assuming the volume varies with RPV pressure in relation to the pump discharge pressure.

In the cross check analysis of the base case, the results were roughly similar to TEPCO's results. At 18:00 on March 14 (75 hours after the Earthquake began), the fuel uncovering began, and core damage commenced within two hours. The time when the RPV was damaged in the cross check analysis was earlier than the time given in the TEPCO analysis, and was about five hours after the Earthquake began, and the PCV pressure behavior results are consistent with measured data.

Results showed the release rate of radioactive materials to be about 0.4% to 7% for iodine nuclides, about 0.4% to 3% for tellurium nuclides, and about 0.3% to 6% for cesium nuclides. Release rates may change with operating conditions, as release rates vary with the sea water flow rate and the set operating conditions are unclear.

3) Evaluation of the conditions of the RPV, PCV, etc.

a Verification of plant data

First, the following studies the plant data from March 17 to May 31, during which the plant was relatively stable. Interpretation of plant data during this period is as follows:

With regard to the reactor water level around the reactor fuel, when the PCV pressure remained high, the PCV temperature was high. As a result, the water in the condensation tank and instrumentation piping in the PCV, whose water level is used as a reference water level, evaporated, causing the reference water level to drop. This may have caused the indicated reactor water level to be higher than the actual reactor water level. Since then, the reactor water level showed the same trend as that of Unit 1, and therefore, it was determined that during this period, the water level in the RPV was not measured properly.

The measured RPV pressure in system A was consistent with that in system B, and it was determined that the indicated pressure was mostly correct. For the period during which negative pressure was indicated, the pressure was out of the measurable range of the pressure meter and determined to be not measured properly.

Since March 27, the RPV temperature trend has been consistent with the amount of water injected, and it was determined that the indicated temperature was roughly correct. However, some data shows the temperature was kept constant, which is not consistent with other readings. Therefore, such data is not used for evaluation.

With regard to the interpretation of plant data up to March 17, especially from March 14 to 15, the data fluctuated significantly, and could not be used for numerical values. The data was used as a reference for the rough understanding of fluctuations, along with event information such as the operation of equipment.

b Presumed condition of the RPV, PCV, etc. when they were relatively stable

-RPV boundary condition

TEPCO estimated the amount of water injected into the RPV until May 31 to be 21,000 tons, but the amount of steam generated since the injection of water began was estimated to be about 7,900 tons although it was estimated by the decay heat evaluation method and the amount of decay heat was estimated to be a little larger than the actual amount. If the pressure boundary remains undamaged, at least about 13,100 tons of water should remain in the RPV. The volume of the RPV is estimated to be less than 500 m^3. Therefore, the injected water vaporized inside the RPV. In addition to the leakage of steam, liquid is also suspected of leaking. Water was injected into the RPV through the recirculation water inlet nozzle, and flowed to the bottom of the RPV via the jet pump diffuser. Judging from the fact that the reactor fuel was kept cool, at this point, it is presumed that the injected water had leaked from the bottom of the RPV.

From May 29 to May 30, water was injected through the recirculation water inlet nozzle and, in addition, water was injected through the feed-water nozzle. From around 17:00 on May 30, water was injected through the feed-water nozzle only.

Since March 16, the RPV pressure has been kept around the atmospheric pressure, and equal to the D/W pressure of the PCV. At this point, it is presumed that the RPV has been connected to the PCV in the vapor phase area.

-Condition of the inside of the RPV (core condition and water level)

Since March 20 the RPV temperature has been measured when the amount of water injected increased. During most of the period after the start of measurements, the temperature was stable at around 100°C, and during most of the period after March 29 when the amount of water injected was decreased, the RPV temperature was around 150°C. Accordingly, at this point, it is presumed that a significant amount of the fuel remained in the RPV. However, there is a possibility that the bottom of the RPV was damaged and some of the fuel might have dropped and accumulated on the D/W floor (lower pedestal).

Judging from the fact that the temperature in some part of the RPV is higher than the saturated temperature in relation to the RPV pressure, it is presumed that part of the fuel was not submerged and cooled by steam.

-PCV condition

On March 15, the D/W pressure exceeded the maximum useable pressure of the PCV (0.427 MPag) and increased to about 0.6 MPag. Accordingly, at this point, it is presumed that the sealing performance deteriorated at the gaskets of the flanges and the penetration parts. The D/W pressure is kept at around the atmospheric pressure (0 MPag) and it is presumed that the steam generated by decay heat is being released from D/W into the outside environment through these deteriorated parts.

Because, most of the time, the S/C pressure is not measured, at this point, it was difficult to estimate the condition of the inside of the S/C and the water level in the D/W based on the plant data. However, judging from the fact that high levels of contaminated water were found in the turbine building, at this point, it was presumed that the water injected into the RPV was leaking from the RPV through the PCV. Currently, TEPCO is studying how to estimate the water level in the D/W.

4) Presumption of the condition of the RPV, PCV, etc. as it changed with time

According to TEPCO, early on March 12, the water source was switched to the S/C and the injection of water continued by the reactor core isolation cooling system (RCIC). On the morning of May 14, the water level was above the Top of Active Fuel (TAF). Accordingly, at this point, it was presumed that at least until then, the RCIC had functioned properly. It is also presumed that because the steam for driving the turbine of the RCIC was continuously released into the S/C gas phase on the morning of March 12, the S/C pressure increased, the steam flowed from the S/C into the D/W, and at around 12:00 on March 12, the D/W pressure increased.

On the morning of March 14, the RPV pressure increased and the reactor water level dropped presumably because the RCIC malfunctioned, and the RPV pressure was about 7.4 MPag. Accordingly, it is presumed that the reactor water level further dropped after the SRV was activated. A report was received that the PCV was vented before that, but during part of the time, the PCV pressure did not decrease. There is a possibility that the RCIC did not fulfill its required function. To know to what extent the RCIC functioned, it is necessary to closely examine and analyze the condition of each component.

At around 0:00 on March 15, the S/C pressure did not increase but the D/W pressure increased, and after that, there had been a significant difference between the D/W pressure and S/C pressure for a long time and they had been inconsistent with each other. It is unknown why this happened.

In addition to these presumptions, the water level did not return to normal, and at around 0:00 on March 15, the readings on the PCV atmosphere monitoring system (hereinafter referred to as CAMS) for the D/W and S/C increased by three to four digits. Accordingly, it is presumed that the fuel was damaged at this time. In addition, TEPCO reported that from late afternoon on March 14, water was injected by fire trucks, but the water level did not rise, and there is a possibility that they did not fulfill their required function because of the reactor pressure. To know what extent they functioned, it is necessary to closely examine and analyze the condition of each component.

5) Event development analysis and summarization of the events based on the presumptions of the condition of the RPV, PCV, etc.

With regard to accident event progress in Unit 2, analyses carried out to date suggest that the loss in RCIC functionality caused damage to the reactor core, and that water injection may not have been sufficient as injection of seawater commenced at a time of high pressure in the reactor. As a result, insufficient cooling may have caused melting of the reactor core, and the melted fuel, etc, to transfer to the bottom of the RPV.

Considering the balance of volume of injected water and volume of steam generated from decay heat, it is presumed that the water injected into the RPV is leaking.

Considering the results of RPV temperature measurement, a significant amount of fuel is thought to have cooled in the bottom of the RPV.

With regard to the sounds of an impact around the S/C, we cannot say anything for sure because we are limited in checking the site where the explosion was heard. In addition to severe accident analysis, we conducted numerical fluid dynamics analysis, and at this point, it is presumed that in the reactor, the hydrogen generated when zirconium used in the fuel cladding reacted with water flowing into the S/C when the SRV was opened, leaked from the S/C, and exploded in the torus room. With regard to the waste processing building, at this point, we cannot deny the possibility that it was damaged by the blast and the hydrogen flowed into it through the pipe penetrations etc.

At this point, we cannot indentify to what extent each component functioned, and therefore, cannot determine how the events of the accident have developed. However, based on results of the severe accident analysis of the current situation, regarding the release of substances to the environment via a leak in the PCV up until the morning of March 15, it is estimated that nearly all the noble gas was released and the proportions released into the environment of iodine, cesium, and tellurium are approx. 0.4% to 7%, 0.3% to 6%, and 0.4% to 3%, respectively.

Table IV-5-2 Fukushima Daiichi NPS, Unit 2 – Main Chronology (Provisional)

* The information included in the table is subject to modifications following later verification. The table was established based on the information provided by TEPCO, but it may include unreliable information due to tangled process of collecting information amid the emergency response. As for the view of the Government of Japan, it is expressed in the body text of the report.

	Unit 2	
	Situation before the earthquake: operating	
3/11	14:47	Reactor SCRAM (large earthquake acceleration) All control rods were fully inserted. Turbine trip Loss of external power supply Emergency diesel generator start-up Main steam isolation valve (MSIV) close
	14:50	Reactor core isolation cooling system (RCIC) was manually started up.
	14:51	RCIC trip (L-8)
	15:00	Residual heat removal system pumps were started up sequentially (for cooling the water in the suppression chamber).
	15:02	RCIC was manually started up.
	15:07	Residual heat removal system pumps were ended sequentially
	15:28	RCIC trip (L-8)
	15:39	RCIC was manually started up.
	15:41	All AC power supplies were lost.
	15:42	TEPCO determined that notification event according to NEPA Article 10 (loss of all AC power supplies) had occurred.
	16:36	EPCO, believing that it became impossible to inject water using the emergency core cooling system, determined that the event according to NEPA Article 15 had occurred.
	20:30	RCIC under shutdown Preparation for main control room illumination (temporary power).
	22:00	Reactor water level Top of Active Fuel (TAF) +3400 mm
	22:47	RCIC operation cannot be confirmed
3/12	0:30	RCIC under shutdown, water level TAF at 3500 mm (as of 0:00 on 3/12) and reactor pressure at 6.3 MPa (as of 23:25 on 3/11) Dry well (D/W) pressure at 40 Kpa (as of 23:55 on 3/11)
	2:55	The RCIC start-up state was checked
	4:20 - 5:00	RCIC water supply was switched from storage tank (CST) to suppression chamber (S/C).
3/13	3:00	D/W pressure rises (315 KPa) (40 KPa as of 0:30 on 3/12).
	11:00	The second valve was set to "open" for venting
3/14	11:01	It was confirmed that the suppression chamber (S/C) side valve was closed and also confirmed that the valve was inoperable.
	12:00	The S/C temperature (147°C) and the S/C pressure (485 KPa) were increasing. Since the reactor water level tended to decrease, sea water injection was prepared (12:00: 3400 mm → 12:30: 2950 mm (A), (12:00 3400 mm → 12:30: 3000 mm (B))
	13:25	RCIC shut down (assumed) Since the reactor water level decreased and there was the possibility that the RCIC was inoperable, the operator determined that an NEPA Article 15 event (loss of reactor cooling function) had occurred.
	15:00	The RCIC operation state was being checked.
	16:00	The operation to open the suppression chamber (S/C) side valve.
	16:20	It was confirmed that the suppression chamber (S/C) side valve was closed.
	16:34	The operation to depressurize the reactor pressure vessel (safety relief valve (SRV) open) was performed, and the sea water injection operation was started using fire engine lines.
	17:17	The water level reached to TAF.
	around 18:00	The reactor pressure decrease was observed. Thereafter, due to the problems including the air pressure for driving SRV and the maintaining excitation of the solenoid valve of the air supply line, the SRV was seemed to be closed and the reactor pressure increased.
	18:22	The reactor water level reached from TAF to -3700 mm, and it was determined that the whole of the fuel was uncovered.
	19:20	Fire pumps for sea water injection stopped due to lack of fuel.
	19:54	The sea water injection started (the first fire pump started up).
	19:57	The second fire pump started up.
	21:00	The operation of opening the pressure suppression chamber (S/C) side small valve (opening was unknown).
	21:03	The reactor pressure decreased (1418 KPa).
	21:20	By opening two safety relief valves, reactor depressurization and water level restoration were confirmed. Thereafter, due to the problems including the air pressure for driving SRV and the maintaining excitation of the solenoid valve of the air supply line, the closing operation and the opening operation of SRV were seemed to be performed.
	around 21:20	It was observed that the reactor water level tended to recover.
	22:14	The reactor water level recovered -1800 mm, the core damage was evaluated and determined as 5% or less.
	22:50	Since the D/W pressure exceeded the maximum operating pressure for design, the operator determined that an event according to NEPA Article 15 (abnormal increase of the reactor containment) had occurred. D/W pressure at 540 KPa.

	Unit 2	
	Situation before the earthquake: operating	
3/15	0:02	Valve set to "open" for dry venting
	0:45	Reactor pressure at 1823 KPa
	3:00	D/W pressure at 750 KPa Since the D/W pressure exceeded the maximum operating pressure for design, the depressurizing operation and the injection operation into the reactor were performed, but they were not sufficiently depressurized.
	5:00	The reactor pressure decreased (626 KPa)
	around 6:00 - 6:10	An explosion thought to be a hydrogen explosion came from near the S/C (loud explosion sound near pressure control room), and all personnel were evacuated except for those necessary for operation (the reactor water level TAF -2800 mm, the reactor pressure unknown, the S/P pressure unknown, the D/W pressure 0.73 MPa.
	8:25	White smoke (seemed to be steam) was observed near the fifth floor of the reactor building.
	15:25	The reactor pressure was lower than the containment pressure (the reactor pressure 0.119 Pa the D/W pressure 0.174 MPa gauge
	15:30	The core damage amount was changed from 14% to 35%
3/16		
3/17		
3/18		
3/19		
3/20	15:05	The sea water injection into the spent fuel pool was started by using the fuel pool cooling system (FPC) and subsequent seawater injection was done from the FPC.
	15:46	480 V low pressure board for emergency (power center P/C 2C) received power. A temporary power supply was supplied from Tohoku nuclear power line.
	17:20	Seawater injection into the spent fuel pool ends. Injected water volume approx. 40 t.
3/21	18:20	It was confirmed that the white haze mist like smoke (steam) observed in the reactor building was newly coming out from the roof at the roof floor.
3/22	7:11	The white haze mist like smoke (steam) decreased to be almost disappeared.
	16:07	Seawater injection into the spent fuel pool was started.
	17:01	Seawater injection into the spent fuel pool ends. Injected water volume approx. 18 t.
3/23		
3/24		
3/25	10:30	Seawater injection into the spent fuel pool was started.
	12:19	Seawater injection into the spent fuel pool ends. Injected water volume approx. 30 t.
3/26	10:10	Fresh water injection into the core was started by using the temporary tank with boric acid dissolved.
	16:40	Turbine building (T/B) Motor Control Center (MCC) 2A-1 received power.
	16:46	The main control room lighting recovered.
3/27	18:31	For water injection into the reactor, injection by the fire pumps was switched to fresh water injection by temporary motor pumps.
3/28		
3/29	15:30	For water injection into the spent fuel pool, injection by the fire pumps was switched to injection by temporary motor pumps.
	16:45	Transfer of pooled water from the Condensate Storage Tank (CST) to the suppression pool tank (SPT) starts
3/30	around 9:45	Malfunction of the temporary motor pump for injecting cooling water into the spent fuel pool was observed, and the temporary motor pumps were switched to the fire pumps: Injection was interrupted.
	12:30	Water injection restarted after switching the coolant water injection for the spent fuel pool to the fire pumps.
	12:47	Crack confirmed in the fire pump hose
	13:10	Fire pump hose changed
	17:05	Water injection restarted to the spent fuel pool using the fire pumps.
	19:05	For water injection into the spent fuel pool, injection by the fire pumps was switched to injection by temporary motor pumps, and the injection was restarted.
	23:50	Water injection to the spent fuel pool completed, less than 20 t
3/31	14:24	Transfer of pooled water from CST to SPT ends
	15:25	Transfer of pooled water from CST to SPT starts
4/1	11:50	Transfer of pooled water from CST to SPT ends
	14:56	Fresh water injection into the spent fuel pool through the spent fuel pool cooling system by the temporary motor pumps was started
	17:05	Fresh water injection into the spent fuel pool through the spent fuel pool cooling system by the temporary motor pumps was ended, approx. 70 t.
4/2	11:05	It was observed that water exceeding 1000 mSv accumulated in pit near the bar screen, the crack of about 20 cm on the concrete at the side of the pit, and water leakage from the pit into the sea from the crack.
	16:25	Cement was injected in a pit adjacent at the upstream side of the pit concerned.
	17:02	The cement injection into the pit concerned was started
	17:10	Transfer of pooled water from the hot well (H/W) to the Condensate Storage Tank (CST) started
	19:30	The operation to prevent water leaking from the pit into the sea was suspended since the Alarm Pocket Dossimeter (APD) on the workers exceeded the alarm set point. No significant decrease in outflow status is apparent.
4/3	11:50	The temporary motor-driven pumps used to inject water to the reactor were connected to an permanent power supply, switching from an temporary power supply.
	13:47	As a measure to stop the leak of accumulated water in a pit near the Inlet Bar Screen, 20 bags of sawdust, 80 bags of polymeric water absorbent, and 3 bags of shredded newspaper were started to be put into the water.
	14:30	As a measure to stop the leak of accumulated water in a pit near the Inlet Bar Screen, 20 bags of sawdust, 80 bags of polymeric water absorbent, and 3 bags of shredded newspaper were ended to be put into the water.

	Unit 2	
	Situation before the earthquake: operating	
4/4	11:05 13:07	Fresh cooling water injection into the Spent Fuel Pool via a temporary motor-driven pump started. Fresh cooling water injection into the Spent Fuel Pool via a temporary motor-driven pump ended (about 70 t).
4/5	14:15 around 17:00	A tracer solution was injected through two holes which were made by the workers around the pit near the Inlet Bar Screen. It was confirmed that the tracer solution was observed leaking from the crack into the sea. About 1500 L of coagulant was injected. As a result, the flow rate of contaminated water outflow temporarily decreased, but then went back to the original level, and remained at that level.
4/6	5:38 13:15	It was confirmed that the outflow of contaminated water from the pit crack had stopped. A rubber board and base jacks were used to cover the crack in the pit from which contaminated water was flowing out
4/7	13:29 14:34	Fresh water injection into the Spent Fuel Pool via the Spent Fuel Cooling Line using a motor-driven pump started. Fresh water injection into the Spent Fuel Pool via the Spent Fuel Cooling Line using a motor-driven pump stopped (about 36 t).
4/8		
4/9	13:10	The transfer of held water in the condenser hot well (H/W) to the Condensate Storage Tank was completed.
4/10	10:37 12:38	Fresh cooling water injection into the Spent Fuel Pool using a temporary motor-driven pump started Fresh cooling water injection into the Spent Fuel Pool using a temporary motor-driven pump stopped (about 60 t).
4/11	About 17:16 17:56 18:04	The external power supply (Tohoku Electric Power Co. lines) to Units 1 and 2 was interrupted after an earthquake, and the pumps used for water injection to reactors stopped. External power supply restored The pumps used for water injection to reactors resumed.
4/12	19:35	Transfer of pooled water from the trench to H/W started
4/13	8:30 11:00 11:00 13:15 14:55 15:02 17:04	Installation of boards (two of the total of seven steel plates) on the ocean side of the Inlet Bar Screen of Unit 2 was started to temporarily stop water leak; and the installation work continued until 10:00. The transfer of the accumulated water in the trench of the turbine building to the Hot Well of the Condenser was temporary suspended to check for any leakage. (Amount transferred: about 600 t) Transfer of pooled water from the trench to H/W ended Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a motor-driven pump started Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a motor-driven pump stopped The transfer of the accumulated water in the trench of the turbine building to the Hot Well of the Condenser resumed after having ensured that there was no leakage. Transfer of the accumulated water in the trench of the turbine building to the Hot Well of the Condenser stopped
4/14	7:45 12:20	Installation of silt fences in front of the Inlet Bar Screens of Units 1 and 2, and at the Curtain Wall to prevent further diffusion of contaminated water started. Installation of silt fences in front of the Inlet Bar Screens of Units 1 and 2, and at the Curtain Wall to prevent further diffusion of contaminated water stopped.
4/15	10:19 17:00	As a countermeasure against possible tsunamis, transfer of the distribution boards for the water injection pumps to higher ground started. As a countermeasure against possible tsunamis, transfer of the distribution boards for the water injection pumps to higher ground ended.
4/16	10:13 11:54	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump started. Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump stopped (about 45 t).
4/17		
4/18	12:13 12:37 13:42 14:33	The work of replacing the hose that had been used for injecting water to the reactor core with a new one started. The replacement of the hose that had been used for injecting water to the reactor core with a new one was completed. The operation of the injection pump resumed. A survey by an unmanned robot to check the conditions in the reactor building started. A survey by an unmanned robot to check the conditions in the reactor building ended.
4/19	10:08 10:23 16:08 17:28	The transfer of contaminated water from the trench to the Radioactive Waste Treatment Facility started. The power supply reinforcement work for Units 1 and 2 to Units 3 and 4 was completed. (Both the Tohoku Genshiryoku Line and the Okuma Line can be used to each other.) Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump started. Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump stopped. Approx. 50 t.
4/20		
4/21		
4/22	15:55 17:40	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump started. Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump stopped. Approx. 50 t.
4/23		
4/24		

	Unit 2	
	Situation before the earthquake: operating	
4/25	10:12	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump started.
	11:18	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump stopped. Approx. 38 t.
	14:44	To reinforce power supply security (connection between Units 1-2 and Units 5-6), the work to shut off the 6.9-kV power panel for Units 1 and 2 was started.
	17:38	To reinforce power supply security (connection between Units 1-2 and Units 5-6), the work to shut off the 6.9-kV power panel for Units 1 and 2 was stopped.
	18:25	The power supply for the pumps injecting water into the reactors was restored to the status in which the external power source was used.
4/26		
4/27		
4/28	10:15	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump started.
	11:28	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump stopped. Approx. 43 t.
4/29	9:16	The transfer of accumulated water in the trench of the turbine building to the Radioactive Waste Process Facility was temporary suspended due to inspection of the equipment for transferring and monitoring work.
4/30	14:05	The transfer of accumulated water in the trench of the turbine building to the Process Main Building of the Central Radioactive Waste Process Facility had been suspended due to inspection of the equipment for transferring and monitoring work; but the transfer work resumed using a pump after the completion of the inspection.
5/1	13:35	The work of blocking the trench pit with broken stone and concrete was started.
5/2	10:05	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump started.
	11:40	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump stopped. Approx. 55 t.
	12:53	The water injection pump was temporarily switched to a fire-engine pump in order to install an alarm device onto the pump used for injecting water into the reactor core.
	14:53	After the completion of the installation of an alarm device onto the water injection pump, the water injection pump into the reactor core was put back on; and water injection was carried out.
5/3		
5/4		
5/5		
5/6	9:36	Fresh water injection into the Spent Fuel Pool via the Spent Fuel Cooling Line using a motor-driven pump started.
	11:16	Fresh water injection into the Spent Fuel Pool via the Spent Fuel Cooling Line using a motor-driven pump stopped. Approx. 58 t.
5/7	9:22	The transfer of accumulated water in the trench of the turbine building to the Radioactive Waste Process Facility had been temporary suspended due to the work performed on the piping of the reactor feed water system for Unit 3.
	16:02	The transfer of accumulated water in the trench of the turbine building to the Radioactive Waste Process Facility had been temporary suspended due to the work performed on the piping of the reactor feed water system for Unit 3; but the transfer work resumed.
5/8		
5/9		
5/10	9:01	The transfer of accumulated water in the trench of the turbine building to the Radioactive Waste Process Facility was temporary suspended.
	13:09	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a motor-driven pump started.
	14:45	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a motor-driven pump stopped. Approx. 56 t.
5/11	8:47	The pump to inject water into the reactor was connected to a temporary diesel generator; and water injection was carried out.
	15:55	The pump to inject water into the reactor was connected to an auxiliary power system, switching from temporary diesel generator; and water injection was carried out.
5/12	15:20	The transfer of accumulated water in the trench of the turbine building to the Radioactive Waste Process Facility had been temporary suspended (due to transfer piping work); but the transfer resumed.
5/13		
5/14		
5/15	13:00	Fresh water injection into the Spent Fuel Pool via the Spent Fuel Cooling Line using a temporary motor-driven pump started.
	14:37	Fresh water injection into the Spent Fuel Pool via the Spent Fuel Cooling Line using a temporary motor-driven pump stopped. Approx. 56 t.
5/16		

