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 crosscheck by using other severe Accident Analysis Code, MELCOR in order to 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 concerned by using MELCOR, another severe accident analysis code. The report of analysis and evaluation conducted by Tokyo Electric Power Company is shown in Appended Reference IV-1, and analytic results by crosscheck 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 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 an correspond event (non-operation of emergency core coolant device injection) according to the provisions of Article 15, Paragraph 1 of the NEPA had occurred. Additionally, the loss of function of the component cooling system seawater pump meant that the seawater 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 an correspond event (abnormal increase of containment vessel pressure) according to the provisions of Article 15, Paragraph 1 of the NEPA had occurred 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 taking 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 are being 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 assumed not 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 changed according to the injection flow rates of seawater, the results may be changed by operation condition because the operation condition was not cleared.

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 water level by the reactor fuel lowered through evaporation of water in the instrumentation piping and the condensation tank inside the PCV, the water level in which is considered the standard water level, due to the high temperatures in the PCV when it was changing under high pressure. 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. In regard to the question of whether the fuel has been cooled, 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, the bottom of the RPV is damaged, and it is thought at the present stage it is possible that some of the fuel has fallen through 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.

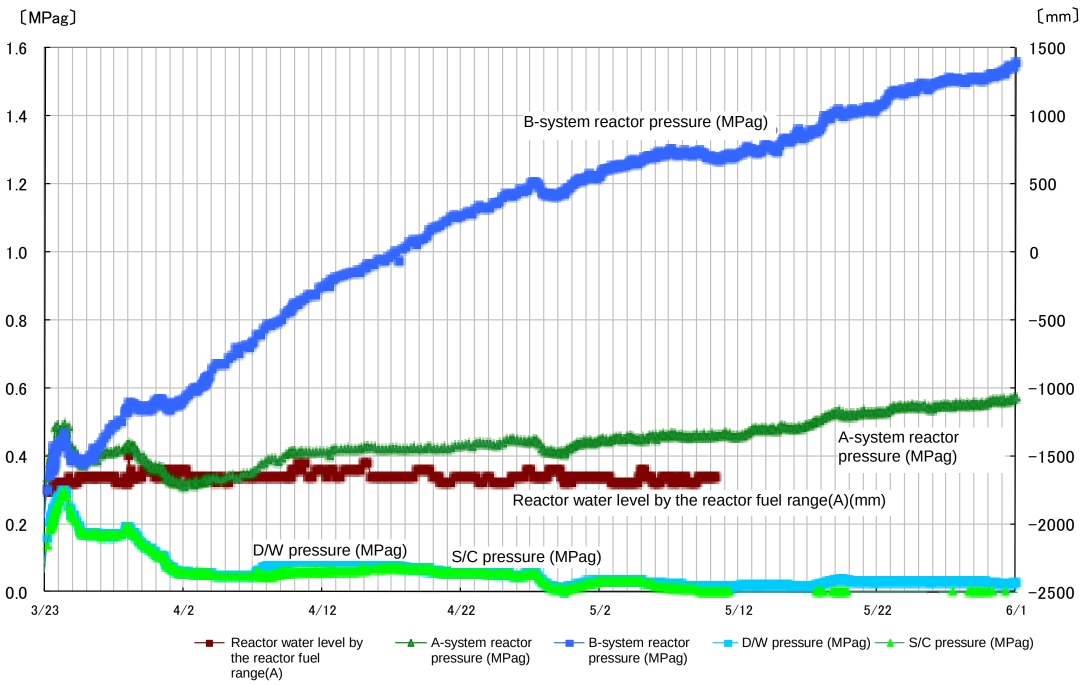
Table IV-5-1 Fukushima Daiichi NPS, Unit 1 – Main Chronology (Provisional)

* 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	In the reactor building, atmosphere investigation by using an unmanned robot was started.
	around 17:30	In the reactor building, atmosphere investigation by using an unmanned robot was completed.
4/18	11:50	Replacement of the hoses used for reactor injection with new ones was started. The injection pumps were stopped.
	12:12	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	For power supply enhancement, the nitrogen injection device was shut down.
	14:44	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.
	17:38	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.
	18:25	The reactor injection pump recovered its state of using external power supply.
	19:10	The shut down nitrogen injection device was restarted.
4/26	11:35	Atmosphere investigation (for radiation dosage, leakage, and the like) by using an unmanned robot was started on the reactor building.
	around 13:24	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	In association with installation of an alarm device to the core injection pump, the core injection pump was switched to fire pumps.
	14:53	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	The power supply to the reactor injection pump was switched to a temporary diesel generator, and injection was performed.
	8:50	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.
	15:55	The power supply to the reactor injection pump was switched from the temporary diesel generator to the reactor power supply.
	15:58	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	Spraying (fresh water) on the spent fuel pool by Tokyo Electric Company's concrete pump truck and the checking the spraying position were started.
	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 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		



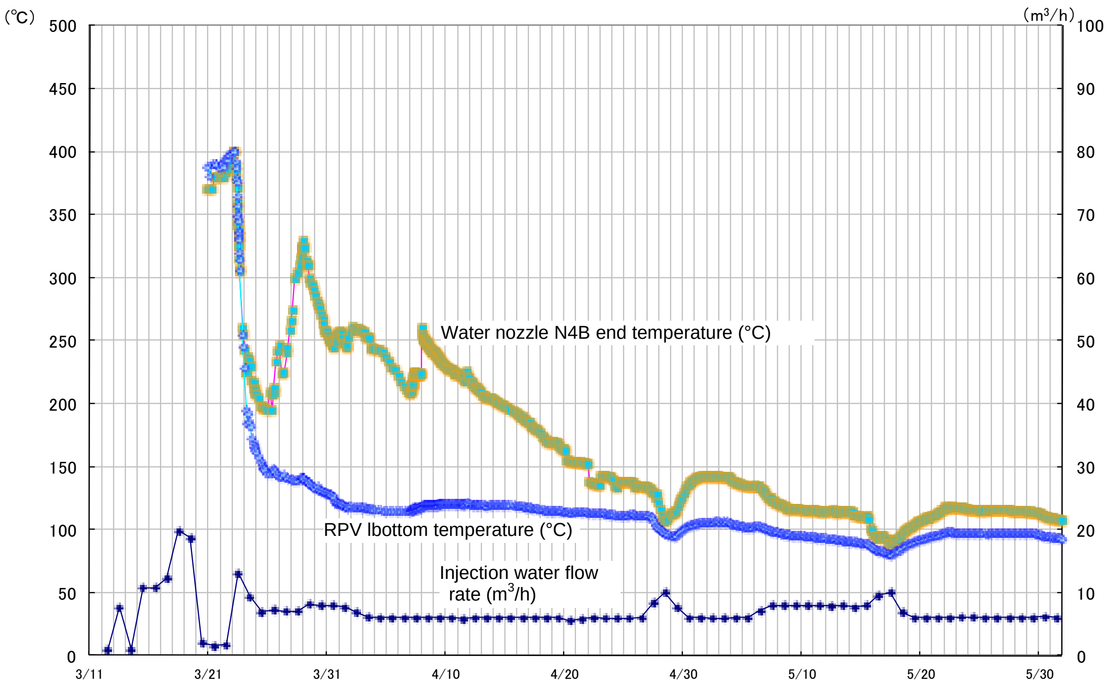


Figure IV-5-1 Changes in major parameters [1F-1] (From March 11 to May 31)