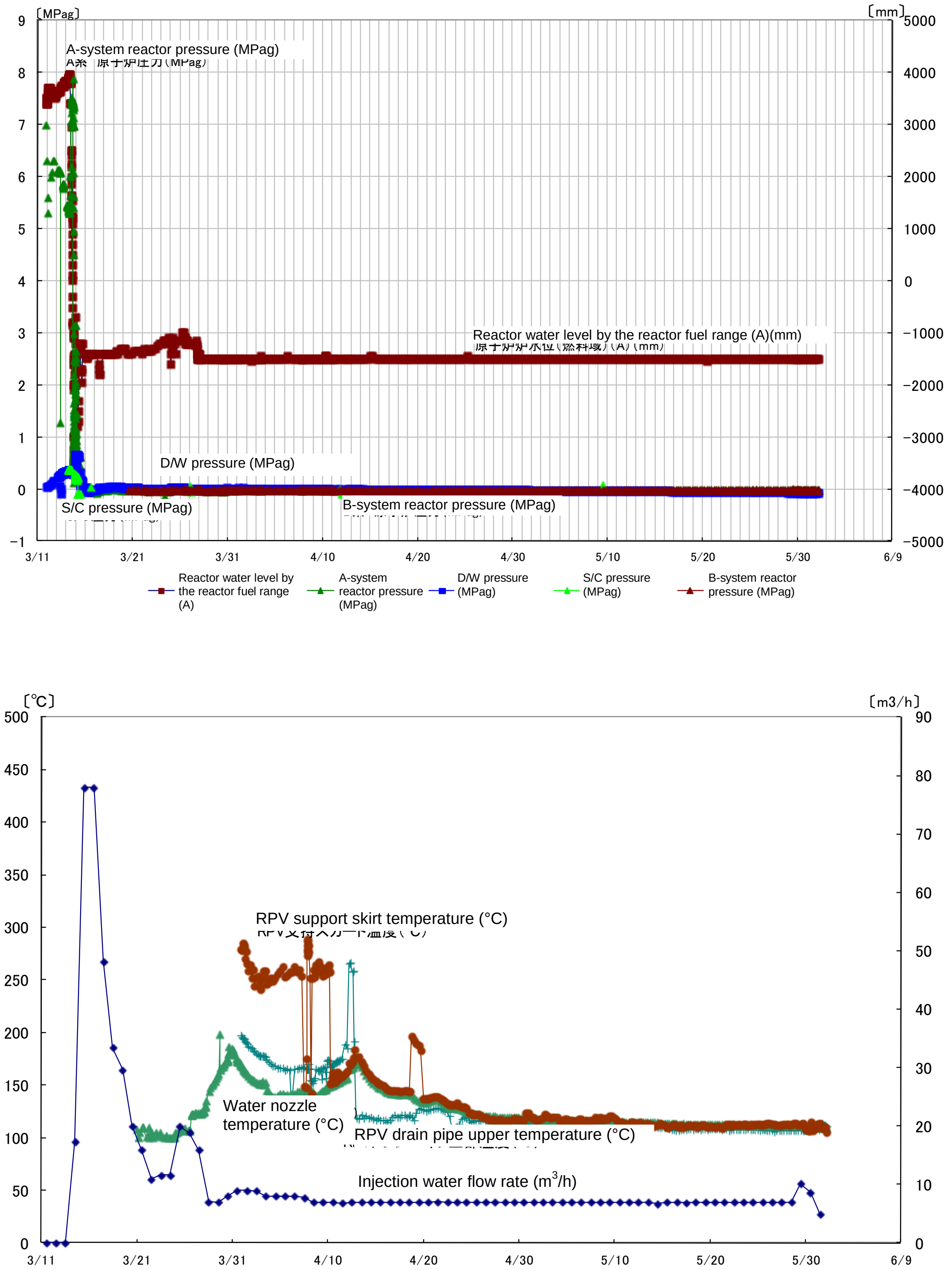


Fig. IV-5-4　Changes in key parameters [1F-2] (From March 11 to May 31)

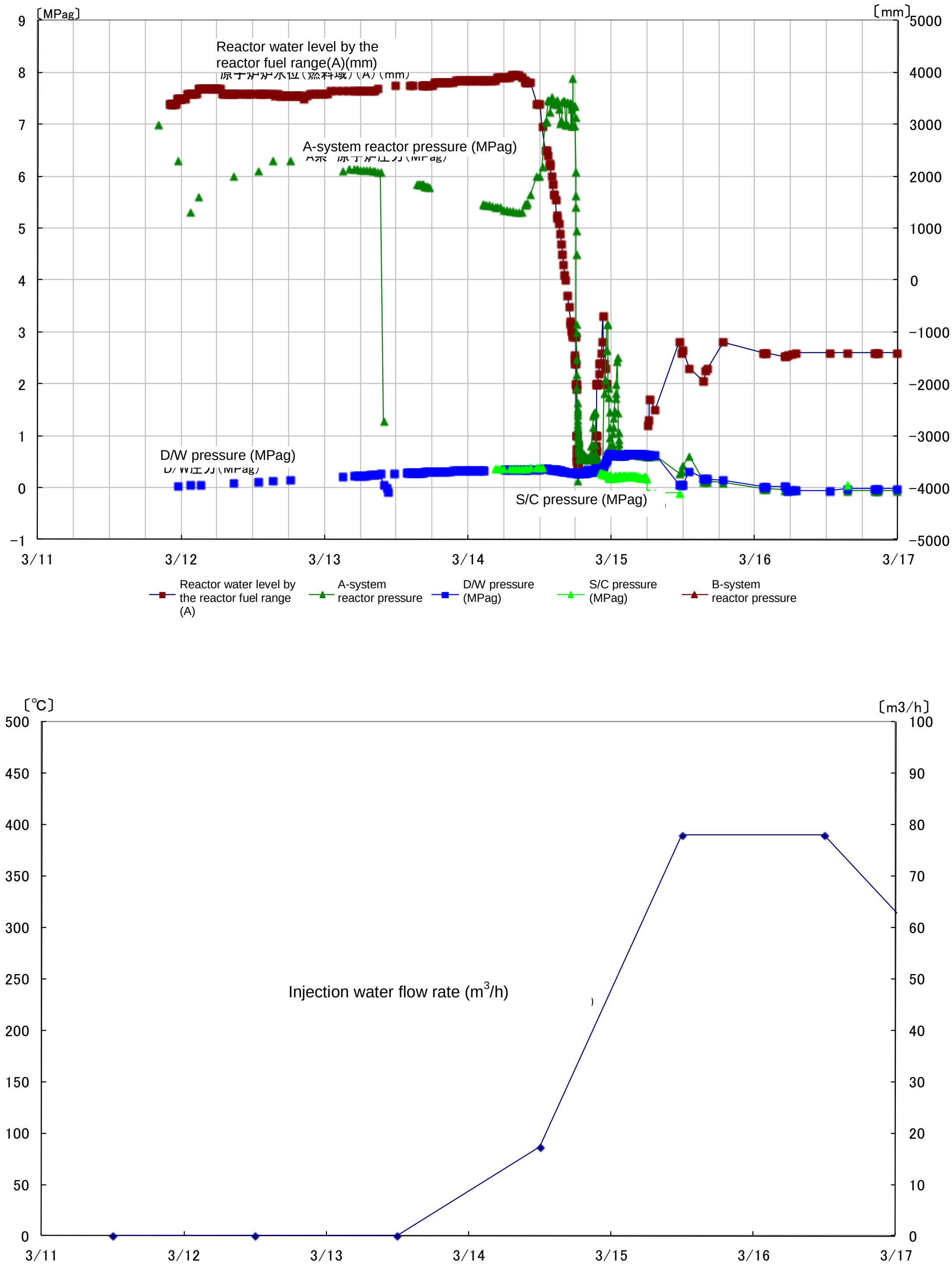
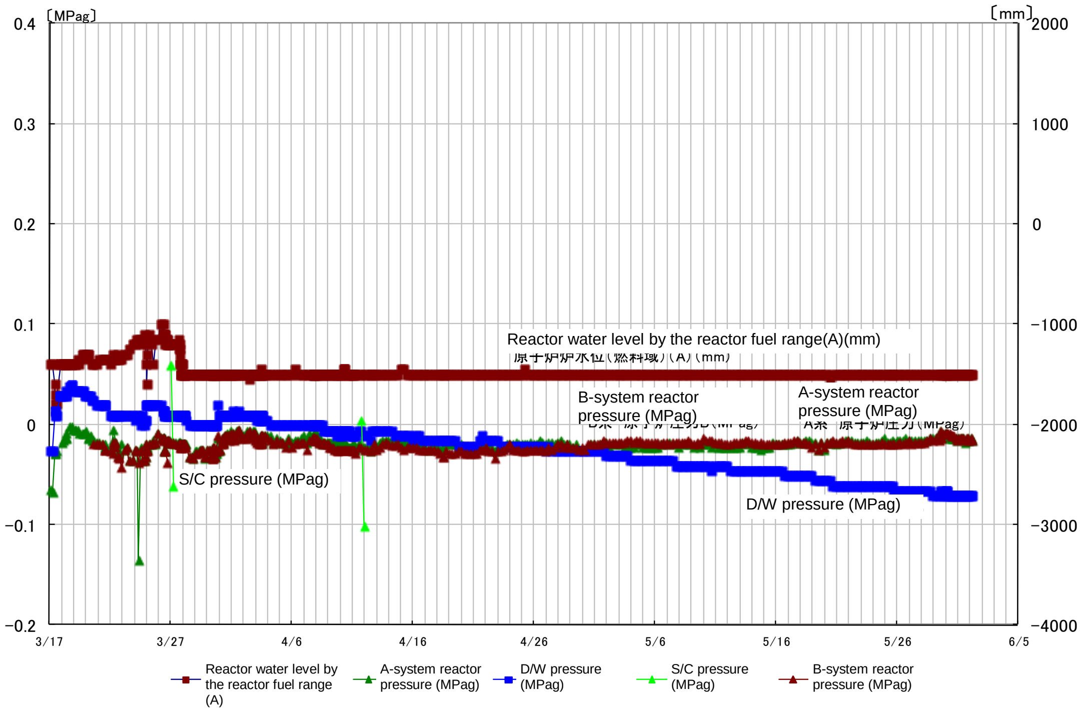


Fig. IV-5-5 Changes in key parameters [1F-2] (From March 11 to March 17)



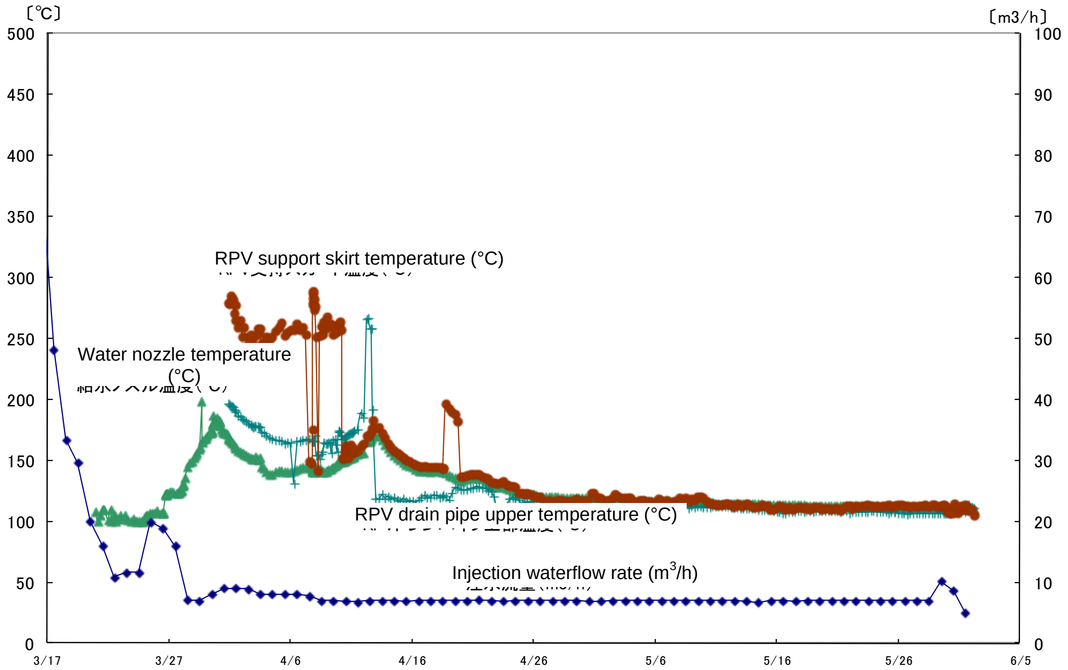


Fig. IV-5-6 Changes in key parameters [1F-2] (From March 17 to May 31)

(3)Fukushima Daiichi NPS, Unit 3

1) Order of accident progress and provisional expedient (chronological sequence)

a From the earthquake until the arrival of the tsunami

As described in Chapter 3, the plant was in full power operation before the earthquakes. After the earthquakes hit, the nuclear reactor at Unit 3 scrammed at 14:47 on March 11 due to the great acceleration of the earthquakes and automatically shut down as all control rods were inserted to bring the reactor into subcritical. In addition to Okuma Line 3, which was powered off due to repair work started before the earthquake, the breaker at Shintomioka Substation tripped and the breaker for receiving electricity at the switchyard in the power station was damaged, disrupting the power supply from Okuma Line 4. By causing the loss of external power supply, two emergency DGs started automatically.

At 14:48, the loss of power to instruments caused by the loss of external power supply triggered a closure signal at the main steam isolation valve (MSIV) in accordance with the fail-safe design. Regarding the closure of the MSIV, the Tokyo Electric Power Co., Inc. (TEPCO) considered that the main steam pipes did not rupture with the records of the flow rate of the main steam, which would be observed as the increase of the flow rate when the main steam piping breaks. The Nuclear and Industrial Safety Agency (NISA) also agrees that such a judgment would be reasonable.

The closure of the MSIV resulted in increasing of RPV pressure and at 15:05, the reactor core isolation cooling system (RCIC) was manually activated as a precautionary measure. At 15:28, the pressure increase stopped due to the high water level in the reactor.

b Effects of the tsunami

At 15:38, as a result of the impact of the tsunami, two emergency DGs stopped operating and all AC power was lost due to the drenching/submersion of the cooling seawater pumps, the metal-clad switchgear and the emergency bus of Unit 3.

The inability to use the residual heat removal system seawater pumps meant the loss of residual heat removal system (RHR) functions, resulting in a failure to shift the decay heat in the PCV to the sea, the final heat sink.

However, the DC bus of Unit 3 escaped being drenched. Power was not supplied through AC-DC transfer from the DC bus, but rather the backup storage batteries supplied power to the loads (RCIC valves, recorders, etc.) that required direct current for an extended time compared to those of other units.

Because of the drawdown resulting from the shutdown of the RCIC at 15:25, the RCIC started again at 16:03 and stopped at 11:36 on March 12.

The reason why the RCIC stopped at 11:36 on March 12 is unknown at this time, but the storage batteries for valve manipulation might have become exhausted as more than 20 hours had passed since the RCIC started operation.

Afterwards, the HPCI started automatically at 12:35 on March 12 due to the low water level of the core and stopped at 2:42 on March 13. At that time, the plant-related parameters did not indicate any water level, and so the core coolant injection system stopped as the water level in the core was unknown.

At 3:51, after more than one hour had passed since the HPCI stopped, the power was restored to the water level gauge, which showed that the water level for the reactor fuel was -1600 mm (TAF-1600 mm).

It is thought that the HPCI stopped as a result of the lower reactor pressure.

TEPCO judged that the situation corresponded to a “loss of reactor coolant functions” event stipulated according to the provisions of Article 15, NEPA for Nuclear Disaster and notified NISA and other parties in accordance with the requirements of the Act.

c Reactor pressure changes

The reactor pressure transitioned fairly stably after the scram, but at around 9:00 on March 12, the reactor pressure began to show larger fluctuations. From 12:30 to about 19:00, it decreased by more than 6 MPa.

From around 19:00 on March 12, the reactor pressure was being stable around one MPa, but from 2:00 to 2:30 on March 13, being decreased once and then increased to 7 MPa by around 4:00 on the same day. During the initial stage of this reactor pressure change, the HPCI was working. But when the HPCI stopped, the reactor pressure may have risen suddenly.

Considering that the reactor pressure dropped for more than six hours from 12:30 on March 12, it is considered unlikely that a large-scale pressure leak occurred. Steam may have leaked from the HPCI, since the pressure began to drop at around the same time as the HPCI started and the reactor pressure began rising after the HPCI stopped.

At around 9:00 on March 13, the reactor pressure dropped rapidly down to approximately 0 MPa. This may have occurred because of rapid depressurization resulting from the operation of the major steam SRV.

d Emergency measures

In order to lower the PCV pressure after the HPCI stopped at 2:42 on March 12, TEPCO carried out wet venting from 8:41 the same day. From approximately 9:25 on the same day, though TEPCO started injecting fresh water containing boric acid through the fire extinguishing system by using fire engines, the RPV water level still dropped. Even taking this injection into account, this meant that no injection had occurred for six hours and 43 minutes since the HPCI stopped. At 13:12 the same day, water injection was changed to seawater.

To reduce the PCV pressure, wet venting was carried out at 5:20 on March 14.

e Explosion at the building and subsequent measures

An explosion, which was likely a hydrogen explosion, occurred at the upper part of the reactor building at 11:01 on March 14. The explosion destroyed the operation floor and all floors above it, the north and south external walls of the floor below the operation floor, and the waste processing building. At this time, radioactive materials were released into the atmosphere and the radiation dose in the vicinity of the site increased.

On March 25, fresh water from the pure water storage tank was once again used as an alternative injection to the reactor. As of the end of May, the total injection volume had reached approx. 20,625 m^3 (approx 16,130 m^3 of fresh water and approx. 4,495 m^3 of seawater).

On March 28, reactor injection was performed by temporary motor-driven pumps, and on April 3, their power supply was switched to a permanent power supply. The injection system was thus shifted to a stable system.

While verifying the integrity of load systems through the repair of the transformer at Shin Fukushima Substation and the bypass operation between Line 1 of the Yorunomori Line and Line 3 of the Okuma Line, the power supply has been gradually restored. On March 18, power supply was restored as far as the site metal-clad switchgear, and on March 22, the lighting of the main control room was restored.

The main chronological sequence is shown in Table IV-5-3. Plant data, such as the RPV pressure, is shown in Figures IV-5-7 to IV-5-9.

2) Evaluation using severe accident analysis codes

a Analysis by TEPCO

When TEPCO's analysis showed that the flow volume of the alternative injection water was low, it resulted in damage to the RPV due to melted fuel. TEPCO has used these results in addition to the existing PRV temperature measurement results to evaluate that the greater part of the fuel has in fact been cooled at the bottom of the RPV.

TEPCO estimated that during this process the reactor fuel was exposed for about four hours from 2:42 on March 13, when the HCPI stopped (about forty hours after the earthquake hit), and two hours later, damage to the core began. Later, as the reactor water level was not able to be maintained around the fuel, flow volume for the alternative water injection was assumed. The decay heat began melting the core and the melted fuel shifted to the lower plenum and then some 66 hours after the earthquake, it started to damage the RPV.

The analysis results show that, along with the damage to the core and the core melt of reactor fuel, the embedded radioactive materials were released into the RPV and moved to the S/C, with the noble gases almost all being released into the environment through PCV vent operation, and approximately 0.5% of the radioactive iodine was released.

Note that TEPCO carried out an additional analysis, which assumed leakage from the HPCI steam system as the RPV and D/W pressures had dropped while HPCI was operating. The analysis results show that the RPV pressure changes and the D/W pressure changes were generally in alignment, but, including the problems with instrumentation, it is not possible to pinpoint the reason the RPV and D/W pressures dropped, nor their current status.

b Crosscheck by NISA

In the crosscheck analyses, NISA analyzed using the MELCOR codes based on the conditions (basic conditions) that TEPCO adopted. In addition, a sensitivity analysis and other analyses were carried out in terms of the relationship with the pump output pressure and determined that the injected water volume for the alternative water injection was in line with the RPV pressure.

The crosscheck under basic conditions indicated nearly the same tendencies as seen by TEPCO. It showed that the fuel was exposed at about 13:08 (41 hours after the earthquake) and three hours later core damage started. The time period the RPV was damaged was about 79 hours after the earthquake.

The analysis results show that the amount of radioactive materials was approx. 0.4% to 0.8% of radioactive iodine was released, and the other nuclides were approx. 0.3% to 0.6%. However, the released amount changes according to the settings for seawater injection flow amounts, etc., and the operating status is unclear, so there is the possibility that this will change depending on the operating status.

Regarding the assumption by TEPCO of operational status for the high pressure water injection system, as there is no quantitative setting basis shown, it is difficult to evaluate what exactly has happened, and further investigation is required. However, regardless of the high pressure water injection system operating status, the reactor pressure has been restored due to stopping the high pressure water injection system and if the reactor water level can be maintained, then there will be no major effects on the core status and of course no effects on the evaluation of core status.

3) Estimation of RPV and PCV situations

a Confirmation of plant information

The study was done on plant data obtained during the period from March 15 to May 31, when the plant was in a comparatively stable condition, and the plant data from this period was handled as shown below.

An instruction may have been issued to maintain a higher water level in the fuel area since the PCV temperature was high when the PCV pressure was remaining at a high level, and the normal water level dropped due to the evaporation of water in the PCV condensation tank as well as the instrumentation piping. As Unit 3 showed the same tendency that Unit 1 later showed, the water level in the RPV was considered immeasurable.

The RPV pressure was nearly equal to the measured values of the A and B systems, so it was considered to show a close approximation of the actual pressure. For the period when negative pressure was shown, it was considered to be within an error range as such pressure is immeasurable by the pressure gauge.

After March 30, the RPV temperature stayed around 100°C in connection with the RPV pressure and so it was considered to generally show an actual temperature. However, some pieces of data showing high temperature values were excluded from the evaluation as they did not meet with the trend of other measured values.

The plant data up to March 15, which is very limited, was added to the data from March 15 on, and excepting the data regarding the reactor water level, was referred to under the assumption that it reflected the actual situation.

As stated above, there may have been an instruction to keep the water level high in the reactor fuel area. As it is impossible to determine when deviation from the instruction began to occur, only the changes in the situation were referred to roughly in considering information on equipment operation and so forth.

b Estimation of RPV and PCV situations during comparatively stable period

-Situation of RPV boundary

According to the information of the Tokyo Electric Power Co., Inc. (TEPCO), the total injection amount to RPV up to May 31 is considered to be about 20,700 tons. The total amount of vapor generated from the start of injection is about 8,300 tons when the decay heat is estimated on the outside in the decay heat evaluation formulation. If the pressure boundary is secured, a difference of about 12,400 tons at least may be kept there. As the capacity of RPV is 500 m^3 at most, the injected water may not only evaporate within RPV and leak as vapor, but also may leak as water. The injection to RPV was executed through the nozzles of recirculating water inlet and water supply equipment. The water injected through the nozzle of water supply equipment would gather once in the outside of shroud (from about 17:00 May 21 to about 23:00 May 28) and then would move to the bottom of RPV via the jet pump diffuser to cool the reactor fuel. The water is very likely to leak to outside at this portion.

From about 23:00 May 29 and on, the injection was switched and continued only through the nozzle of water supply equipment.

The RPV pressure has been close to the atmosphere pressure from March 22 and similar to the D/W pressure of PCV, and so it is now estimated that RPV seems to connect to PCV through the gas phase portion.

-Situation in RPV (reactor core status and water level)

Some RPV temperatures exceeded the measurable range (higher than 400°C) due to the lower injection flow rate caused by the increase of RPV pressure on March 20, but the temperature dropped through the securing of injection flow rate on March 24 and stayed around 100°C. Accordingly a considerable amount of reactor fuel may remain within the RPV. However, there is a possibility that the bottom part of the RPV was damaged and some of the fuel might have dropped and accumulated on the dry well floor (lower pedestal).

The temperature tends to rise in general from the beginning of May. Considering that it partially exceeds 200°C and is higher than the saturation temperature for the RPV pressure, part of reactor fuel may still remain unsubmerged and be cooled by vapor.

-Status of PCV

As the pressure of D/W and S/C exceeded the maximum operating pressure (0.427 MPag) of the PCV to reach about 0.5 MPag on March 13, it is assumed at this moment that the performance of the gaskets of flanges and the seals of penetrations deteriorated. The D/W pressure is maintained around the atmospheric pressure (0 MPag). Therefore, it is assumed at this moment that the vapor generated by decay heat may be released to the outside through D/W.

As the pressure of gas phase portions of S/C stayed at a higher level than the atmospheric pressure and the D/W pressure is close to the atmospheric pressure, the temperature of water that flows from the lower part of D/W down to S/C is 100°C at a maximum. Accordingly, it is now estimated that the 0 MPag or higher pressure of the gas phase portions of S/C is due to noncondensable gasses. Right now, TEPCO is studying how to estimate the water level of D/W.

4) Estimation of situations of RPV, PCV and others at a given moment over time

After the earthquake, water injection continued through the reactor core isolation cooling system (RCIC). Around 12:00 on May 12, the RCIC stopped operation. Alternatively, water injection was made through the high-pressure coolant injection system (HPCI) but the reactor pressure decreased and thus the reactor water level is estimated to have increased. Before dawn on the morning of March 13, however, the reactor pressure dropped and HPCI stopped operation.

The stoppage of HPCI is estimated to have triggered the reactor pressure to exceed the operation pressure of about 7 MPa. But the main steam safety relief valve (SRV) is estimated to have been activated to release the vapor to S/C to maintain the pressure at around the 7 MPa level, during which time it is estimated that the reactor water dropped and the reactor fuel was damaged.

It is estimated that the main steam SRV opened to lower the reactor pressure, and at 9:25 on March 13 alternative injection was carried out and wet vent operation done in response to the increase in PCV pressure. It was reported that the alternative injection from fire engines was executed, but this measure could not demonstrate the required performance due to the relation with the reactor pressure, etc. as the water level has not been restored yet. More detailed investigations and analyses of the conditions/situations of equipment would be necessary in order to find out to what extent such measures worked.

5) Analysis of accident event progress

Regarding the progress of events in the accident at Unit 3, previous analyses showed that the RCIC and HPCI ceased to function, so PCV spraying using fire engines and wet vent operation were carried out. In addition, there is the possibility that, based on the water level situation following the start of fresh water injection and RPV pressure reduction operations, not enough water was injected and it is estimated that the lack of sufficient cooling led to core melt, with the melted fuel moving down to the bottom of the RPV.

From the balance between the injected water volume and volume of steam produced, it is estimated that the water injected into the RPV is leaking.

Based on the RPV temperature measurement results, it is considered that a considerable amount of fuel is cooling on the RPV bottom.

The situation of the reactor building after the explosion is not known in detail for certain yet due to the limited site verification. As a result of the execution of numerical fluid dynamic analysis in addition to the severe accident analysis, the release of the gas that contained the hydrogen generated through the reaction between zirconium in the clad of fuel rods and the water in the reactor might accumulate hydrogen sufficient enough to reach the detonation range in the upper space of reactor building to cause the explosion. Along with the explosion, the oil for the MG sets for the control of the rotating speed of recirculation pumps burnt concurrently at the heavily damaged west side of the 4th floor of reactor building. For the waste processing building, it cannot be denied now that it might be damaged not only by the blast waves but also by the explosion of the hydrogen that flew in through the piping penetrations. The high dose contamination that hinders works in the vicinity of the building was found on part of debris scattered by the explosion. The severe accident analysis, while it does not assume any leakage from the

PRV, suggests that it might be the result of radioactive materials that leaked from the PCV adhering to the reactor building structure, as the PCV maximum operating pressure was exceeded.

As it is impossible to identify to what extent each system functioned actually, it is also impossible to determine the event progress situation at this moment. From the results of the severe accident analysis, however, it can be estimated that radioactive materials were released into the environment by the wet vent operation starting at noon on March 13, and almost all the noble gases in the core were released, and the iodine and cesium in the core were released at ratios of approx. 0.5% to 0.8% and approx. 0.3% to 0.6% respectively.

Table IV-5-3 Fukushima Daiichi NPS, Unit 3 – Main Chronology (Provisional)

* The information included in the table is subject to modifications following later verification. The table was established based on the information provided by TEPCO, but it may include unreliable information due to tangled process of collecting information amid the emergency response. As for the view of the Government of Japan, it is expressed in the main body of the report.

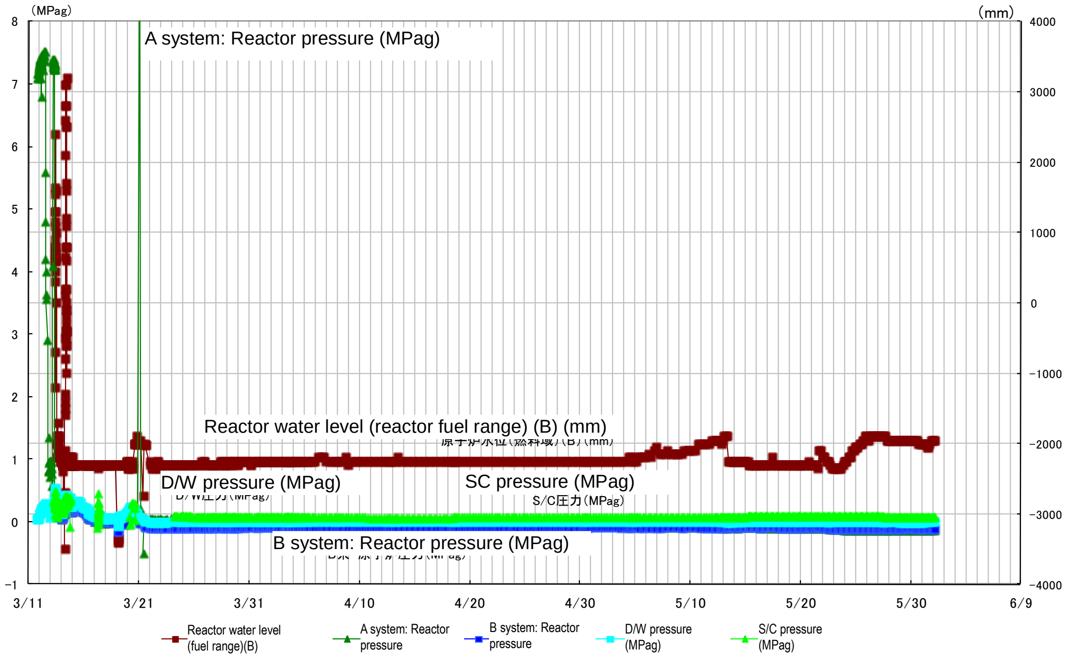
	Unit 3	
	Status before the earthquake: in operation	
3/11		
	14:47	Reactor scram (high seismic acceleration) Control rods fully inserted (sub-critical) Turbine trip Loss of the external power supply
	14:48	Emergency diesel generator (emergency DG) turned on Main steam isolation valve (MSIV) closed
	14:52	Safety relief valve (SR valve) repeatedly opened and closed from this point onwards
	15:05	Reactor core isolation cooling system (RCIC) manually turned on
	15:25	RCIC trip (L-8)
	15:38	All AC power supply lost
	15:42	TEPCO judged that an event falling under Article 10 of the NEPA (loss of all AC power supplies) had occurred.
	16:03	RCIC manually turned on
	20:30	RCIC in operation Lighting in Central Operating Room (temporarily secured and in preparation)
	23:35	Water level on the decrease (400 mm at 22:58→350 mm (wide range))
3/12		
	11:36	RCIC trip
	12:35	High pressure coolant injection system (HPCI) turned on (L2)
	12:45	Reactor pressure on the decrease (7.53 Mpa at 12:10→ 5.6 MPa)
	20:15	Reactor pressure on the decrease (0.8 MPa)
3/13		
	2:42	HPCI stopped
	4:15	Reactor water level was judged to have reached the top of active fuel (TAF).
	5:10	Due to stoppage of HPCI, injection by RCIC into the reactor was attempted. As RCIC could not be turned on, the event was judged by TEPCO to fall under Article 15 of the NEPA (loss of reactor cooling function).
	6:00	Water level in the reactor: -3500 mm (wide range)
	7:39	Spraying onto the PCV began. Water level as of 7:45: TAF -3,000 mm. Reactor pressure: 7.31 MPa. DW pressure: 460 kPa. SC pressure: 440 kKPa.
	8:41	The second valve (AO valve) was set to "open" for venting.
	9:08	Operation to reduce pressure in the RPV by relief valve (SRV) It appears that some time after this point the safety relief valve (SRV) was closed and opened, due to issues with maintenance of air pressure for driving SRV and excitation on the electro-magnetic valve on the air supply line.
	About 9:20	Decrease trend of pressure inside PCV detected
	9:25	Injection of fresh water (borated) into the reactor through the Fire Extinguishing Line began.
	11:17	Vent line AO valve found closed (through loss of pressure in the tank) From this point on, it was difficult to keep the AOV open due to issues with maintenance of air pressure for driving AOV and excitation on the electro-magnetic valve on the air supply line, and the operation to open it was repeated multiple times.
	12:30	Operation to open the AO valve on the pressure chamber side.
	13:12	Fresh water injection to the reactor was switched to seawater injection.
	22:15	Diesel-driven fire pump (D/DFP) stopped (before it ran out of fuel)

	Unit 3	
	Status before the earthquake: in operation	
3/14		
	1:10	Seawater injection suspended as supply of seawater for the reactor was running low.
	3:20	Injection of seawater resumed.
		Measurement by the Containment Atmospheric Monitoring System (CAMS) was 1.4×10^2 Sv/h (DW); the core damage probability was estimated to be about 30%.
	5:20	The valve (AO valve) was set to "open" for venting.
	6:10	D/W pressure was 460 Kpa abs
	9:05	D/W pressure was 490 Kpa abs
	About 11:00	An explosion that appeared to be a hydrogen explosion occurred in the upper part of the reactor building (what appeared to be white smoke rose).
	11:25	Reactor pressure (A) was 0.185 MPa. DW pressure was 360 KPa. SC pressure was 380 KPa. Water level (A) was -1800 mm.
3/15		
	16:00	AO valve on the SC side found closed
	16:05	AO valve on the SC side opened
3/16		
	1:55	AO valve on the SC side opened
	About 8:30	A great deal of white smoke was emitted from Unit 3.
3/17		
	9:48	Seawater spraying onto the spent fuel pool by helicopter started.
	10:01	Seawater spraying onto the spent fuel pool by helicopter stopped. Approx 30 t.
	About 19:05	National Police Agency riot police started to spray water onto the spent fuel pool with a high-pressure water cannon truck.
	19:13	National Police Agency riot police stopped spraying water onto the spent fuel pool with a high-pressure water cannon truck. Approx. 44 t.
	19:35	The riot police started to spray water onto the spent fuel pool with their fire engine
	20:09	The riot police stopped spraying water onto the spent fuel pool with their fire engine. Approx. 30 t
	21:00	AO valve on the SC side found to be closed.
	About 21:30	AO valve on the SC side opened.
3/18		
	About 5:30	AO valve on the SC side found closed
	14:00	The Self-Defense Force started spraying water onto the spent fuel pool with their fire engine.
	14:38	The Self-Defense Force stopped spraying water onto the spent fuel pool with their fire engine. Approx. 40 t.
	14:42	US Armed Forces started spraying water onto the spent fuel pool with their water truck.
	14:45	US Armed Forces stopped spraying water onto the spent fuel pool with their water truck. Approx. 2 t.
3/19		
	0:30	The Tokyo Fire Department started spraying water with their fire engines onto the spent fuel pool.
	1:10	The Tokyo Fire Department stopped spraying water with their fire engines onto the spent fuel pool. Approx. 60 t.
	11:30	AO valve on the SC side found closed.
	14:10	The Hyper Rescue Unit of the Tokyo Fire Department started spraying water onto the spent fuel pool.
3/20	3:40	The Hyper Rescue Unit of the Tokyo Fire Department stopped spraying water onto the spent fuel pool. Approx. 2430 t. Radiation levels before the water was sprayed were 3417 μSv/h (at 14:10) and after water spraying were 2758 μSv/h (at 3:40)
	11:00	Pressure inside PCV rose.
	About 11:25	11:25 AO valve on the SC side opened..
	About 21:36	The Hyper Rescue Unit of the Tokyo Fire Department started spraying water to cool the spent fuel pool.
3/21	3:58	The Hyper Rescue Unit of the Tokyo Fire Department stopped spraying water onto the spent fuel pool. Approx. 1137 t.
	About 15:55	Grayish smoke rose from the south-eastern part of the rooftop of the reactor building.
3/22		
	10:36	The emergency low-pressure distribution panel (Power Center (P/C) 4D) received power.
	15:10	The Hyper Rescue Unit of the Tokyo Fire Department started spraying water to cool the spent fuel pool.
	15:59	The Hyper Rescue Unit of the Tokyo Fire Department stopped spraying water onto the spent fuel pool. Approx. 150 t.
	22:28	Main Bus Panel for measurement received power (120 VAC).
	22:46	Lighting in Central Operating Room recovered

	Unit 3	
	Status before the earthquake: in operation	
3/23	11:03	Seawater injection from the fuel pool cooling and clean-up system (FPC) to cool down the spent fuel pool started.
	13:20	Seawater injection from the fuel pool cooling and clean-up system (FPC) to cool down the spent fuel pool stopped. Approx. 35 t.
	About 16:20	Slightly blackish smoke was emitted from the reactor building.
3/24	About 5:35	Seawater injection from the FPC to cool down the spent fuel pool started
	About 16:05	Seawater injection from the FPC to cool down the spent fuel pool stopped. Approx. 120 t.
3/25	13:28	Water spraying onto the spent fuel pool by the Kawasaki City Fire Bureau supported by the Tokyo Fire Department started.
	16:00	Water spraying onto the spent fuel pool by the Kawasaki City Fire Bureau supported by the Tokyo Fire Department stopped. Approx. 450 t.
	18:02	Seawater injection into the reactor was switched to fresh water injection.
3/26		
3/27	12:34	Seawater spraying onto the spent fuel pool by TEPCO's Concrete Pump Truck (hereafter, "concrete pump truck") started.
	14:36	Seawater spraying onto the spent fuel pool by the Concrete Pump Truck stopped. Approx. 100 t.
3/28	17:40	Transfer of pooled water from the Condensate Storage Tank (CST) to the Suppression Pool Water Surge Tank (SPT) started.
	20:30	Water injection into the reactor is switched from the fire truck pump to injection using the temporary electric pump.
3/29	14:17	Water spraying onto the spent fuel pool by the Concrete Pump Truck starts (from here, fresh water is used).
	18:18	Water spraying onto the SFP by the Concrete Pump Truck stops (from here, fresh water is used). Approx. 100 t.
3/30		
3/31	8:37	Transfer of pooled water from the CST to the SPT completed.
	16:30	Water spraying onto the spent fuel pool by the Concrete Pump Truck started.
	19:33	Water spraying onto the spent fuel pool by the Concrete Pump Truck stopped. Approx. 105 t.
4/1		
4/2	9:52	Water spraying onto the spent fuel pool by the Concrete Pump Truck started.
	12:54	Water spraying onto the spent fuel pool by the Concrete Pump Truck stopped. Approx. 75 t.
4/3	11:50	The power supply for the temporary motor-driven pump used for water injection into the reactor was switched from a temporary one to a permanent one.
4/4	17:03	Water spraying onto the spent fuel pool by the Concrete Pump Truck started.
	19:19	Water spraying onto the spent fuel pool by the Concrete Pump Truck stopped. Approx. 70 t.
4/5		
4/6		
4/7	6:53	Water spraying onto the spent fuel pool by the Concrete Pump Truck started.
	8:53	Water spraying onto the spent fuel pool by the Concrete Pump Truck stopped. Approx. 70 t.
4/8	17:06	Water spraying onto the spent fuel pool by the Concrete Pump Truck started.
	About 18:30	AO valve on the SC side found closed.
	20:00	Water spraying onto the spent fuel pool by the Concrete Pump Truck stopped. Approx. 75 t.
4/9		
4/10	17:15	Water spraying onto the spent fuel pool by the Concrete Pump Truck started.
	19:15	Water spraying onto the spent fuel pool by the Concrete Pump Truck stopped. Approx. 80 t.
4/11	About 17:16	As a result of an earthquake, the external power supply for Units 1 and 2 (Tohoku Nuclear Power Line) was lost, and the water injection pump for the reactor was suspended.
	18:04	The water injection pump for the reactor was restarted.

	Unit 3	
	Status before the earthquake: in operation	
4/12		
	16:26	Water spraying onto the spent fuel pool by the Concrete Pump Truck started.
	17:16	Water spraying onto the spent fuel pool by the Concrete Pump Truck stopped. Approx. 35 t.
4/13		
4/14		
	15:56	Water spraying onto the spent fuel pool by the Concrete Pump Truck started.
	16:32	Water spraying onto the spent fuel pool by the Concrete Pump Truck stopped. Approx. 25 t.
4/15		
	10:19	Work began to move the power distribution panel for injection pumps and other equipment to higher ground against tsunami.
	17:00	Work completed to move the power distribution panel for injection pumps and other equipment to higher ground against tsunami.
4/16		
4/17		
	11:30	An unmanned robot inspection of the reactor building started.
	14:00	An unmanned robot inspected the reactor building finished.
4/18		
	12:38	Work began to replace the hose used to inject water into the reactor with a new one. The reactor injection pump was stopped.
	13:05	The replacement of the hose used to inject water into the core with a new one was completed. The reactor injection pump was restarted.
	14:17	Water spraying onto the spent fuel pool by the Concrete Pump Truck started.
	15:02	Water spraying onto the spent fuel pool by the Concrete Pump Truck stopped. Approx. 30 t.
4/19		
	10:23	Tie line between Units 1 and 2 and Units 3 and 4 was completed. (The Tohoku Genshiryoku Line and the Okuma Line can be used interchangeably.)
4/20		
4/21		
4/22		
	14:19	Water spraying onto the spent fuel pool by the Concrete Pump Truck started.
	15:40	Water spraying onto the spent fuel pool by the Concrete Pump Truck stopped. Approx. 50 t.
4/23		
4/24		
4/25		
	18:25	The power supply for the injection pump for the reactor was restored to an external one.
4/26		
	12:00	Fresh water sprayed into the spent fuel pool by the Concrete Pump Truck. A water surface was detected.
	12:25	Water injection using the fuel pool cooling and clean-up system (FPC) to cool down the spent fuel pool started.
	14:02	Water injection using the FPC to cool down the spent fuel pool stopped. Approx. 47.5 t.
4/27		
4/28		
4/29		
4/30		
	10:31	To reinforce the external power supply for Units 3 and 4 (Okuma Line No. 3) from 6.6 KV to 66 KV, the 480 V power supply panel for Unit 4 and the 480 V power supply panel shared with the spent fuel pool were suspended.
	11:34	The 480 V power supply panel for Unit 4 and the 480 V power supply panel for the spent fuel pool were restored, and power supply reinforcement work was completed.
5/1		
	13:35	To prevent the stagnant water inside the sea-side shafts in the trenches of Units 2 and 3 from spilling over and seawater from coming into them as a result of tsunami, work began to fill the trench shafts with crushed stone, concrete, etc.
5/2		
	12:53	The pump used to inject water into the reactor core was switched to a fire engine pump in order to install an alarm system to the former.
	14:53	With an alarm system installed, the pump used to inject water into the reactor core was put back to use.
5/3		
5/4		
5/5		
5/6		
5/7		

	Unit 3	
	Status before the earthquake: in operation	
5/8		
	11:38	Measurement of water level in spent fuel pool.
	12:10	Water injection to the spent fuel pool from the FPC started
	14:10	Water injection to the spent fuel pool from the FPC stopped. 60 t.
		Measure of water level in the spent fuel pool and sampling started
	14:50	Measure of water level in the spent fuel pool and sampling finished
5/9		
	12:14	Water injection to the spent fuel pool from the FPC started
	12:39	Along with injection of water from the FPC to the spent fuel pool, injection of a corrosion inhibitor (hydrazine) is started.
	14:36	Along with injection of water from the FPC to the spent fuel pool, injection of a corrosion inhibitor (hydrazine) is stopped.
	15:00	Injection of fresh water using the fuel pool cooling and cleaning system to cool the spent fuel pool is stopped. Approx. 80 t. (Water level of spent fuel pool measured after water injection)
5/10		
5/11		
	8:47	The power supply for the pump to inject water into the reactor core was switched to a temporary diesel generator.
	About 12:30	It was confirmed that there was an inflow of water into the cable pit near the screen.
	15:55	The power supply for the pump to inject water into the reactor core was switched back to the in-house power supply from the temporary diesel generator.
	18:40	Work began to stop the inflow of water into the cable pit near the screen.
	18:45	The inflow of water into the cable pit near the screen is confirmed to have stopped.
5/12		
	16:53	As part of the process of switching the source for the injected water from the Fire Extinguishing Line to the Feedwater System, about 3 tons/h of water was injected from the Feedwater System in addition to the 9 tons/h from the Fire Extinguishing Line.
5/13		
5/14		
5/15		
5/16		
	15:10	Along with injection of water using the temporary electric pump to the spent fuel pool, injection of a corrosion inhibitor (hydrazine) is started.
	17:30	Along with injection of water using the temporary electric pump to the spent fuel pool, injection of a corrosion inhibitor (hydrazine) is stopped.



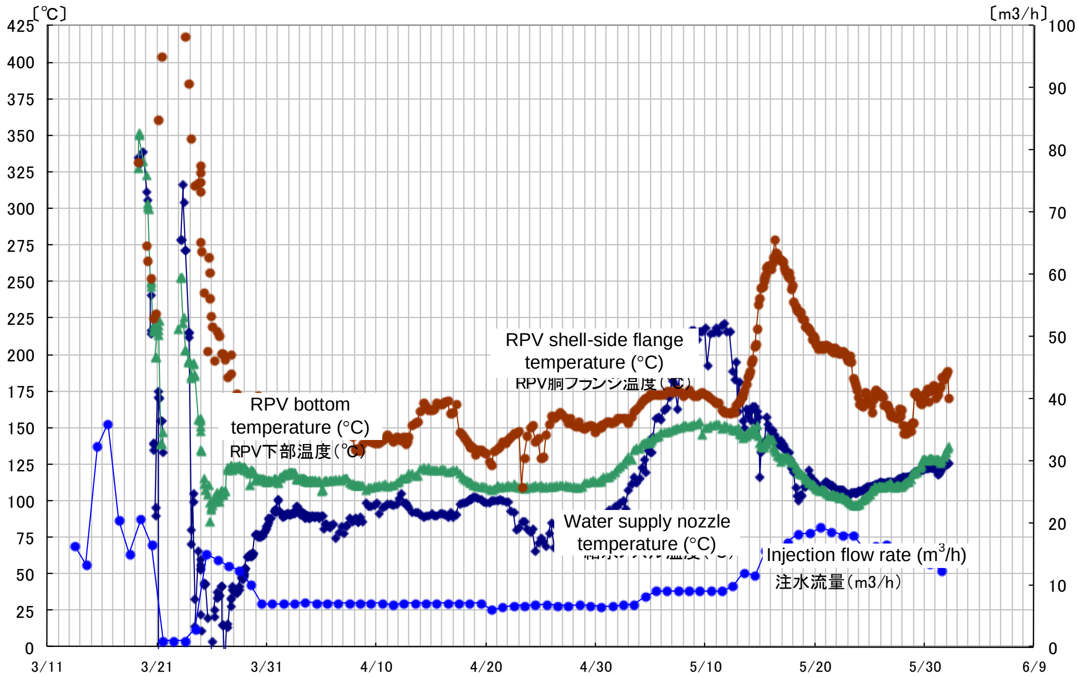
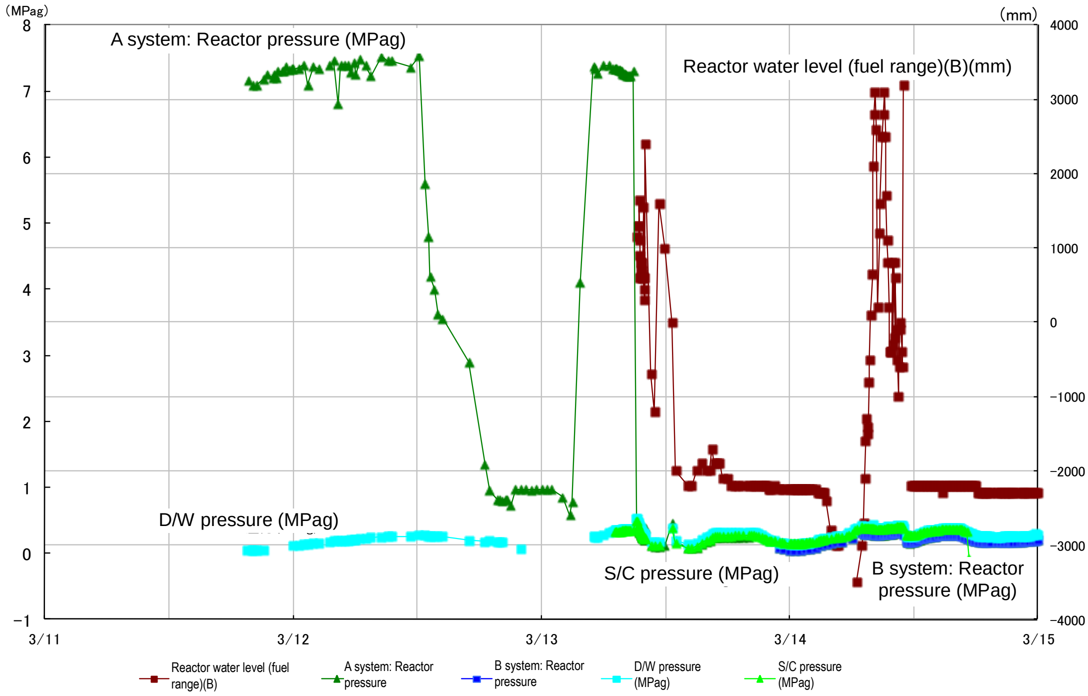


Figure IV-5-7 Changes of Main Parameters (1F-3) (March 11 to May 31)



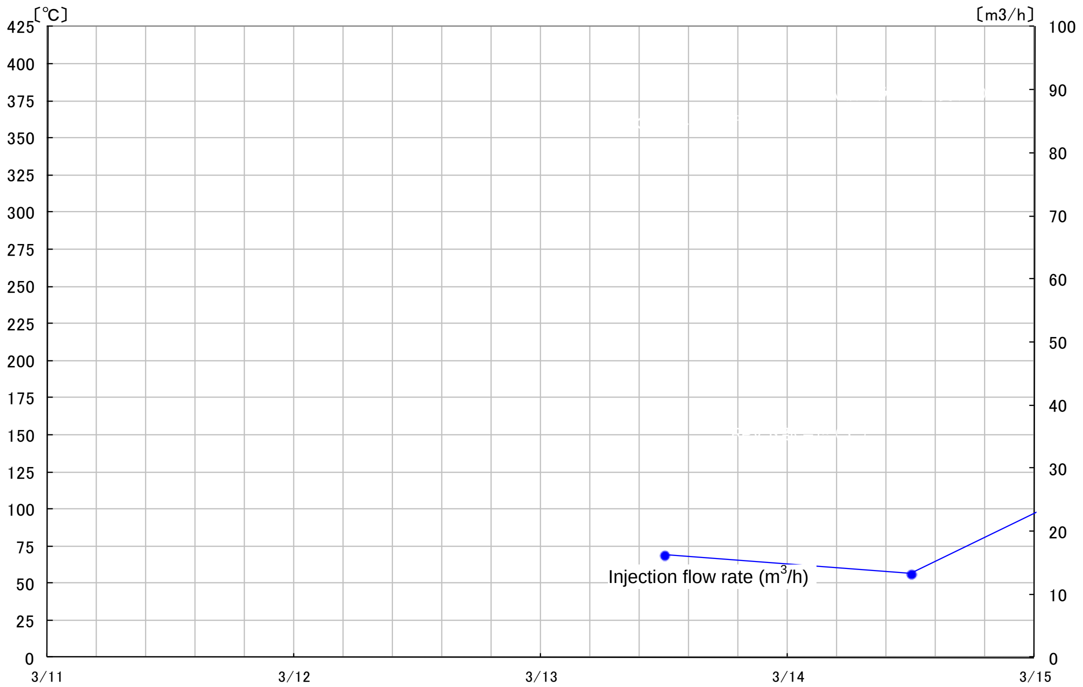
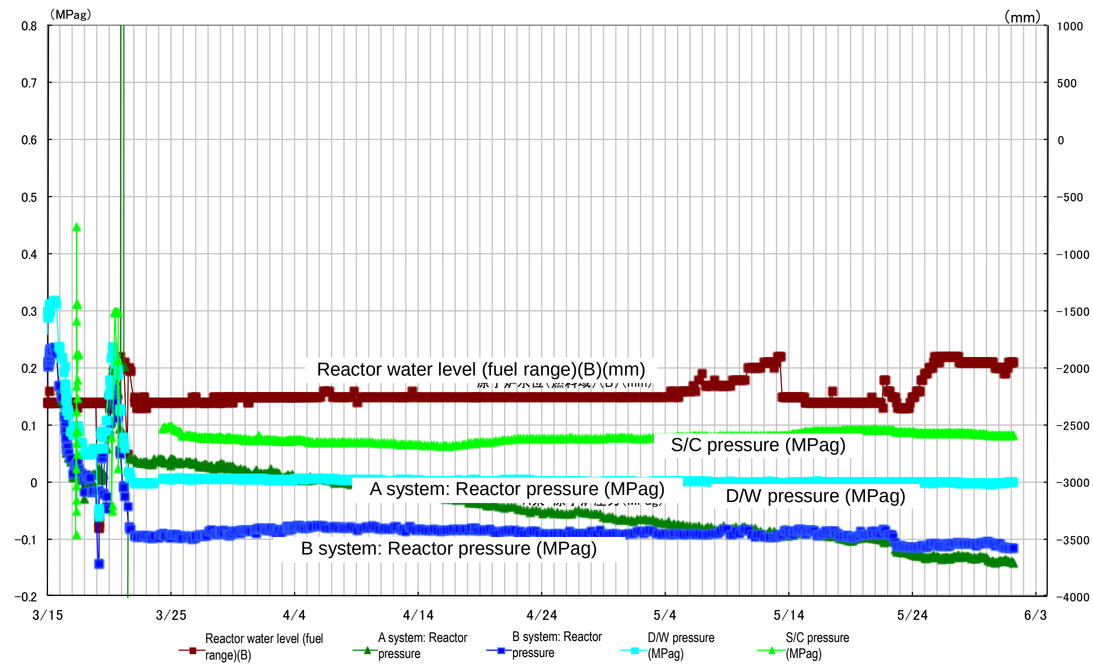


Figure IV-5-8 Changes of Main Parameters (1F-3) (March 11 to March 15)



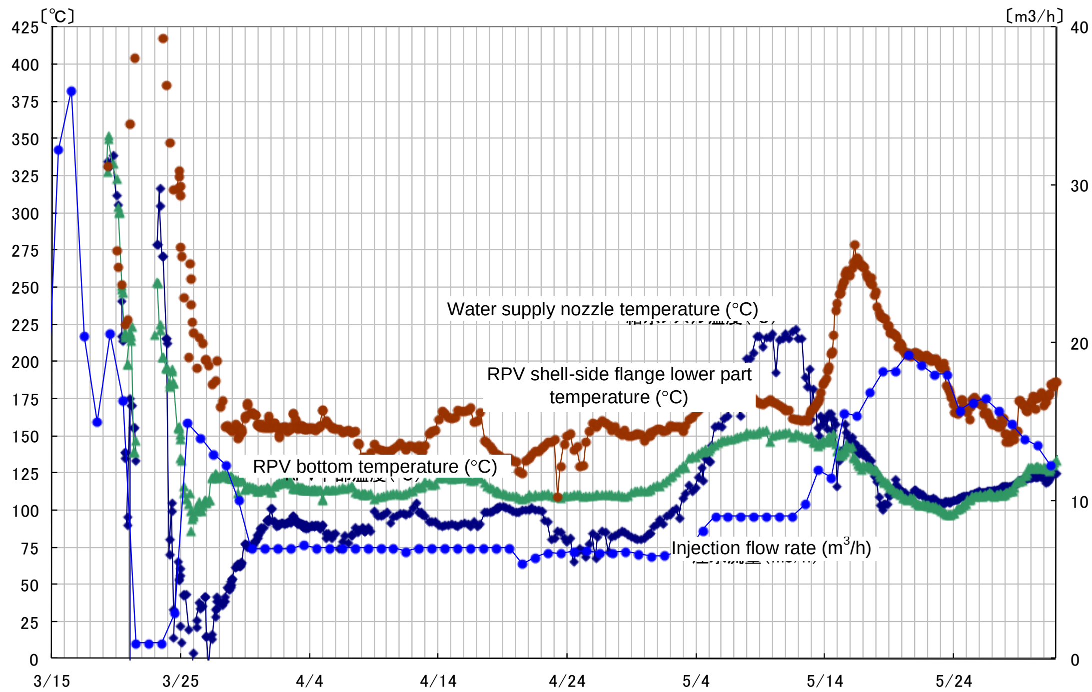


Figure IV-5-9 Changes of Main Parameters (1F-3) (March 15 to May 31)

(4)Fukushima Dai-ichi NPS, Unit 4

1) Order of accident event progress and emergency measures (chronological sequence)

a From the earthquake to the arrival of the tsunami

As described in Chapter 3, Unit 4 was in the periodic inspection and all fuel assemblies were removed from the reactor to the spent fuel pool due to the shroud replacing works of RPV. Therefore, the fuel with relatively high decay heat for one full core was stored in the spent fuel pool. 1,535 pieces of spent fuel assemblies were stored there, which amounted to 97% of its storage capacity of 1,590 pieces.

It was known that the spent fuel pool was fully filled with water as the cutting work of the shroud had been carried out at the reactor side and the pool gate (a divider plate between the reactor well and the spent fuel pool) was closed.

In addition to Okuma Line 3, to which no power was being supplied due to modification work before the earthquake, the Shintomioka Substation breaker tripped and that for receiving electricity at the switchyard in the power station was damaged by the earthquake, disrupting the power supply from Okuma Line 4 as well to cause the loss of external power supply.

As Unit 4 was undergoing periodic inspection, and its process computer and transient recorder were being replaced, the record to verify the startup of the emergency DG does not exist. Judging from the facts that the level of fuel oil tank decreased and the equipment powered by the emergency DG were operating, one emergency DG (the other was being checked) is estimated to have started.

The loss of external power supply stopped the cooling water pump for the spent fuel pool but it was possible to use the RHR system and others that would be powered by the emergency DG when the external power supply was lost.

However, such switching required on-site manual operation and so did not take place before the arrival of the tsunami.

b Effects of the tsunami

At 15:38, Unit 4 went into the situation of the loss of all the AC power supply when one emergency DG stopped its operation due to the drench of the seawater pumps and metal-clad switch gear caused by the tsunami, and the cooling and water supply functions of the spent fuel pool failed.

c Building explosion and subsequent emergency measures

At 4:08 on March 14, the cooling function of Unit 4's spent fuel pool was lost and the water temperature rose to 84°C. At around 6:00 on March 15, an explosion assumed to be a hydrogen explosion occurred in the reactor building, and the whole part upward from below the operation floor as well as the western wall and the wall along the stairs were collapsed. Furthermore, at 9:38, a fire was identified in the northwest part of the fourth floor of the reactor building, but TEPCO confirmed at about 11:00 that it had gone out on its own. A fire was also reported to have broken out in the northwest part of the third floor of the building around 5:45 on March 16, but TEPCO was not able confirm this fire on-site at around 6:15.

The cause of the explosion at the reactor building has not been clearly identified because of various limitations for confirmation at the field. For example, assuming that the stored spent fuel had been exposed because of the low water level and the raised temperature, the explosion should have been caused by the hydrogen generated through the reaction of water vapor with the zirconium in the clad of fuel rod; if so, such a phenomenon should have occurred earlier than at the stage when the temperature had risen and the water level had been lowered as estimated from the decay heat of the stored spent fuel. Therefore, at present, the following must be taken into account: cracks produced in the spent fuel pool and the additional decreases in the water level, such as the overflow caused by flushing due to the increase in temperature. As shown in Table IV-5-4 of the analysis result of nuclides in the water extracted from the spent fuel pool using a concrete pump truck, it is assumed no extensive damage in the fuel rods occurred. No damage to the pool, including water leaks and cracks, was found from visual inspections of the pool's condition. On the other hand, at the adjacent Unit 3, it is assumed that a large amount of hydrogen was generated as a result of the core damage, and a part of it was released by the PCV vent line. Also, as shown in Figs. IV-5-10 and IV-5-11, the exhaust duct of the PCV vent line is connected at the exhaust duct of Unit 4 before the exhaust pipe, and a stop valve to prevent reverse flow is not installed at the emergency gas treatment facility. Therefore, it is thought that the hydrogen discharged by venting at Unit 3 may have flowed in.

As mentioned above, the results of analyzing nuclides from the spent fuel pool and visual inspections have revealed that Unit 4's spent fuel pool remains nearly undamaged.

Subsequent water injections are described later in the section regarding the spent fuel pool.

(Currently under analysis)
The main events are described in chronological order in Table IV-5-5.

Table IV-5-4 Analysis of Nuclides from Unit 4's Spent Fuel Pool

Extracted on	Major Nuclides Detected	Concentration(Bq/cm^3)
April 12	Cesium 134	88
	Cesium 137	93
	Iodine 131	220
April 28	Cesium 134	49
	Cesium 137	55
	Iodine 131	27
May 7	Cesium 134	56
	Cesium 137	67
	Iodine 131	16

Table IV-5-5 Fukushima Daiichi NPS Unit 4 Main Chronology (Provisional)

* The information included in the table is subject to modifications following later verification. The table was established based on the information provided by TEPCO, but it may include unreliable information due to tangled process of collecting information amid the emergency response. As for the view of the Government of Japan, it is expressed in the main body of the report.

	Unit 4	
	Status before earthquake: Stopped	
3/11		
	14:46	Stopped for regular inspection
	15:38	All AC power supply lost
	20:30	Lighting in Central Operating Room temporarily secured
3/12		
3/13		
3/14		
	4:08	Spent fuel pool temperature: 84°C
3/15		
	6:00 to about 6:10	6:00-6:10 (approx.) A large blast is heard. Damage is discovered in the vicinity of the 5th floor roof of the reactor building.
	6:56	The roof top appears distorted.
	8:11	Damage to the reactor building is confirmed. As radiation exceeded 500 μSV/h near the main gate, the operator judged it to be a reportable event under Article 15 (Release of radioactive materials through fire or explosion)
	9:38	A fire is confirmed to have broken out in the vicinity of the north-west corner of the reactor building's third floor. The fire brigade is notified.
		Fire suppression activities are scheduled to be carried out with the US Armed Forces and the In-house Fire Brigade System.
	About 11:00	When the situation with the reactor building fire is confirmed on-site it is confirmed that the fire had gone out naturally.
3/16		
	5:45	Flames are confirmed to be rising from the vicinity of north area of the fourth floor of the Unit 4 building.
		The fire brigade is notified and it prepares to put out the fire.
	6:15	Reconfirmation of the reactor building fire fails to confirm any fire.
	10:43	Clouds of what appears to be white steam are coming out from Unit 3, so outside work is stopped, and workers are directed to evacuate to the Emergency Action Room (2.9 mSv/h, 10:55 at the main gate)
3/17		
3/18		
3/19		
3/20		
	8:21	The SDF starts spraying water into the spent fuel pool to cool it down.
	9:40	The SDF stops spraying water into the spent fuel pool to cool it down. Approx 80 t.
	18:30	The SDF sprays water into the spent fuel pool.
	19:46	The SDF sprays water into the spent fuel pool. Approx. 80 t.
3/21		
	6:37	The SDF starts spraying water into the spent fuel pool.
	8:38	A US Armed Forces water truck sprays water until 8:41. Approx. 2.2 t
	8:41	All 13 units stop spraying. Approx. 90 t.
3/22		
	10:35	The emergency low-pressure power panel (Power Center (P/C) 4D) receives electricity
	17:17	Water spraying onto the spent fuel pool by TEPCO's Concrete Pump Truck (hereafter, "concrete pump truck") starts.
	20:32	Water spraying onto the spent fuel pool by the Concrete Pump Truck stops. Approx. 150 t.
	21:52	Power reaches main bus board power for measuring
3/23		
	10:00	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	13:02	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 125 t.
3/24		
	14:36	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	17:30	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 150 t.

	Unit 4	
	Status before earthquake: Stopped	
3/25	6:05	Spraying seawater to cool the spent fuel pool using the Spent Fuel Pool Cooling and Clean-up Line (FPC) starts.
	10:20	Spraying seawater to cool the spent fuel pool using the FPC stops. Approx. 20 t.
	19:05	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	22:07	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 150 t.
3/26		
3/27	16:55	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	19:25	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 125 t.
3/28		
3/29	11:50	Power reaches the Central Operating Room lights
3/30	14:04	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	18:33	Water spraying from the Concrete Pump Truck is continued until the water level can be confirmed with the gauges. Fresh water is sprayed. Approx. 140 t (fresh water used from here on).
3/31		
4/1	8:28	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	14:14	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 180 t.
4/2	14:25	Transfer of pooled water from the Concentrated Water Processing Facility (Concentrated RW) to the Turbine Building (T/B) starts.
4/3	10:00	Number of pumps for transferring from concentrated RW to T/B increased from 1 to 5.
	17:14	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	22:16	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 180 t.
4/4	9:22	Transfer from the concentrated RW to the T/B stops to check the rise in level of the vertical shaft for Unit 3.
4/5	17:35	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	18:22	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 20 t.
4/6		
4/7	18:23	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	19:40	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 38 t.
4/8		
4/9	17:07	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	19:24	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 90 t.
4/10		
4/11		
4/12	12:00	Sampling work starts in the spent fuel pool to check the status of the fuel stored there.
	13:04	The spent fuel pool sampling work is completed.
4/13	0:30	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	6:57	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 195 t.
4/14	18:10	The results of the April 13 analysis of radioactive material nuclides on the water taken from the pool on April 12 are reported.
4/15	14:30	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	18:29	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 140 t.
4/16		
4/17	17:39	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	21:22	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 140 t.
4/18		

	Unit 4	
	Status before earthquake: Stopped	
4/19		
	10:17	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	10:23	Tie line completed between Units 1, 2 and Units 3, 4 (Can use both the Tohoku-Genshiryoku Line and the Okuma Line)
	11:35	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 40 t.
4/20		
	17:08	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	20:31	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 100 t.
4/21		
	17:14	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	21:20	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 140 t.
4/22		
	17:52	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	23:53	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 200 t.
4/23		
	12:30	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	16:44	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 140 t.
4/24		
	12:25	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	17:07	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 165 t.
4/25		
	18:15	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	0:26	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 210 t.
4/26		
	10:23	As part of the power supply reinforcement work for changing over from the Units 3 & 4 System to the Units 1 & 2 System, work starts on stopping the 480 V power panel for Unit 4.
	16:50	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	20:35	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 130 t.
4/27		
	12:18	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	15:15	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 85 t.
4/28		
	11:43	Measurement of the water level in order to spray water using the Concrete Pump Truck into the spent fuel pool starts.
	11:54	Measurement of the water level in order to spray water using the Concrete Pump Truck into the spent fuel pool stops
	11:55	Spent fuel pool sampling starts.
	12:07	Spent fuel pool sampling stops.
4/29		
	10:29	Spent fuel pool water level measured
	10:35	Spent fuel pool temperature measured
4/30		
	10:14	Spent fuel pool water level and temperature measurement started.
	10:28	Spent fuel pool water level and temperature measurement stopped.
	10:31	To reinforce the external power supply for Units 3 and 4 (Okuma Line No. 3) from 6.6 KV to 66 KV, the 480 V power supply panel for Unit 4 and the 480 V power supply panel shared with the spent fuel pool were suspended.
	11:34	To reinforce the external power supply for Units 3 and 4 (Okuma Line No. 3) from 6.6 KV to 66 KV, the 480 V power supply panel for Unit 4 and the 480 V power supply panel for the spent fuel pool were restored, and power supply reinforcement work was completed.
5/1		
	10:32	Spent fuel pool water level and temperature measurement started.
	10:38	Spent fuel pool water level and temperature measurement stopped.
5/2	10:10	Spent fuel pool water level and temperature measurement started.
	10:20	Spent fuel pool water level and temperature measurement stopped.
5/3		
	10:15	Spent fuel pool water level and temperature measurement started.
	10:23	Spent fuel pool water level and temperature measurement stopped.
5/4		
	10:25	Spent fuel pool water level and temperature measurement started.
	10:35	Spent fuel pool water level and temperature measurement stopped.

	Unit 4	
	Status before earthquake: Stopped	
5/5	11:55	Spent fuel pool water level and temperature measurement started.
	12:05	Spent fuel pool water level and temperature measurement stopped.
	12:19	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	20:46	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 270 t.
5/6	12:16	Spent fuel pool water level and temperature measurement.
	12:16	Spent fuel pool water level and temperature measurement.
	12:38	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	17:51	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 180 t.
5/7	11:00	Water level measured. Temperature measured, sampling
	14:05	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	17:30	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 120 t.
5/8	16:18	Draining of water from the condenser hot well in the turbine building in order to prepare for work on the injection line into the reactor of Unit 3 starts
5/9	16:05	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	19:05	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 100 t.
5/10		
5/11	16:07	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	19:38	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 120 t.
5/12	12:20	Reconnection of the 480 V power panel for Unit 4 and the 480 V power panel for the spent fuel pool in order to boost the external power supply (the Okuma No. 3 Line) for Units 3 and 4 from 6.6 KV to 66 KV to receive power from the TEPCO Genshiryoku Line is completed.
5/13	16:04	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	16:20	Along with spraying water into the spent fuel pool, injection of an anti-corrosion agent (hydrazine) is started.
	18:41	Along with spraying water into the spent fuel pool, injection of an anti-corrosion agent (hydrazine) is stopped. Amount of hydrazine is 0.12 m3.
	19:04	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops. Approx. 100 t.
5/14		
5/15	16:25	Spraying from the Concrete Pump Truck to cool the spent fuel pool starts.
	16:26	Along with spraying water into the spent fuel pool, injection of an anti-corrosion agent (hydrazine) is started.
	18:30	Along with spraying water into the spent fuel pool, injection of an anti-corrosion agent (hydrazine) is stopped. Amount of hydrazine is 0.3 m3.
	20:25	Spraying from the Concrete Pump Truck to cool the spent fuel pool stops.
5/16		

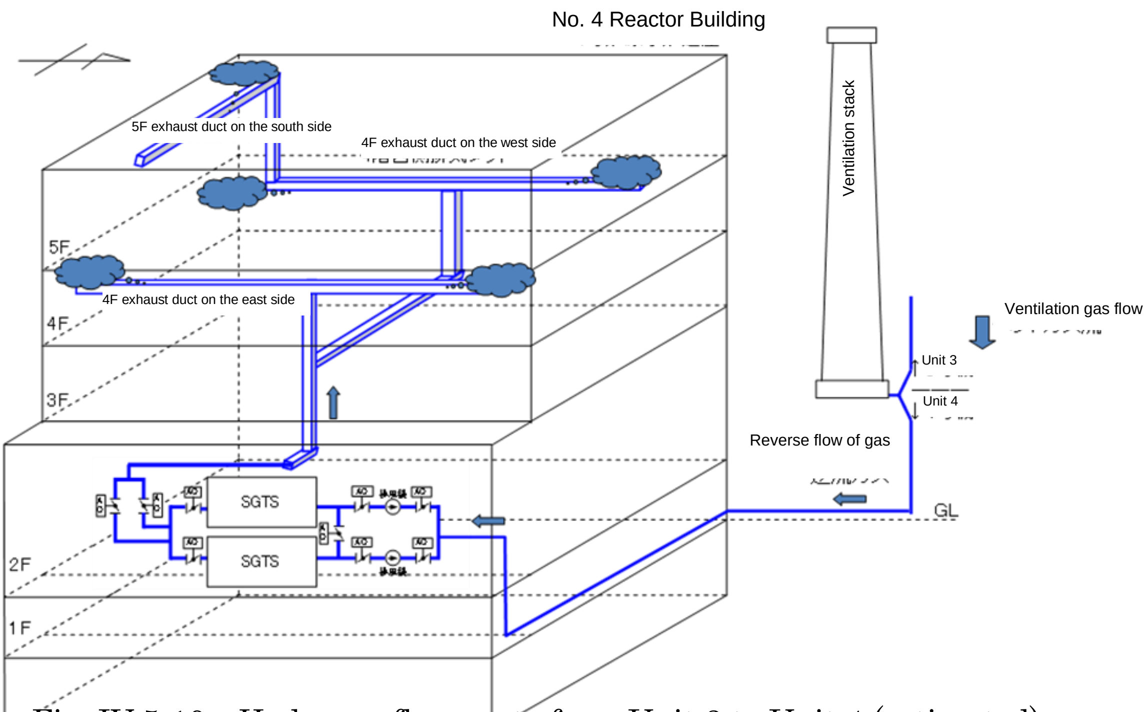
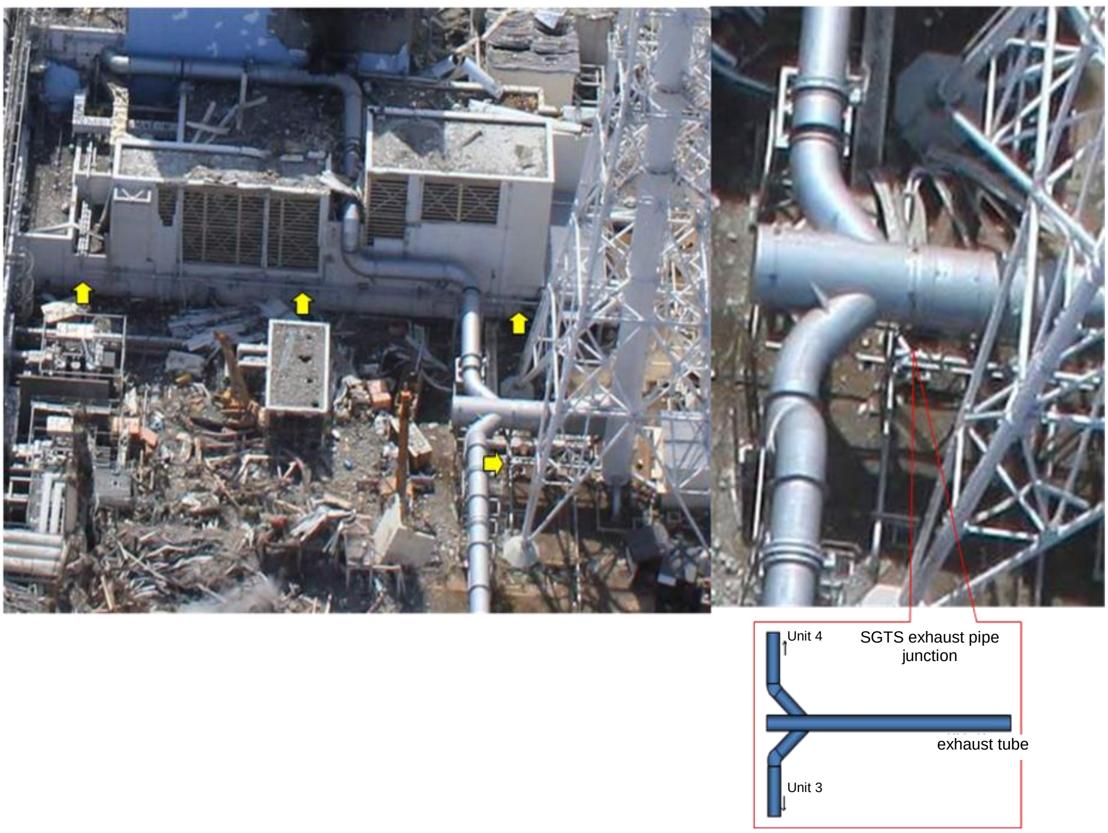


Fig. IV-5-10 Hydrogen flow route from Unit 3 to Unit 4 (estimated)

Fig. IV-5-11 Standby Gas Treatment System exhaust pipe



(5) Unit 5 at the Fukushima Daiichi NPS

1) From the outbreak of the earthquakes until the strike of the tsunami

Unit 5 had been suspended due to a periodic inspection since Jan. 3, 2011. On the day of the earthquake, RPV pressure leakage tests had been conducted with fuel being loaded in the reactor. Further, two 66-kV lines from Yorunomori 1 and 2 of were secured as an external power supply.

On March 11, the 66kV transmission line towers at Yorunomori Line 27 were collapsed when the earthquake hit them and the external power supply was lost. Thus, two emergency DGs were automatically activated.

2) Impact of the tsunami

At 15:40, AC power was totally lost because the two emergency DGs halted due to the flooding of the seawater pumps or damage to the metal-clad switch gear resulting from the tsunami. Loss of function of the seawater pumps disabled the RHR system, resulting in a failure to transfer the decay heat to the ocean, the final heat sink.

In the reactor, the pressure had increased to 7.2 MPa because of the pressure leakage test; however, the equipment that had been applying pressure on the reactor pump halted because of the loss of power supply, leading to a temporary pressure drop. Then, the decay heat caused the pressure to moderately increase, resulting in a pressure of around 8 MPa. At 6:06 on March 12, pressure reduction was performed on the RPV, but the pressure continued to increase moderately because of the decay heat.

3) Control of pressure and water level in the reactor

On March 13, water was successfully injected into the reactor using the condensate transfer pump at Unit 5, which received power from the emergency DG at Unit 6. Accordingly, after 5:00 on March 14, the reactor pressure and the water level were controlled by reducing pressure with the SRV and repeatedly refilling the reactor with water from the condensate storage tank through the condensate transfer pump in parallel.

On March 19, a temporary seawater pump was installed to activate the RHR system. The spent fuel pool and the reactor were alternately cooled by switching the components of the RHR, and the reactor achieved cold shutdown at 14:30 on March 20.

The major events that occurred are described in chronological order in Table IV-5-6.

Table IV-5-6 Fukushima Daiichi NPS, Unit 5 – Main Chronology (Provisional)

	Unit 5
	Situation before the earthquake: stopped
3/11	14:46 Stopped for periodic inspection (pressure inspection under way) 15:40 Loss of all AC power supply
3/12	6:06 Pressure reduction operation on the RPV
3/13	Condensate transfer pump started up by means of power supply from Unit 6
3/14	
3/15	
3/16	
3/17	
3/18	
3/19	5:00 Residual Heat Removal system (RHR) pump (C) started up Completed making (three) holes on the roof in order to prevent hydrogen gas from accumulating within the reactor building
3/20	14:30 Cold shutdown
3/21	11:36 Receiving electricity for metal-clad (M/C) (6C) from starter transformer 5SA (Receiving on-site electricity (for 6.9 kV control panel of power source (6C)) from Yorunomori Line)
3/22	20:13 Receiving electricity for Power Center P/C (P/C) 5A-1 from metal-clad (M/C) (6C)
3/23	17:24 As to Residual Heat Removal Seawater system operated by the temporary pump, test operation after switching its power from temporary to permanent resulted in trip.
3/24	8:48 Receiving electricity in the important seismic isolation building 16:14 The temporary seawater pump of the Residual Heat Removal Seawater system started up, Residual Heat Removal system pump started up by reactor shut-down cooling mode (SHC mode) at 16:35.
3/25	
3/26	23:30 SHC mode (reactor shut-down cooling mode)
3/27	
3/28	Pumped the accumulated water in RHR pump room and CS pump room up to the torus room (continued since March 28th) Drainage from Reactor Building (R/B) (start transfer from CS room → torus room (continued since March 28th))
3/29	
3/30	
3/31	
4/1	
4/2	
4/3	
4/4	
4/5	17:25 Accumulated water discharge to the ocean through the Sub Drain Pit started
4/6	
4/7	

4/8	12:14 Accumulated water discharge to the ocean through the Sub Drain Pit stopped. Amount of discharged water：950 m3
4/9	
4/10	
4/11	
4/12	
4/13	
4/14	
4/15	
4/16	
4/17	
4/18	
4/19	
4/20	
4/21	
4/22	
4/23	
4/24	
4/25	Implemented the tie line with Units 1 and 2 systems generating line 12:22 Stopped Residual Heat Removal system (RHR) pump cooling the reactor for the preparation for suspension of the power supply 16:43 Residual Heat Removal system (RHR) pump which had been stopped started up again
4/26	
4/27	
4/28	
4/29	
4/30	
5/1	
5/2	12:00 Stopped Residual Heat Removal system (RHR) pump and temporary Residual Heat Removal system (RHR) pump for the test charging of the start-up voltage regulator of Units 5 and 6 in connection with the work for recovery of the permanent power supply 15:03 Test charging of the start-up voltage regulator of Units 5 and 6 terminated and Residual Heat Removal system (RHR) pump started up again in connection with the work for recovery of the permanent power supply
5/3	
5/4	
5/5	
5/6	
5/7	
5/8	
5/9	
5/10	
5/11	
5/12	
5/13	
5/14	
5/15	
5/16	

The information included in the table is subject to modifications following later verification. The table was established based on the information provided by TEPCO, but it may include unreliable information due to tangled process of collecting information amid the emergency response. As for the view of the Government of Japan, it is expressed in the main body of the report.

(6) Unit 6 at the Fukushima Daiichi NPS

1) From the outbreak of the earthquakes until the strike of the tsunami

Unit 6 had been suspended due to a periodic inspection since Aug. 14, 2010. The reactor was in a cold shutdown condition with the fuel being loaded. Further, two 66-kV lines from Yorunomori Line 1 and 2 had been secured as an external power supply.

On March 11, the 66-kV transmission line towers at Yorunomori Line 27 collapsed when the earthquake hit them and the external power supply was lost. Thus, three emergency DGs were automatically started.

2) Impact of the tsunami

At 15:40, two emergency DGs (6A, 6H) halted due to the flooding of the seawater pumps and damage to the metal-clad switchgears resulting from the tsunami. However, one emergency DG (6B) continued to function. Because the emergency DB (6B) was installed in the DG building at a relatively high location rather than the turbine building, it remained in operation. Thus, Unit 6 did not lose AC power completely. Because of the tsunami, the seawater pumps lost their functions.

The pressure in the reactor moderately increased due to the decay heat; however, the rate of increase was more modest than that of Unit 5 because a longer period of time had elapsed after the halt.

3) Control of pressure and water level in the reactor

On March 13, water was successfully injected into the reactor using the condensate transfer pump, which received power from the emergency DG. Accordingly, after March 14, the reactor pressure and the water level were controlled by reducing pressure with the SRV and repeatedly refilling the reactor with water from the condensate storage tank through the condensate transfer pump in parallel.

On March 19, a temporary seawater pump was installed to activate the RHR system. The spent fuel pool and the reactor were alternately cooled by switching the RHR system interchangeably, and the reactor achieved cold shutdown at 19:27 on March 20.

The major events that occurred are described in chronological order in Table IV-5-7.

Table IV-5-7 Fukushima Daiichi NPS, Unit 6 - Main Chronology (Provisional)

* The information included in the table is subject to modifications following later verification. The table was established based on the information provided by TEPCO, but it may include unreliable information due to tangled process of collecting information amid the emergency response. As for the view of the Government of Japan, it is expressed in the main body of the report.

	Fukushima Daiichi Nuclear Power Station	
	Unit 6	
	Situation before the earthquake: stopped	
3/11	14:46	Stopped for periodic inspection
	15:36	2 diesel generators (DG) trip
3/12		
3/13		Condensate transfer pump started up
3/14		Decompression by the safety bypass valve
3/15		
3/16		
3/17		
3/18		
3/19	4:22	The second unit of Emergency Diesel Generator (A) started up
	5:11	Fuel Pool Cooling and Cleaning System (FPC) pump started up
		Completed making (three) holes on the roof in order to prevent hydrogen gas from accumulating within the reactor building
	21:26	Temporary Remaining Heat Removal Seawater System (RHRS) pump started up
	22:14	Remaining Heat Removal System (RHR) (B) started up
3/20	19:27	Cold shutdown
3/21	11:36	Receiving electricity to metal-clad (M/C) (6C）from starter transformer 5SA (Receiving on-site electricity (6.9 kV control panel of power source (6C)) from Yorunomori Line)
3/22	19:17	Started receiving electricity from external power supply (2 systems of emergency control panel of power source (6C, 6D) of 6.9 kV on-site power supply system received electricity from the external power supply, Yorunomori Line)
3/23		
3/24		
3/25	15:38	In operation with power supply for (one) substitute pump for RHRS switched from the temporary to the permanent
	15:42	In operation with power supply for (one) substitute pump for RHRS switched from the temporary to the permanent
3/26		
3/27	10:14	RHR operating, reactor shut-down cooling mode (SHC mode)
3/28		
3/29		
3/30		
3/31		

4/1	13:40	Waste Processing Facility (R/W) underground ® drainage to hot well (H/W) (13:40 April 1st to 10:00 April 2nd）
4/2		
4/3		
4/4	21:00	Accumulated water discharge to the ocean through the Sub Drain Pit started.
4/5	17:25	As for the second Sub Drain Pit and succeeding Sub Drain Pits after that, groundwater is being discharged to the ocean by means of three operational pumps.
	18:37	One Sub Drain Pump stopped operation because an unusual sound was detected.
4/6		
4/7		
4/8		
4/9	18:52	Discharge of the low-level radioactive groundwater in Sub Drain Pit stopped with approximately 373 tons of aggregate amount of discharged water
4/10		
4/11		
4/12		
4/13		
4/14		
4/15		
4/16		
4/17		
4/18		
4/19		Transfer from Turbine Building (T/B) ® hot well (H/W)
4/20		
4/21		
4/22		
4/23		
4/24		
4/25		Implemented the tie line with 1/2 systems generating line
4/26		
4/28		
4/29		
4/30		
5/1	14:00	Started the work to transfer accumulated water in the turbine building to an outside temporary tank.
	17:00	Transferred 120 m3 of accumulated water in the turbine building to an outside temporary tank.
5/2	11:03	Stopped the temporary Residual Heat Removal Seawater system (RHRS) pump (for investigation of intake channel).
	13:20	Investigation of the intake channel completed.
	15:03	Residual Heat Removal system (RHR) pump restarted.
5/3		
5/4		
5/5		
5/6		
5/7		
5/8		
5/9		
5/10		
5/11		
5/12		
5/13		
5/14		
5/15		
5/16		

(7) The spent fuel pool at the Fukushima Daiichi NPS

At the Fukushima Daiichi NPS, in addition to the spent fuel pools at Units 1 through 6, a common spent fuel pool is provided for all six reactors. Table IV-5-8 summarizes the capacity, the amount of fuel stored, and the decay heat of the spent fuel stored at these pools. In Unit 4, all fuel had been removed from the reactor because of the shroud replacement work, and the spent fuel pool was being used to store fuel from the core with a relatively high decay heat, so that pool had a higher decay heat than other pools. The condition of Unit 4's spent fuel pool is shown in Figure IV-5-12. On the other hand, because nearly one year had passed since Unit 1's last fuel removal, the decay heat had attenuated. Although the water in the spent fuel pool is usually cooled by releasing heat to the sea, which is the ultimate heat-sink, using FPC (the pool cooling and purification system), cooling failed due to the function loss of both the seawater pumps and the external power supply. In Units 1, 3 and 4, since the upper parts of their buildings were damaged, in order to tentatively secure the cooling function, efforts were made to maintain the proper water levels by external hosing, which was conducted using the Self-Defense Force's helicopters, water cannon trucks, and seawater supply system against fire and squirt fire engines of Emergency Fire Response Teams. Since Unit 4 had the greatest decay heat and the fastest decrease in water level due to evaporation, special attention was paid to it to maintain the proper water level. On the other hand, Unit 2's building remained undamaged, and this was thought to suppress the decrease in water level to some extent as evaporated steam condensed on the building's ceiling; efforts were made to recover the water supply line while maintaining the water level by hosing the opening of the building. On and after March 20, water injection began from the primary water supply line. In Units 5 and 6, the power supply was secured from Unit 6's emergency DG as mentioned above, and the cooling function was also secured using the temporary seawater pump, allowing the spent fuel pool and the reactor to be alternately cooled.

Nuclides from the water of the spent fuel pools of Units 2 through 4 were analyzed. The results of Unit 4 have already been shown in Table IV-5-4, and the analysis results of Units 2 and 3 are shown in Table IV-5-9.

It was confirmed that the common pool was almost full on March 18 and the water temperature was 55°C. On March 21, water was tentatively injected from fire engines and the power supply was restored on March 24, after which cooling was started using the common pool's cooling pump. The major events that occurred are described in chronological order in Table IV-5-10.

Table IV-5-8 Capacity of the spent fuel pool, number of stored assemblies and decay heat.

	Stored assemblies (new fuel assemblies)	Storage capacity	Decay heat	
			At the time of the accident (March 11)	3 months after the accident (June 11)
Unit 1	392 (100)	900	0.18	0.16
Unit 2	615 (28)	1,240	0.62	0.52
Unit 3	566 (52)	1,220	0.54	0.46
Unit 4	1,535 (204)	1,590	2.26	1.58
Unit 5	994 (48)	1,590	1.00	0.76
Unit 6	940 (64)	1,770	0.87	0.73
Common pool	6,375	6,840	1.13	1.12

Table IV-5-9 Nuclide analysis of Unit 2 and 3 spent fuel pools

	Date of sampling	Major nuclides detected	Concentration (Bq/cm^3)
Unit 2	April 16	Cesium 134	160,000
		Cesium 137	150,000
		Iodine 131	4,100
Unit 3	April 28	Cesium 134	140,000
		Cesium 136	1,600
		Cesium 137	150,000
		Iodine 131	11,000

Table IV-5-10 Fukushima Daiichi NPS, Common Spent Fuel Pool – Main Chronology (Provisional)

* The information included in the table is subject to modifications following later verification. The table was established based on the information provided by TEPCO, but it may include unreliable information due to tangled process of collecting information amid the emergency response. As for the view of the Government of Japan, it is expressed in the main body of the report.

	Fukushima Daiichi Nuclear Power Station	
	Common Spent Fuel Pool	
	Situation before the earthquake: stopped	
3/11		The water temperature in Common Spent Fuel Pool before the earthquake: approximately 30°C
3/12		
3/13		
3/14		
3/15		
3/16		
3/17		
3/18	0:00	The water temperature in the pool is 57°C
3/20		
3/21	10:37	Operation of water injection to Common Spent Fuel Pool by fire engines under way
3/22		
3/23		
3/24	15:37	Recovery of the temporary power supply of Common Spent Fuel Pool
	18:05	Cooling pump for the Spent Fuel Pool started up
3/25	15:20	The water temperature in the pool is 53°C
3/26		
3/27	8:00	The water temperature in the pool is 39°C
3/28		The water temperature in the pool is 53°C
3/29		
3/30		
3/31		
4/1		
4/2		
4/3		
4/4		
4/5		
4/6		
4/7		
4/8		
4/9		
4/10		
4/11		
4/12		
4/13		
4/14		
4/15		
4/16		Measures against the stagnant water in order to prevent inflow of groundwater into the building (April 16 to April 18)
4/17	14:36	Temporary power supply for Common Spent Fuel Pool stopped (14:36 to 17:30)
4/18		
4/19		
4/20		

4/21		
4/22		
4/23		
4/24		
4/25		
4/26		
4/27		
4/28		
4/29		
4/30	10:31	In order to reinforce the external power supply for Units 3 and 4 (Okuma 3 Line) from 6.6 KV to 66 KV, 480 V control panel of power source for Unit 4 and 480 V control panel of power source for Common Spent Fuel Pool stopped and recovered at 11:34 to terminate the power supply reinforcement work.
5/1		
5/2		
5/3		
5/4		
5/5		
5/6		
5/7		
5/8		
5/9		
5/10		
5/11		
5/12		
5/13		
5/14		
5/15		
5/16		

(8) Status of accumulated water in the Fukushima Daiichi NPS

It is confirmed that water has accumulated in the basements of the turbine buildings of Unit 1 to 4, and such water hinders restoration work. In addition, highly concentrated radioactive material has been found existed in the stagnant water in Unit 2. Attention therefore must be paid with respect to the unintentional discharge of such radiation-tainted water into the environment.

It was decided that some of the stagnant water should be transferred to the condenser. In preparation for this, a plan to transfer the water in the condensed water storage tank to the suppression pool water surge tank and then transfer the water in the condenser to the condensed water storage tank was planned and carried out. A schematic diagram of this transfer work is shown in Figure IV-5-13. However, since the water level of the condenser is increasing in Units 1 and 3 and it is necessary to understand why this is happening, other measures are being planned. Specific details of the plan of future work are described in Section X. Measures to Bring the Accident Under Control. Cameras have been installed to monitor the water level in the turbine building basements and are remotely controlled for this objective.

It has also been confirmed that water has accumulated in the vertical shaft of the trench outside the turbine buildings. Work was carried out to transfer some of the accumulated water to the tanks in the buildings on March 31. At the same time cameras were installed in the shafts to remotely monitor water levels. The work to transfer the accumulated water in the trench in Unit 2 to the centralized waste treatment facility commenced on April 19. Prior to this work, both the low-concentration radioactive wastewater existed in the centralized waste treatment facility and the groundwater in the subdrain of Units 5 and 6 which contained radioactive materials were discharged into the sea in order to obtain some space in the treatment facility and prevent equipment important to safety of Units 5 and 6 from being submerged. Details of these operations are described in Section VI. Discharge of Radioactive Materials to the Environment.

Water samplings were carried out from the accumulated water to analyze the nuclides contained within it, and the results are shown in Table IV-5-11. The concentration detected for Unit 2 is some ten times higher than that for Unit 1 or 3. Since it is estimated that the water in the PCV that had been in contact with the damaged fuel has been directly discharged through a certain route, measures have been taken to start treatment of the accumulated water and intensively sample the groundwater and seawater to confirm the safety of environment. In addition, as water was found to be being released into the sea near the intake ports adjacent to the trenches of Unit 2 and Unit 3, the release was terminated on April 6 and on May 11. Details are described in Section VI. Discharge of Radioactive Materials to the Environment

Table IV-5-11 Nuclide analysis result of accumulated water (as of June 5)

Unit		Unit 1	Unit 2	Unit 3	Unit 4
Place of collection		Basement floor of the turbine building	Basement floor of the turbine building	Basement floor of the turbine building	Basement floor of the turbine building
Date of sample collection		2011/3/26	2011/3/27	2011/3/24 (2011/4/22)	2011/3/24 (2011/4/21)
Nuclide detected (half-life) Unit: Bq/cm^3	Molybdate-99 (about 66 hours)	Below detection limit	Below detection limit	Below detection limit (Below detection limit)	1.0×10^{0} (Below detection limit)
	Technetium-99m (about 6 hours)	Below detection limit	Below detection limit	2.0×10^{3} (Below detection limit)	6.5×10^{-1} (Below detection limit)
	Tellurium-129m (about 34 days)	Below detection limit	Below detection limit	Below detection limit (Below detection limit)	1.3×10^{1} (Below detection limit)
	Iodine-131 (about 8 days)	1.5×10^{5}	1.3×10^{7}	1.2×10^{6} (6.6×10^{5})	3.6×10^{2} (4.3×10^{3})
	Iodine-132 (about 2 hours)	Below detection limit	Below detection limit	Below detection limit (Below detection limit)	1.3×10^{1} (Below detection limit)
	Tellurium-132 (about 3 days)	Below detection limit	Below detection limit	Below detection limit (Below detection limit)	1.4×10^{1} (Below detection limit)
	Cesium-134 (about 2 years)	1.2×10^{5}	3.1×10^{6}	1.8×10^{5} (1.5×10^{6})	3.1×10^{1} (7.8×10^{3})
	Cesium-136 (about 13 days)	1.1×10^{4}	3.2×10^{5}	2.3×10^{4} (4.4×10^{4})	3.7×10^{0} (2.4×10^{2})
	Cesium-137 (about 30 years)	1.3×10^{5}	3.0×10^{6}	1.8×10^{5} (1.6×10^{6})	3.2×10^{1} (8.1×10^{3})
	Barium-140 (about 13 days)	Below detection limit	6.8×10^{5}	5.2×10^{4} (9.6×10^{4})	Below detection limit (6.0×10^{2})
	Lanthanum-140 (about 2 days)	Below detection limit	3.4×10^{5}	9.1×10^{3} (9.3×10^{4})	4.1×10^{-1} (4.8×10^{2})

(2) Transfer from condensers to condensate storage tanks		
Unit	Transfer date	Changes in the water level of condensate storage tanks
No. 1	Apr. 3 to 10	5% → 56%
No. 2	Apr. 2 to 9	4% → 88%
No. 3	Mar. 28 to 31	58.2% → 1.2%

(1) Transfer from condensate storage tanks to suppression pool water surge tanks		
Unit	Transfer date	Changes in the water level of condensate storage tanks
No. 1	Mar. 31 to Apr. 2	33% → 5%
No. 2	Mar. 29 to Apr. 1	28% → 4%

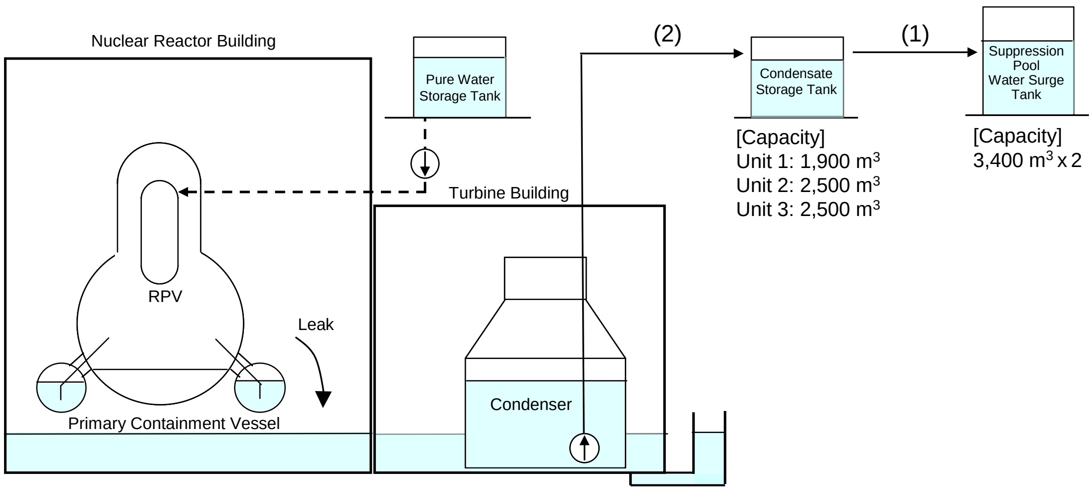


Fig. IV-5-13 Transfer of accumulated water

(9) Fukushima Daini NPS

No significant changes were recorded in the plant data of the Fukushima Daini NPS for Units 1 through 4, prior to the occurrence of the earthquake, and constant rated thermal power operations were being conducted. The live external power sources before the earthquake comprised lines 1 and 2 of the 500 kV Tomioka line and the No. 2 of 66 kV Iwaido line, making three lines in total.

The four nuclear reactors, Units 1 to 4, underwent an automatic shutdown (SCRAM) due to the great seismic acceleration at 14:48 on March 11, and control rods were inserted to the reactors to make them subcritical. The No. 2 of Tomioka line stopped supplying power because of the failure and subsequent repair process of the substation equipment, and additionally, the No. 2 of Iwaido line stopped supplying power approximately one hour after the earthquake.. So the supply of power to Units 1 to 4 was maintained through the No. 1 of Tomioka line. The No. 2 of Iwaido line was recovered from repair at 13:38 on the next day, and the power supply with two lines resumed.
At around 15:34, the tsunami attacked the site of the Daini NPS. This rendered all reactor coolant systems (excluding the RCIC system) including the RHR system for Unit 1 and 2

and all reactor cooling systems (excluding the HPCS system and the RCIC system) including the RHR system for Unit 4 out of operation. The nuclear operator therefore judged that an event defined in Article 10 of the NEPA, “The loss of reactor heat removal,” occurred at 18:33.

1) Unit 1

The reactor was being cooled and the sufficient water level of the reactor core was maintained by the RCIC system and the condensate water supply system. However, as final heat removal could not be realized and the temperature of the SC water exceeded 100°C, the nuclear operator notified the NISA and related departments that the event was judged to correspond to an event defined in Article 15 of the NEPA “Loss of reactor pressure control,” at 05:22 on March 12, and the cooling of the reactor with a drywell spray was started at 07:10 on March 12.

The motors of the RHR system cooling water pump (D) and emergency component cooling water pump (B) necessary for the RHR system (B) operation were replaced with new ones in order to maintain a means of heat removal by the RHR. In relation to the motors of the seawater pump of the cooling system (B) of the RHR system, the cooling water pump (D) of the RHR system, and the emergency component cooling water pump (B), since the power supply panels connected to those motors were rendered inoperable, the power was supplied to those motors from other available power supply panels with provisional cables. As a result, the operation of the RHR system (B) started to cool the suppression chamber at 01:24 on March 14. This continuation of cooling decreased the temperature of the suppression chamber to below 100˚C at 10:15 on March 14, and the reactor itself came into a status of cold shutdown at 17:00 of the same day.

2) Unit 2

The reactor was being cooled, and the sufficient water level of the reactor core was maintained by the RCIC system and the condensate water supply system. However, as final heat removal could not be realized and the temperature of the suppression chamber water exceeded 100°C, TEPCO notified the NISA and related departments that the event was judged to correspond to an event defined in Article 1 of the NEPA “Loss of reactor pressure control,” at 05:32 on March 12., Following this, the cooling of the reactor with a D/W spray was started at 07:11 on March 12.

As regards the motors of the seawater pump (B) of the cooling system of the RHR system, the cooling water pump (B) of the RHR system, and the emergency component cooling water pump (B), since the power supply panels connected to those motors were rendered inoperable, the power was supplied to those motors from other available power supply panels with provisional cables in order to maintain a means of heat removal by RHR. As a result, the operation of the RHR system (B) started to cool the suppression chamber at 07:13 on March 14.

Cooling continued, and the SC temperature decreased to below 100˚C at 15:52 on March 14, and the reactor itself achieved cold shutdown at 18:00 of the same day.

3) Unit 3

Although the RHR system (A) and the LPCS system of Unit 3 failed because of the tsunami damage, the RHR system (B) was not damaged and was able to continue its operation. Thus cooling by this system continued and put the reactor into a status of cold shutdown at 12:15 on March 12.

4) Unit 4

The reactor was being cooled, and the sufficient water level was maintained by the RCIC system and the condensate water supply system. However, as final heat removal could not be realized and the temperature of the SC water exceeded 100°C, the nuclear operator concluded that an event corresponding to an emergency situation defined in Article 15 of the NEPA (loss of reactor pressure control) had occurred and notified the Prime Minister at 06:07 on March 12.

In order to secure a means of heat removal by RHR, the motors of the RHR cooling water pump (B) necessary for RHR (B) were replaced. Since the power supply panels connected to the motors of the seawater pump (D) of the cooling system of the RHR system, the cooling water pump (B) of the RHR system, and the emergency component cooling water pump (B) were rendered inoperable, the power was supplied to these motors from other available power supply panels with provisional cables. As a result, the operation of the RHR system (B) started to cool the suppression chamber at 15:42 on March 14.

As cooling then continued, it decreased the SC temperature to below 100˚C and put the reactor into cold shutdown at 07:15 on March 15.

The time series of major events are shown in Table IV-5-12.

Table IV-5-12 Fukushima Daini NPS, Main Chronology (Provisional)

* The information included in the table is subject to modifications following later verification. The table was established based on the information provided by TEPCO, but it may include unreliable information due to tangled process of collecting information amid the emergency response. As for the view of the Government of Japan, it is expressed in the main body of the report.

	Overall	Unit 1	Unit 2	Unit 3	Unit 4
		Status before earthquake: Under operation	Status before earthquake: Under operation	Status before earthquake: Under operation	Status before earthquake: Under operation
3/11	14:46 Great East Japan Earthquake strikes				
		14:48 All control rods inserted (subcriticality confirmed) Automatic reactor shutdowr Automatic turbine shutdowr External power being supplie Main steam isolation valve; closed	14:48 All control rods inserted (subcriticality confirmed] Automatic reactor shutdowr Automatic turbine shutdowr External power being supplie Main steam isolation valve; closed	14:48 All control rods inserted (subcriticality confirmed] Automatic reactor shutdowr Turbine automatic shutdowr External power being supplie Main steam isolation valve; closed	14:48 All control rods inserted (subcriticality confirmed) Automatic reactor shutdowr Automatic turbine shutdowr External power being supplie Main steam isolation valve; closed
	17:35 Unit 1: Operator judges that a Specific Initial Event falling under Article 10 of the NEPA (leakage of reactor coolant) has occurred.	17:35 Operator judges that a Specific Initial Event falling under Article 10 of the NEPA (leakage of reactor coolant) has occurred (the operator judges that there is no leakage of reactor coolant as of 19:30			
	18:33 Units 1, 2 4: Operator judges that a Specific Initial Event falling under Article 10 of the NEPA (loss of reactor heat removal function) has occurred.	18:33 Operator judges that a Specific Initial Event falling under Article 10 of the NEPA (loss of reactor heat removal function) has occurred.	18:33 Operator judges that a Specific Initial Event falling under Article 10 of the NEPA (loss of reactor heat removal function) has occurred.		18:33 Operator judges that a Specific Initial Event falling under Article 10 of the NEPA (loss of reactor heat removal function) has occurred.
		Emergency Core Cooling System (ECCS) high pressure system: not operating ECCS low pressure system: manually shut down after actuation (at 20:00)	Emergency Core Cooling System (ECCS) high pressure system: manually shut down after actuatior ECCS low pressure system: manually shut down after actuation (at 20:00)	Emergency Core Cooling System (ECCS) high pressure system: prevention of actuation beforehanc ECCS low pressure system: prevention of actuation beforehand Emergency diesel generator (D/G) (B), (H) operating with no load Residual Heat Removal (RHR) system normal	Emergency Core Cooling System (ECCS) high pressure system: prevention of actuation beforehanc ECCS low pressure system: prevention of actuation beforehand Emergency D/G (H) operating with no load. (at 20:00]
3/12	5:22 Unit 1: Operator judges that an Event falling under Article 15 of the NEPA (loss of reactor pressure suppression function) has occurred.	5:22 Operator judges that an Event falling under Article 15 of the NEPA (loss of reactor pressure suppression function) has occurred.			
	5:32 Unit 2: Operator judges that an Event falling under Article 15 of the NEPA (loss of reactor pressure suppression function) has occurred.		5:32 Operator judges that an Event falling under Article 15 of the NEPA (loss of reactor pressure suppression function) has occurred.		
	6:07 Unit 4: Operator judges that an Event falling under Article 15 of the NEPA (loss of reactor pressure suppression function) has occurred.				6:07 Operator judges that an Event falling under Article 15 of the NEPA (loss of reactor pressure suppression function) has occurred.Operator judges that an
		7:10 Dry well (D/W) spraying started			
			7:11 Dry well (D/W) spraying started		
		8:19 Control rod (DR) 10-51 drift alarm sounded			
				9:36 RHR (B) shutdown cooling mode	
		9:43 Containment Vessel (PCV) preparation started			
			10:33 Containment Vessel (PCV) preparation started		
		10:43 Control rod (DR) 10-51 drift alarm cleared			
			10:58 PCV vent preparation completed		
					11:17 HPCS system activatec
					11:44 Containment Vessel (PCV) preparation started
					11:52 PCV vent preparation complete
				12:08 Containment Vessel (PCV) preparation started	
	12:15 Unit 3: Reactor cold shutdown			12:13 PCV vent preparation complete	
				12:15 Reactor cold shutdown	
		18:30 PCV vent preparation complete			
3/13		2:03 Control rod (DR) 10-51 drift alarm Control rod (DR) 10-51 drift alarm cleared (as of 12:00)			12:43 Control rod (DR) 10-19 drift alarm sounded
3/14	1:24 Unit 1: Cooling started using Residual Heat Removal system (RHR) (B)	1:24 Cooling started using Residual Heat Removal system (RHR) (B)			
	7:13 Unit 2: Cooling started using RHR (B)		7:13 Cooling started using Residual Heat Removal system (RHR) (B)		
			7:50 Suppression Chamber (S/C) spraying (using RHR (B)) started		
	15:42 Unit 4: Cooling started using RHR (B)				15:42 Cooling started using Residual Heat Removal system (RHR) (B)
	17:00 Unit 1: Reactor cold shutdown	17:00 Reactor cold shutdown			
	18:00 Unit 2: Reactor cold shutdown		18:00 Reactor cold shutdown		
	22:07 Operator judges that a Specific Initial Event falling under Article 10 of the NEPA (increase in radiation within site limits) has occurred. (Is assumed to be the effects of Fukushima Daiichi NPS)				
3/15	0:12 Operator judges that a Specific Initial Event falling under Article 10 of the NEPA (increase in radiation within site limits) has occurred. (Is assumed to be the effects of Fukushima Daiichi NPS)				
	7:15 Unit 4: Reactor cold shutdown				7:15 Reactor cold shutdown
3/16					
3/17				9:55 Restored to normal status from PCV vent preparation completed status	
					11:24 Restored to normal status from PCV vent preparation completed status
			17:19 Restored to normal status from PCV vent preparation completed status		
		17:22 Restored to normal status from PCV vent preparation completed status			
3/18					
3/19		15:28 RHR (B) shut down (for inspection of RHRC system pump)			
		22:14 RHR pump (B) start-up			
3/20				14:36 RHR (B) shut down (to switch to Suppression Chamber (S/C) cooling)	
				15:05 RHR pump (B) start-up S/C cooling started	

	Overall	Unit 1	Unit 2	Unit 3	Unit 4
		Status before earthquake: Under operation	Status before earthquake: Under operation	Status before earthquake: Under operation	Status before earthquake: Under operation
3/21					
3/22					
3/23					
3/24					
3/25					
3/26					
3/27				10:50 RHR (B) shut down Currently switching RHR operation mode	
3/28					
3/29					10:52 RHR pump (B) shut down (for inspection of intake)
					14:00 RHR pump (B) start-up
3/30			10:25 RHR (B) shut down (for installation of temporary power system)		
		10:34 RHR (B) shut down (for installation of temporary power system)			
			14:04 RHR (B) start-up		
		14:30 Acquisition of RHR (B) back-up power (emergency power) RHR (B) start-up			
		17:56 Detection of smoke occurrence from power board located in 1F of turbine			
		18:13 After shutdown of power supply, disappearance of smoke was confirmed			
		19:15 It was concluded that smoke occurrence was caused by abnormal condition of power board and therefore not by the fire			
3/31					14:35 RHR (B) shut down (reactor shutdown cooling mode (SHC) + Suppression Chamber cooling mode (S/C)→ SHC + S/C + Fuel Pool Cooling mode (FPC)
4/1					15:36 RHR (B) activated
		13:43 RHR pump (B) shut down (for inspection of intake)			
		15:07 RHR pump (B) start-up			
4/2					
4/3					
4/4					
4/5					
4/6					
4/7					
4/8					
4/9					
4/10					
4/11					
4/12					
4/13					
4/14					
4/15					
4/16					
4/17					
4/18					
4/19					
4/20					
4/21					
4/22					
4/23					
4/24					
4/25					
4/26					
4/27					10:20 RHR (B) shut down (for switching of power system)
					17:41 RHR (B) activated
4/28					
4/29					
4/30		9:10 RHR (B) shut down (for inspection of intake waterway)			
		12:54 RHR (B) activated			
5/1					
5/2					
5/3					
5/4					
5/5					
5/6					
5/7					
5/8					
5/9				9:51 RHR (B) shut down (for inspection of intake waterway)	
				14:46 RHR (B) activated	
5/10					
5/11					
5/12			9:36 RHR (B) shut down (for inspection of intake waterway		
			12:13 RHR (B) activated		
5/13					
5/14					
5/15					
5/16					

6. Situation at Other Nuclear Power Stations

(1) Higashidori Nuclear Power Station

Unit 1 was under periodic inspection at the time of earthquake occurrence on March 11, and all the fuel in the reactor core had been taken out and placed into the spent fuel pool.

Since all of the three lines of off-site power supply had stopped due to the earthquake, off-site power supply was lost and the emergency DG (A) (the emergency DG (B) was under inspection) fed power to the emergency generating line.

After the off-site power supply was lost due to the Miyagi Earthquake occurred on April 7, emergency DGs started, and the power was securely restored. Following this, although off-site power supply was restored, the emergency DGs stopped operation in an incident, and all the emergency DGs became inoperable.

(2)Onagawa Nuclear Power Station

Units 1 and 3 were under constant rated thermal power operation at the time the earthquake occurred on March 11 and Unit 2 was under reactor start-up operation. Four out of the five lines of off-site power supply stopped as a result of the earthquake, but off-site power supply was maintained through the continued operation of one power line.

The reactor at Unit 1 tripped at 14:46 due to seismic acceleration high, and the emergency DGs (A) and (B) started automatically. Since the start-up transformer stopped due to an earth fault/ short-circuit in the high-voltage metal-clad switchgear caused by the earthquake at 14:55, this led to a loss of power supply in the station. The emergency DGs (A) and (B) fed power to the emergency generating line.

Since all feed water/condensate system pumps stopped due to loss of normal power sources, the RCIC fed water to the reactor and the Control Rod Hydraulic System fed water after reactor depressurization. Since the condenser was unavailable due to the stoppage of the circulating water pump, the MSIV was totally closed, the cooling and depressurization operations of the nuclear reactor were performed by the RHR and the SRV, and the reactor reached a state of cold shutdown with a reactor coolant temperature of less than 100°C at 0:57 on March 12. Since the reactor was in start-up operation, Unit 2 shifted promptly to cold shutdown because the reactor had stopped automatically at 14:46 as a result of the great seismic acceleration. The emergency DGs (A), (B) and (H) automatically started due to issuance of a field failure signal from the generator at 14:47. But the three emergency DGs remained in a stand-by state since off-site power source was secured.

Subsequently, because the reactor auxiliary component cooling water system B pump, reactor cooling seawater system (RSW) B pump, and the high-pressure core spray auxiliary component cooling system pumps were inundated as a result of the tsunami and lost functions, the emergency DGs (B) and (H) tripped. However, because the component cooling water system A pump was intact, there was no influence on the reactor's cooling function.

The reactor at Unit 3 tripped at 14:46 due to seismic acceleration high. The off-site power source was maintained but the turbine component cooling seawater pump was stopped due to inundation by tsunami. All the feeding water/condenser pumps were then manually stopped and the RCIC fed water to the reactor. In addition, the control rod hydraulic system and condensate water makeup system fed water to the reactor after the reactor depressurization.

Since the condenser was unavailable due to the stoppage of all circulating water pumps resulted from undertow of the tsunami, the MSIV was totally closed and cooling and depressurization operations of the reactor were performed by the RHR and the SRV, leading the reactor to a state of cold shutdown with a reactor coolant temperature of less than 100°C at 1:17 on March 12.

(3) The Tokai Daini Power Station

The Tokai-Daini Power Station was under constant rated thermal power operation at the time of earthquake occurrence on March 11. At 14:48 on the same day, the reactor tripped due to turbine trip caused by turbine shaft bearing vibration large signal due to the earthquake. Immediately after the occurrence of the earthquake, all three off-site power source systems were lost. However, the power supply to the equipment for emergency use was secured by the activation of three emergency DGs.

The HPCS and the RCIC started automatically in response to the fluctuation of the water level immediately after the trip of the reactor, and the water level of the reactor was kept at a normal level. The water level of the reactor was then maintained by the RCIC, and the pressure of the reactor was controlled by the SRV. Moreover, RHRs A and B were manually started in order to cool the S/C for decay heat removal after the nuclear reactor tripped.

Subsequently, the DG2C seawater pump for emergency use tripped as a consequence of tsunami and the DG2C pump became inoperable. But the remaining two DGs secured power supply to the emergency equipment, and the cooling of the S/C was maintained by residual heat removal system RHR (B).

One off-site power supply system was restored at 19:37 on March 13, and the nuclear reactor reached a state of cold shutdown with a coolant temperature of less than 100°C at 0:40 on March 15.

Figure IV-6-1 Map showing the Location of Nuclear Power Stations

7. Evaluation of accident consequences

In the wake of the occurrence of loss of functions in many facilities due to an extensive earthquake and a tsunami, items to be improved in the future will be identified by evaluating a variety of aspects.

(1) Causes of the accident at the Fukushima-Daiichi Nuclear Power Station

Units 1, 2 and 3 of the Fukushima-Daiichi Nuclear Power Station lost all off-site power sources immediately after the earthquake. But the emergency DGs started operation and secured on-site power supply, maintaining the normal operation of cooling systems of the RCIC and the IC.

Then, due to an attack of tsunami, the emergency DGs and the metal-clad switchgear were inundated and covered with water, resulting in loss of all AC power. The seawater cooling system was also covered with water and the function to transport heat to the sea, which is the ultimate heat sink, was lost.

Since all AC power was lost (dc power was also lost for unit 1), the IC of Unit 1 became inoperable. In addition, reactor core cooling of Units 2 and 3 also stopped following the depletion of dc power (in the form of a storage battery) and the halt of cooling water supply. Damage to the reactor began due to the lowering of the water level in the reactor core, resulting in eventual core melt.

Despite the fact that the emergency DGs and the seawater cooling system of the Fukushima-Dai-ni Nuclear Power Station were hit by the earthquake and the tsunami, continued power supply from the off-site power source maintained the water level of the reactor. Additionally, since monitoring of plant conditions was also possible, plant management was possible to control the reactor, and high temperature shutdown could be maintained in a stable way. Meanwhile, recovery efforts, such as the exchange of the electric motors of the seawater cooling system that was covered with water due to tsunami, were conducted, and the system reached a state of cold shutdown within a number of days. Similarly, the Onagawa Nuclear Power Station and the

Tokai-Daini Power Station, also hit by the earthquake and the tsunami, reached cold shutdown states since off-site or on-site power supplies were secured.

From these facts, the direct cause of the accident in Units 1, 2 and 3 of the Fukushima-Daiichi Nuclear Power Station is thought to have been the loss of all power sources, which led to the failure of cooling the reactor core, then damage to the reactor core, resulting in a core melt.

In the light of these facts, it appears that, in cases of complete loss of ac power and losses of seawater and water cooling functions, a power supply necessary for operating the cooling systems, such as the RCIC and a water supply necessary for reactor core cooling, are indispensable. Extensive measures such as prior securing of essential machines and materials and the preparation of response plans such as manuals to be used in case of emergency, were necessary for emergency measures.

(2) Evaluation from the standpoint of preventing accidents: Countermeasures for earthquakes and tsunamis

The accident was caused by the attack of an earthquake and a tsunami.
At present, damage caused by the earthquake was concerned with off-site power supply systems. Damage to safety-important systems and components was not confirmed, and the plant was in a manageable condition until the arrival of the tsunami. However, detailed nature of the destruction has not been clear and remains to be seen. In addition, it has been verified that the acceleration response spectrum of the seismic ground motion observed on the basement of the reactor building of the Fukushima-Daiichi Nuclear Power Station exceeds the acceleration response spectrum at the same location relative to standard design ground motion Ss settled on based on the Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities in a part of the oscillation band. Evaluation of seismic safety by seismic response analysis for the reactor buildings and major safety-important systems is necessary in the future (units 2 and 4 will be evaluated by the middle of June and units 1 and 3 by the end of July).

As for off-site power supply systems, each unit was connected to the power system by more than one power line in accordance with Guideline 48(G48) of Regulatory Guide for Reviewing Safety Design of Light Water Nuclear Power Reactor Facilities (Electrical Systems), and the redundancy requirement was satisfied. However, the point of the Guideline is to secure a reliable off-site power supply, although this is not clearly required in the Guideline.

For instance, the following events occurred in the accident:

- Actuation of protective devices due to collapse and short-circuits of transformers at the major substations connected to the Fukushima-Daiichi Nuclear Power Station.
- The switching stations (Units 3 and 4 and Units 5 and 6) where the off-site power supply is received were damaged by the tsunami. The power receiving circuit breaker was destroyed in Units 1 and 2 due to the earthquake.

Considering these facts, the facilities were not sufficiently prepared in the context of securing resistance to earthquakes, independence, and reducing the likelihood of common cause failure.

As for tsunami, the design tsunami height at Fukushima-Daiichi NPS was O.P. + 5.7 m. But experts estimated that tsunami of 10 m or higher attacked, though no record of tide gauge readings was available as described in III 2(1). Consequently, water tightness of buildings and other facilities in some plants was insufficient for tsunami of such height, and this resulted in total loss of power, including DC power supply, which was outside the scope of design. The design tsunami height at Fukushima-Daini NPS was estimated to be O.P. + 5.2 m. As described in III 2(2), neither record of tide gauge readings nor the height estimated by experts is available, and it is not sure how high the tsunami was. Nevertheless, it is considered that the actual tsunami height exceeded the design tsunami height.

Documented procedures did not assume ingress of tsunami, but specified only operation of stopping circulating water pumps used for cooling condensers as measures against undertow. The PSA referred to in accident management survey of these units did not take into account long time loss of functions of emergency DGs and loss of ultimate heat sink, which could be caused by tsunami.

Just like other equipment, emergency DGs in most units became inoperable due to loss of the emergency DG main units, sea water pumps for cooling, and the metal-clad switchgear. On the other hand, Units 5 and 6 of Fukushima-Daiichi NPS kept operating after tsunami, and kept supplying AC power required for removing residual heat at both Units 5 and 6 through a tie line. This is because the metal-clad switchgear, and the air-cooled emergency DG(B) for Unit 6, which is installed in the emergency DG building and requires no sea water pump for cooling, escaped inundation. This indicates the importance of assuring not only redundancy but also diversity of equipment of especially high importance for safety, from the aspects of arrangements and operation methods.

It is known that Units 2 and 4 of Fukushima-Daiichi NPS are equipped with air-cooled emergency DGs in the common pool building but these units became inoperable as the metal-clad switchgear connecting the DG to an emergency bus line was inundated. This indicates that it is very important to pay close attention to securing of system diversity to eliminate common cause failures.

(3) Main factors that developed the events of accident

This accident resulted in serious core damage in Units 1 through 3 of Fukushima-Daiichi NPS. But Units 5 and 6 of Fukushima-Daiichi NPS and Units 1 through 4 of Fukushima-Daini NPS succeeded in cold shutdown without causing core damage. If any disturbance occurs in a plant during power operation, such as an event of loss of off-site power supply, the following three functions are required to shift the plant into the cold shutdown state; reactor sub-criticality maintenance, core cooling, and removal of decay heat from PCV. Figures IV-7-1 through IV-7-3 show function event trees indicating event sequences these plants followed. These function event trees develop event sequences headed by main functions, such as reactor sub-criticality maintenance, core cooling, removal of decay heat from PCV, AC power, water injection to PCV, and hydrogen control, which were caused by the earthquake and accompanying tsunami and are considered to have seriously affected the progress of events before and after core damage. Estimated event sequences of this accident are shown by thick lines. Based on the above-mentioned event sequences, whether or not a unit suffered from core damage in this accident was mainly estimated by the following events:

a) AC power was not recovered early because:

- it was impossible to interchange electricity because of simultaneous loss of AC power for neighboring units,
- metal-clad switchgear and other accessory equipment were inundated due to tsunami, and
- off-site power supply and emergency DG was not recovered early.

b) Due to accident management carried out at the time of total AC power loss, core cooling was maintained for some time but was not sustained up until recovery of power supply.

c) The tsunami caused loss of functions of the system of transporting heat to the sea, which is the ultimate heat sink.

d) There was no sufficient means to substitute for the function of removing decay heat from PCV.

Next we evaluate whether or not regulatory guides established by the NSC Japan specify safety assurance measures against events that occurred or are estimated to occur in Fukushima-Daiichi NPS and Fukushima-Daini NPS as design requirements for nuclear power stations. If regulatory guides specify such design requirements, we further evaluate whether or not each nuclear power station was designed to satisfy the requirements. We also evaluate whether PSA took these events into consideration and whether or not the accident management, which had been developed by TEPCO under the accident management guidelines, functioned effectively.

1) Tohoku District - Off the Pacific Ocean Earthquake.

It has been confirmed that acceleration response spectra of seismic ground motions caused by this earthquake and observed in the basement of reactor buildings of Fukushima-Daiichi NPS exceeded the acceleration response spectrum of the design basis earthquake ground Motion (DBEGM) Ss in the basement determined under the Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities. However, damage caused by the earthquake was found in the off-site power supply system and no serious damage was found in safety-important systems and components in nuclear facilities. They were kept under control until the tsunami arrived, but detailed damage states are still unknown, requiring further investigations.

Back-check of seismic safety is being carried out for existing nuclear power reactors. Tsunami assessment was not covered in the interim reports submitted by TEPCO regarding Units 3 and 5 of Fukushima-Daiichi NPS and Unit 4 of Fukushima-Daini NPS. Reviews of tsunami were to be carried out later, though government agencies finished reviews of the earthquake. Assessment of residual risks was being carried out by licensees.

2) Loss of off-site power supply

Guideline 48 (Electrical Systems) of the Regulatory Guide for Reviewing Safety Design of Light Water Nuclear Power Reactor Facilities specifies that the external power system shall be connected to the electric power system with two or more power transmission lines. However, it did not give sufficient consideration on measures to reduce possibilities of common cause failures, for example, by using the same pylon for both lines.

On the contrary, events of loss of off-site power supply are taken as design basis events in the Regulatory Guide for Reviewing Safety Assessment of Light Water Nuclear Power Reactor Facilities. TEPCO installed at least two emergency DG for each unit, having a sufficient capacity to activate required auxiliary systems.

In the internal event PSA and the earthquake PSA, loss of off-site power supply is assessed as one of initiating events and induced events. The earthquake PSA did not sufficiently examine measures to prevent loss of off-site power supply in order to reduce occurrence of total AC power loss, with the knowledge that total AC power loss is a critical event leading to core damage.

For example, sufficient consideration was not given to the following actions required for improving reliability of off-site power supply and auxiliary power system.

- Assessment to assure reliability of supplying power to nuclear power stations if a main substation stops supply
- Measures to improve reliability by connecting external power transmission lines to units at the site
- Seismic measures for external power lines (power transmission lines)
- Tsunami countermeasures for power receiving equipment in switching stations

Considerations should also have been given to measures to prevent metal-clad switchgear, storage batteries, and other power supply equipment from being inundated.

An assessment technique for tsunami accompanying earthquake (tsunami PSA) is under development now.

3) Tsunami

TEPCO voluntarily assessed the design tsunami height based on the largest tsunami wave source in the past by using the Tsunami Assessment Method established in 2002 by the Japan Society of Civil Engineers, and took such measures as raising the installation level of pumps and making buildings and other facilities water-tight, based on the assessment results. Nevertheless, the tsunami accompanying the earthquake was higher than the design tsunami height estimated by TEPCO. The design tsunami height at Fukushima-Daiichi NPS was estimated to be O.P. + 5.7 m based on the above-mentioned tsunami assessment method. But experts estimated that tsunami of 10 m or higher arrived, though no record of tide gauge readings was available as described in III 2(1). The design tsunami height at Fukushima-Daini NPS was estimated to be O.P. + 5.2 m. As described in III 2(2), neither record of tide gauge readings nor value estimated by experts was available, and it is not sure how high the tsunami was. Nevertheless, it is considered that the actual tsunami height exceeded the design tsunami height. Documented procedures did not anticipate the ingress of tsunami, but specified only operation of stopping circulating water pumps used for cooling condensers as measures against undertow.

4) Loss of Total AC Power Supply

In the PSA referenced in deriving the level of the accident management system that has been established to date, no consideration has been given to the long-term functional loss of the emergency DGs and loss of the power supply interchange capability between adjacent nuclear reactors.

For the PSA concerning tsunami, assessment methods are under development at present, and trial assessments have been carried out as part of the method development. Such assessments recognized the importance of the above-mentioned functional losses including consideration of simultaneous functional losses of the emergency DG, metal-clad switchgear, etc. that are caused by tsunami, but never leading to reflection in the accident management system. In other words, the analysis of the threat that could cause such a situation was insufficient in considering measures against the total loss of the AC power supply.

In addition, as part of accident management, facilities are provided that ensure interchange of the power supply for the working-use AC power supply (6.9 kV) and low-voltage AC power supply (480 V) between adjacent nuclear reactor facilities, and the documented procedures for the facilities were specified. For Unit 1 through Unit 4 at Fukushima-Daiichi NPS, however, this accident management system did not function effectively since the adjacent units were also subject to the total loss of the AC power supply.

5) Securement of Alternative AC Power Supply (Power Supply Vehicle, etc.)

In the PSA referenced in deriving the accident management system that has been established to date, it was regarded that the probability leading to a serious accident would be sufficiently reduced by giving consideration to the power supply interchange, recovery of the off-site power supply and the emergency DG. For this reason, the securement of a power supply vehicle, etc. was not considered as part of accident management.

This time, as an ad hoc applicable operation, a power supply vehicle was arranged to be carried in the site. But, this could not be utilized smoothly due to the difficult access caused by defects, etc., of the heavy machinery for removing rubble and debris generated by the influence of the tsunami, and water damage of a metal-clad switchgear that was also caused by the tsunami.

6) Securement of Alternative DC Power Supply (Temporary Storage Battery, etc.)

In the PSA referenced in deriving the accident management system that has been established to date, a mechanical failure of a storage battery has been considered, and a period of time during which the DC power supply must function has been defined as 8 hours in the event tree of the off-site power supply loss event. In consideration of the presence or absence of power supply recovery within 8 hours, if the off-site power supply fails to recover during this period, it is assessed that the RCIC system could not continue running. As a result, it was assessed that the off-site power supply might be more likely to recover, and loss of the DC power supply facilities would not be an event having a significant influence on the risk. Therefore, the preparation of temporary storage batteries was not a matter to be dealt with.

In this accident, arrangements were made for carrying the storage batteries in the site. But, since carry-in works were difficult and such work was performed in the dark due to the impact of the earthquake and tsunami disasters, difficulties arose in the recovery of the operation of the equipment following the accident, and the operation of the instrumentation system for recording plant parameters. Furthermore, the plant parameters that serve as important data in developing preventive measures after termination of the accident could not be sufficiently saved.

7) Measures Against Functional Loss of Seawater Pump (Loss of Ultimate Heat Sink)

In the PSA referenced in deriving the accident management system that has been established to date, the functional loss of a seawater pump has been considered in a fault tree related to loss of the residual heat removal capability, but no consideration has been given to the simultaneous functional losses of all the seawater pumps due to tsunami.

For the PSA concerning tsunami, assessment methods are under development at present, and trial assessments have been carried out as part of the method development. Such assessments indicated that the risk sensitivity of an event in which simultaneous functional losses of all the seawater pumps are generated due to tsunami was high. However, being a result of trial assessment, this was not shared widely among those involved, which never brought the importance of this accident management to their attention.

In this accident, as an ad hoc applicable operation, the measures were taken for replacing the seawater pumps suffering from functional losses with temporary seawater pumps, but this was not intended to be provided as part of the accident management.

8) PCV Vent

The PCV venting facilities were put in place as part of accident management before and after damage of the core. In the case of this accident, venting was performed after damage of the core due to depressurization of the reactors and the delay of water injection. Because of the total loss of the AC power supply, motor driven valves had to be opened manually for the PCV venting operations. For operation of pneumatically-actuated valves, the pressurized air required for operating such valves could not be assured, and thus a temporary air compressor had to be mounted to assure the pressurized air. For such reasons, the facilities could not be operated in accordance with the documented operation procedures for severe accidents, which caused the PCV venting operation to be delayed.

9) Alternative Water Injection (Depressurization of Reactor Vessel, Alternative Water Injection Line)

The systems for alternative water injection, including depressurization operations of the reactors and the subsequent utilization of fire pumps, were put in place as part of the accident management. In this accident, depressurization and the subsequent cooling operations of the reactors were carried out using those systems. Due to the total loss of AC power supply, however, difficulties arose in assuring the air pressure for driving the SRV necessary for depressurization and maintaining the excitation of the electromagnetic valves in the air supply line, resulting in time-consuming depressurization operations. Alternative water injection into the reactors, using heavy machinery such as fire engines, was not considered as part of the accident management, but in this accident, as an ad hoc applicable operation, water injection into the reactor using a chemical fire engine that was present at the site was attempted. Nevertheless, since the reactor pressure was higher than the pump discharge pressure of the chemical fire engine, injection of freshwater into the reactor was not available in a few cases.

10) Alternative Water Injection (Water Sources)

As water sources used for alternative water injection, a condensate storage tank and a filtrate tank were considered as part of the accident management, and those tanks were practically utilized. As water sources utilized by a fire engine, a fire-prevention storage tank and seawater were used, but work was required to line up the water injection line.

11) Measures against Hydrogen Explosion at Reactor Building

The Guideline 33 (System for Controlling Containment Facility Atmosphere) of the Regulatory Guide for Reviewing Safety Design of

Light Water Nuclear Power Reactor Facilities requires the provision of functions capable of controlling the atmosphere of the containment facilities so as to ensure safety against assumed events. To meet this requirement, the FCS was installed at BWR plants along with inactivation inside the PCV. No requirements are specified for measures against hydrogen explosion at the reactor building. Also, the Common Confabulation Interim Report which deals with "beyond design basis events" does not describe such requirements.

The PSA includes a scenario in which hydrogen arising from meta-water reaction following core damage, and from the radiolysis of water, leaks from the PCV into the reactor building filled with the normal air resulting in burning inside the reactor building in a severe accident, but this is an assessment from a viewpoint of the integrity of the PCV, and no discussions were made for damage to the reactor building.
It was expected that the FCS installed to cope with the design basis events would be available under the severe accident environment as well. But, since power supplies were not available this time, this capability was not utilized.

For measures against a hydrogen explosion at the reactor building, no consideration was given to the facilities or the documented procedures.

12) Alternative Water Injection into Spent Fuel Pool and Cooling

The Guideline 49 (Fuel Storage Facilities and Fuel Handling Facilities) of the Regulatory Guide for Reviewing Safety Design of Light Water Nuclear Power Reactor Facilities requires a system capable of removing the decay heat and transfer it to the sea, the ultimate heat sink, in the spent fuel pool. However, there are no requirements for the capability to perform alternative water injection in preparation for the case of loss of ultimate heat sink. As it is considered that the risk presented by the spent fuel pool is sufficiently smaller compared to the reactor, there are fewer PSA implementation examples for the spent fuel pool. In the PSR at Unit 1 of Fukushima-Daiichi NPS that was published in March 2010, the PSA was implemented for the spent fuel pool when all of the fuel rods in the reactor were taken out into the spent fuel pool. But, since the risk was thought to be small, no consideration was given to the facilities or documented procedures related to the injection of seawater into the spent fuel pool.

13) Water Injection into D/W for Cooling Reactor or PCV

Further, in addition to installing alternative capabilities, as part of the accident management for water injection into the space of a foundation (pedestal) supporting the RPV in the D/W, TEPCO put the capability to perform water injection using the same piping as the alternative spray capability in place.

The PCV pressure increased in Unit 3 during this time. For depressurization, spray to the S/C was used, and it was confirmed that the accident management system functioned properly. In Units 1 and 2, the PCV vent was superseded, and thus the PCV spray (D/W and S/C) was not performed.

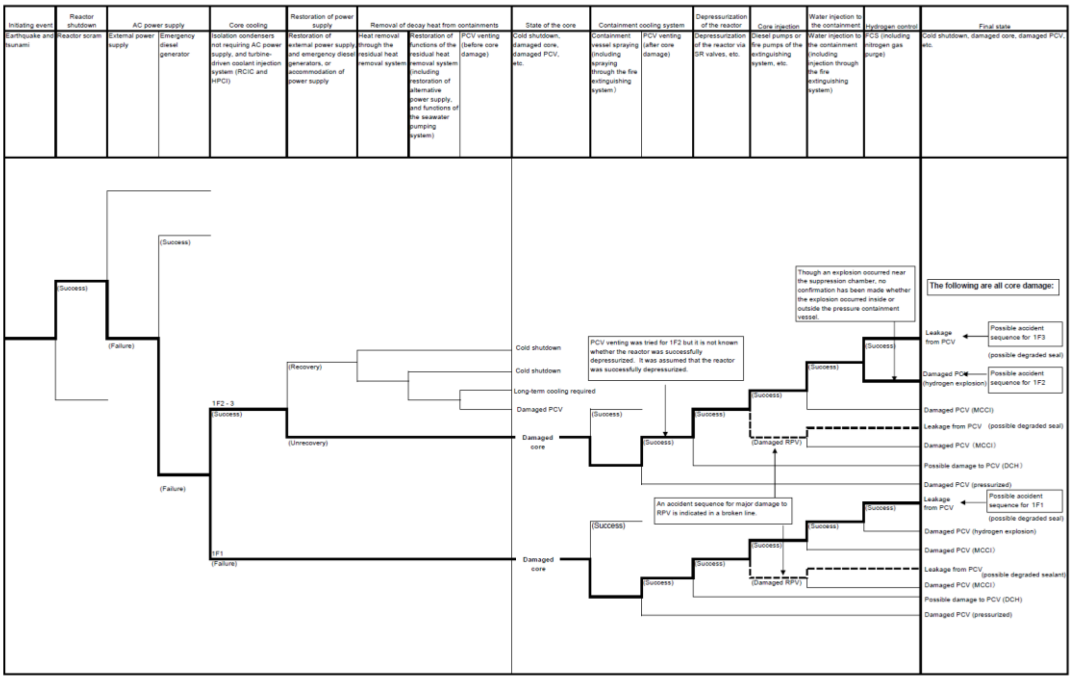


Figure IV. 7-1: Function event tree for units 1, 2 and 3 of Fukushima-Daiichi Nuclear Power Station

Figure IV-7-1 Function Event Tree of Unit 1 to Unit 3 at Fukushima-Dai-ichi NPS

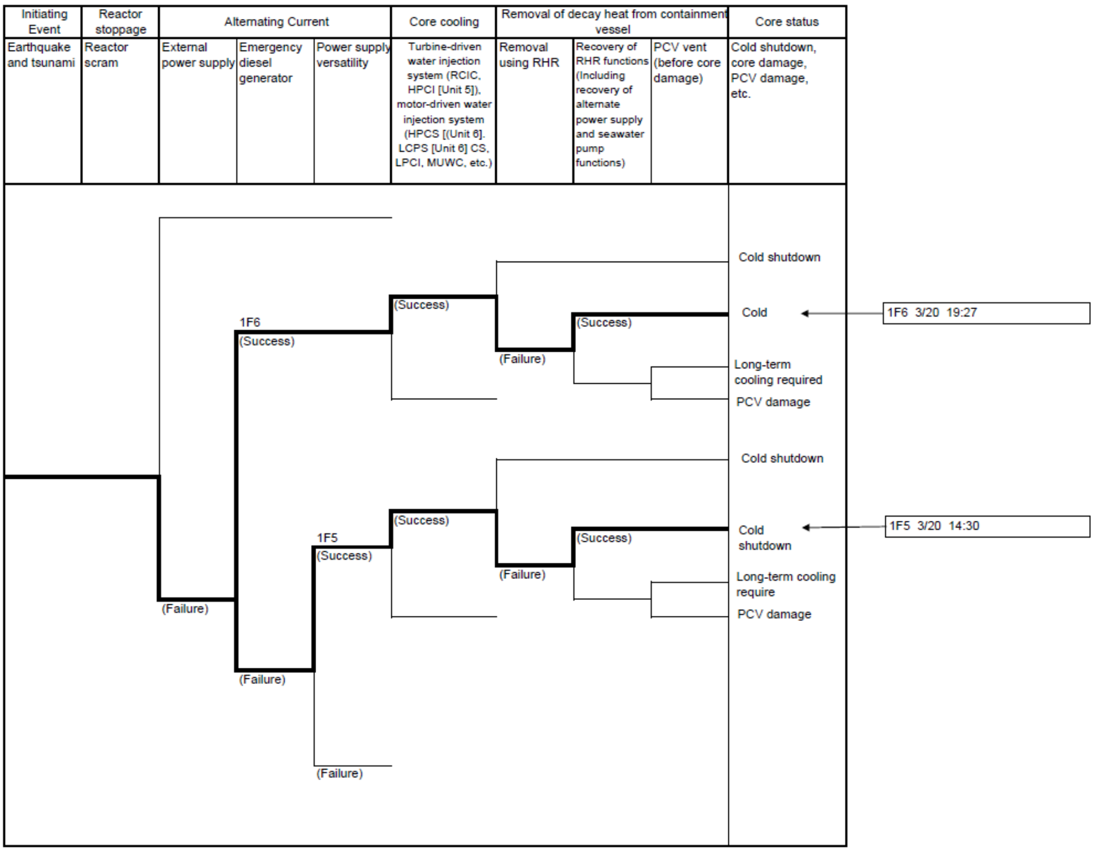


Figure IV-7-2 Function Event Tree of Unit 5 and Unit 6 at Fukushima-Dai-ichi NPS

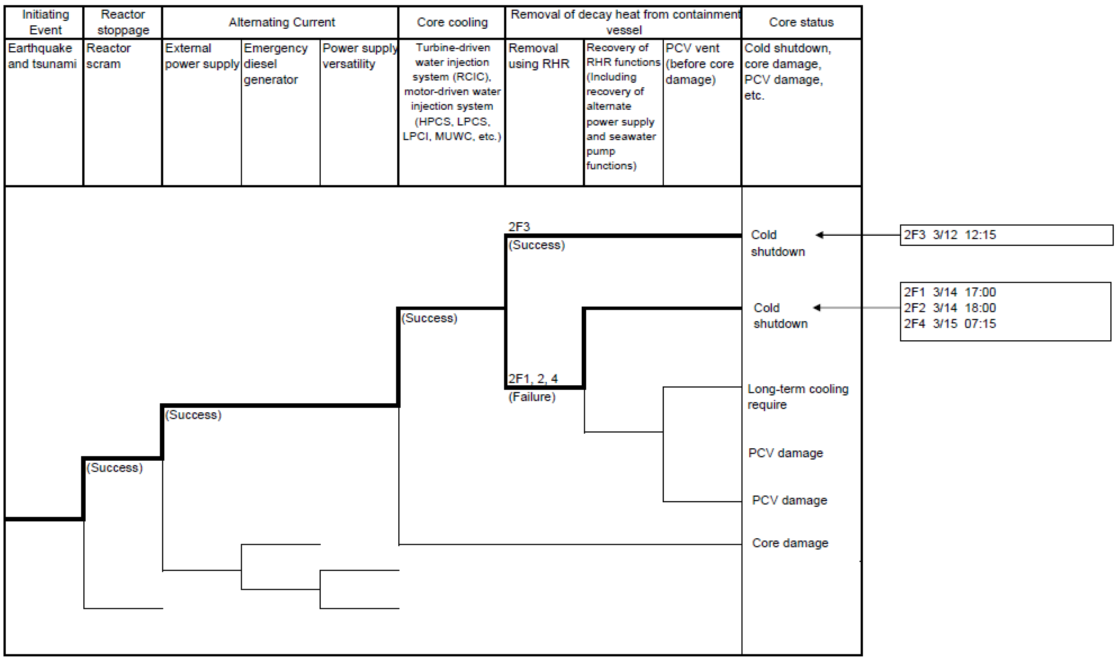


Figure IV-7-3 Function Event Tree of Unit 1 to Unit 4 at Fukushima-Dai-ni NPS

(4) Comprehensive Assessment

1) Conception for tsunami in design stage.

Tsunami Evaluation Group, Nuclear Engineering Committee, Japan Society of Civil Engineers announced in 2002 the "Tsunami Assessment Method for Nuclear Power Plants in Japan"[IV7-1] which established a deterministic tsunami water level evaluation method, triggered by the Hokkaido south-west offshore earthquake which took place in 1993. This characterizes, in setting up design basis tsunami, a consideration of tsunami of which the occurrence in the past was accurately confirmed, as well as a requirement of a method to address uncertainty (variation), accompanied during the course of setting a proper method. Based on this, each licensee voluntarily reviewed the design basis, and the Nuclear Power governmental agency was not involved in this review.

Incidentally, the Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities finalized in 2006 specifies in "8. Consideration for the event accompanied by an earthquake" that "During the service period of the facilities, safety features in the facilities might not be significantly affected even by such a tsunami that could likely to occur on very rare occasions," and the guideline asks for proper design for such a assumed tsunami.

The massive tsunami of last March made it clear that an earthquake or tsunami could cause multiple common cause failures of equipment of safety significance in a nuclear power plant.

For that reason, considering the risk that may be caused by an attack on facilities by tsunami beyond assumed design basis tsunami, from now on, it is required to make efforts to reduce the risk to a level as low as reasonably attainable.

On the other hand, Tsunami Evaluation Group, Nuclear Engineering Committee, Japan Society of Civil Engineers has initiated compiling a detailed work for "a method to analyze tsunami hazard using probability theory (Draft), while recognizing that a sufficient safety level in a nuclear power plant facility cannot always be attained against an earthquake or tsunami which could cause multiple common cause failures, even after providing design measures against a presumed earthquake or tsunami."

Meantime, the Nuclear and Industrial Safety Agency (NISA) conducted back checks based on the most recent findings for all of the existing nuclear power plants under the Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities revised based on the information given by the Nuclear Safety Commission. In Fukushima-Daiichi NPSs Units 3 and 5, an interim report was prepared which has been reviewed by NISA. However, any evaluation relating to tsunami and any remaining risk were left to be made later. From this it is pointed out that the persons in charge had little understanding of designs against tsunami, and that a deterministic approach will never guarantee that a tsunami exceeding the predicted strength will not occur. But, for the responsibility of attaining the targeted safety level (safety goal), they are required to prepare proper design measures and accident management taking the (target) safety level into consideration after analyzing the characteristics of the plant against the attack of an unexpected tsunami exceeding the predicted safety level, .

Background shows that the nuclear regulatory agency supposedly did not have an attitude to translate the standard of "constitute no hindrance to disaster prevention" which was expected in society as a standard of judgment into "Target Safety Level" which was commonly owed to society, nor an attitude to establish a dialogue with society over whether it is adequate or not.

2) Guidelines for accident management

Since the guidelines for accident management were established by the Nuclear Safety Commission in 1992, accident management was prepared at each nuclear power plant over ten years.

Such accident management based on PSA and an analysis of scenarios involving internal events caused by equipment failure and human error conducted in 80's. This guideline was highlighted to emphasize the effectiveness of introducing accident management, and failed to focus on the environmental conditions so as to make accident management effective.

So, the nuclear regulatory agency should have mandated the licensees that the results of PSA in relation to new findings of common cause failures and external events be referenced and training under realistic conditions be periodically implemented at the stage on which equipment and materials provided for accident management are arranged for training. Further, this guideline also should have been revised taking the experience of such efforts and the results of earthquake PSA and tsunami PSA into consideration.

However, accident management was considered to be conducted independently by each licensee and did not require a PDCA system for introducing new findings or improvements. Also, the Nuclear Safety Commission has never reviewed the accident management system.

Taking into account the importance of the role that accident management has for achieving the safety goal, the nuclear regulatory agency should have constantly reviewed the accident management guidelines by introducing new findings for effective operation.

The Fukushima-Daiichi Nuclear Power Station attacked by a large tsunami has six reactor facilities at one site and all the reactors have suffered accidents. Despite the multi-plant attributes, the accident management guidelines did not address these attributes and the licensees did not train for these attributes.

3) Diversity to important systems in safety: Preparation for commonly caused faults

The accident this time was characterized by having a lot of electrical machinery and appliances in the significant safety systems, including a metal-clad switchgear for connecting to an emergency DG and an emergency bus bar, inundated and becoming useless after the arrival of the tsunami, which resulted in the loss of final heat sink. Further, some plants lost their direct-current power source, leading to severe accidents. Namely, water supply to the nuclear reactor by using a fire fighting system maintained to use in good condition for accident management, or PVC vents, did not function immediately due to malfunctions of a pump, a solenoid valve, an air operated valve (AO valve), etc.

On the other hand, a part of the steam-driven system, such as the RCIC continued to cool the reactor core beyond eight hours and only until the battery was exhausted. An emergency DG installed at a higher level worked satisfactorily since the body of the emergency DG and its power source were free from submersion.

Beyond Design Basis Accidents (BDBE) are likely to be due to multiple failures of important facilities caused by earthquake, tsunami, fire, etc. Therefore, in order to limit the occurrence of Beyond Design Basis Accidents (BDBE) and the influences exerted by it, some good ideas are essential to convert or modify a plant to comply with such severe conditions caused by such external events. Also for the preparation of such accident management to work effectively under such severe conditions, some method to avoid simultaneously occurring malfunctions of the facilities is needed.

Therefore, the Nuclear Power governmental agency should have emphasized the necessity of insuring a diversity of facility installation sites, power sources and support systems, from the view point of minimizing the possibility of common cause failures together with water, vibration and sufficient protection against fire. Also, for the accident management of licensees to install a nuclear power plant, training should have been required to ensure that accident management should work effectively under the severe conditions in mind, and reviewing its effectiveness should also have been required.

4) Design pressure of PCV and vent system.

As the loss of PCV functions due to an accident will provide a direct adverse effect on the surrounding environment, the soundness of the PVC should be maintained even when multiple malfunctions, such as those in the Fukushima-Daiichi power plant, occurs. For this purpose designed temperatures and pressures should be determined in consideration of the occurrence of core damage. At the same time a vent system to be free from damage by emergent excess pressure should be kept in good condition as part of accident management. Judging from the accident this time, it should have been assumed that the radiation level adjacent to the PCV would increase after the core was damaged.

From this the vent system should have been remotely controllable even when AC power source was lost. The PCV vent system should have been equipped with a filter with sufficient radiation decontamination capability. Since temperature and pressure are possibly routed, in the occurrence of core damage, through a system connecting to the PCV vent line, the common use of the system should be minimized as much as possible so as to avoid the leakage of hydrogen or radioactive substances from the building. Further, special attention to design allowances in pressurized equipment for continuous parts, or apparatus sealed by packing, should have been taken so that no leakage would occur in the liquid layers even when the designed pressure is exceeded.

5) Hydrogen explosion in nuclear reactor building.

In the accident this time, a hydrogen explosion in the nuclear reactor building had greatly impeded actions to resolve the situation. In the BWR plant as a countermeasure to the hydrogen explosion, all eyes were focused on activation and installation of the FCS in the PCV. This was considered effective even after the core was damaged. This time the generation of hydrogen was contained to some extent, but while paying attention to the loss of the power source and fixing it, hydrogen leaked from a pressurized PVC exploded in Fukushima-Daiichi NPS 1 and 3. In Fukushima-Daiichi Nuclear power plant No.4, an explosion is supposed to have occurred due to an inflow of hydrogen from the PCV vent in Fukushima-Daiichi Nuclear power plant No.3.

From this, for accident management after the occurrence of core damage, ventilation facilities to prevent an explosion in the nuclear reactor building due to hydrogen leakage from the PCV, and some measures of equipment to prevent the collection of hydrogen should have been provided, including an independently-driven power source.

6) Risks relating to the spent fuel pool

In this accident, the cooling function for the spent fuel pool was lost due to a loss of power supply. Notably, because of reactor core internal shroud replacement work at Fukushima Daiichi Nuclear Power Station, Unit 4, there was one reactor core's worth of fuel with relatively high levels of decay heat being stored. As well as dealing with the accident in terms of the reactor core, it also became necessary to quickly carry out measures to introduce an alternative cooling function for the spent fuel pool.

However, as the embedded radioactive inventory is low compared to the reactor core, even though the radioactivity containment function is inferior to that of the reactor core, a definitive decision was made that there was only a small possibility of risks originating from the spent fuel pool, and as such, no particular accident management was considered.

7) PSRs and PSAs

Since 1992, PSRs, that evaluate the overall safety of existing nuclear plants based on the latest technological knowledge, have been carried out as a voluntary security measure by the licensees approximately every 10 years. One of the items in the PSR is to carry out a PSA, and to come up with measures to deal with the results of the assessment. Reviews on the appropriateness of these actions have been carried out by the nuclear regulatory authorities.

However, during the review of the PSR carried out in 2003, other requirements were made operational safety program requirements based on the Reactor Regulation Act, while the PSA remained at the discretion of the licensees, and reviews by nuclear regulatory agency ceased to be carried out. PSAs make known the risk structure that is subject to regulations for risk management for the people, and the nuclear regulatory authorities were somewhat lax in managing quality, in having the licensees carry out PSAs, and in using those results to make regulatory decisions. As a result, there was ambiguity in distinguishing what is significant and what is not significant in achieving the required safety standards. This may have led to deterioration in nuclear safety culture.

The nuclear regulatory agency should have considered it their mission to act on the people's behalf to investigate whether the risks at nuclear reactors were being kept to a minimum and to provide explanations. They should have had the licensees evaluate internal and external risks of each plant and enforce appropriate accident management based on that. This should have then been reviewed and enhanced based on the latest knowledge.

8) Effects of ageing

Data acquired from surveys on equipment operation following the earthquake and the intensity of the shaking showed there had been no effect on important safety related equipment and devices in the reactor. As such, it is thought that the accident was not caused directly by deterioration due to ageing (embrittlement of the reactor, cyclic fatigue, pipe damage, heat ageing, cable deterioration, etc.), but instead was caused largely by insufficient cooling of the reactor, or a halt in cooling of the reactor, resulting in damage to one of the reactor cores and core melt.

In addition, it is necessary to examine in detail from now on whether the reactor systems were vulnerable to such an earthquake and tsunami because of their age. Through PSRs, mentioned above, or by other means, such factors should be investigated thoroughly and, where necessary, safety systems and equipment renewed or upgraded.

9) Environments for dealing with accidents

It is clear that at the time of the accident poor habitability of the main control room and inadequacies in accident clocking devices led to delays in making operational decisions. This stems from the fact that a prolonged loss of AC power supply was not considered as a design standard, and was not also considered as part of accident management.

In the future, for accident management to be effective against prolonged losses of AC power supply, stipulations should have been made on maintaining the habitability of the main control room and surrounding routes following damage to the reactor core. Stipulations should also have been made on ensuring the reliability of instrumentation and a stable direct current power supply to run such instruments if an accident occurs.

In addition, for twin plants with a common main control room, or where plants are adjacent to each other, accidents at the adjacent plant should have been considered as external factors affecting the plant. In the same way, it should also have been a requirement to ensure the necessary habitability for continued operation at the adjacent plant.

Such requirements also are also applicable for on site emergency stations.

When the accident occurred and operators from the main control room took shelter, the on site emergency station became the plant's main means for assessing the situation at the plant. But, poor habitability hampered work to swiftly implement accident management. In consideration of such events, in order to enable accident management to be carried out effectively even in difficult accident environments, detailed investigation should have been carried out into creating emergency stations with all the necessary requirements, including dedicated ventilation and air conditioning systems.

Following damage to the emergency station at the Kashiwazaki Kariwa Nuclear Power Station during the Niigataken Chuetsu-oki Earthquake in July 2007, an independent decision was made at the Fukushima Daiichi Nuclear Power Station to make its emergency station earthquake-proof. It can be said that this measure was of benefit during the earthquake. Investigation should be carried out to determine whether it is necessary to make such functions a regulatory requirement at other nuclear power stations' on site emergency stations as well.

10) Reactor building requirements

One of the difficulties hindering restoration efforts following this accident is the fact that the damaged section of the PCV is positioned low down. Water injected into the nuclear reactor is leaking out into the turbine building, as much electrical conduit and piping runs through the lower levels of the reactor building, and these sections are not water-proofed. As flooding can be considered as a factor of accident management, it would have been advisable to ensure that the lower sections of the nuclear reactor building were water-proof as a measure against flooding and to ensure external cooling of the PCV could be carried out.

In addition, in light of the fact that the presence of ground water is hindering the management of contaminated water, accident management activities should have included investigations into the detrimental effects caused by ground water, and measures such as positioning important sections of the reactor above ground water level or siting the building on premises with water shielding should have been taken.

11) Independence from adjacent plants

One of the difficulties hindering restoration efforts following this accident is the fact that there are underground connections to adjacent plants through which contaminated water runs. Although it is more economically efficient to construct plants adjacent to each other so that facilities and control can be shared, it is important to ensure that the detrimental effects of an accident at one plant can be kept isolated from the adjacent plant. As such, investigation should have been carried out to plan the physical separation of adjacent plants or to make it possible to plan the physical separation of adjacent plants.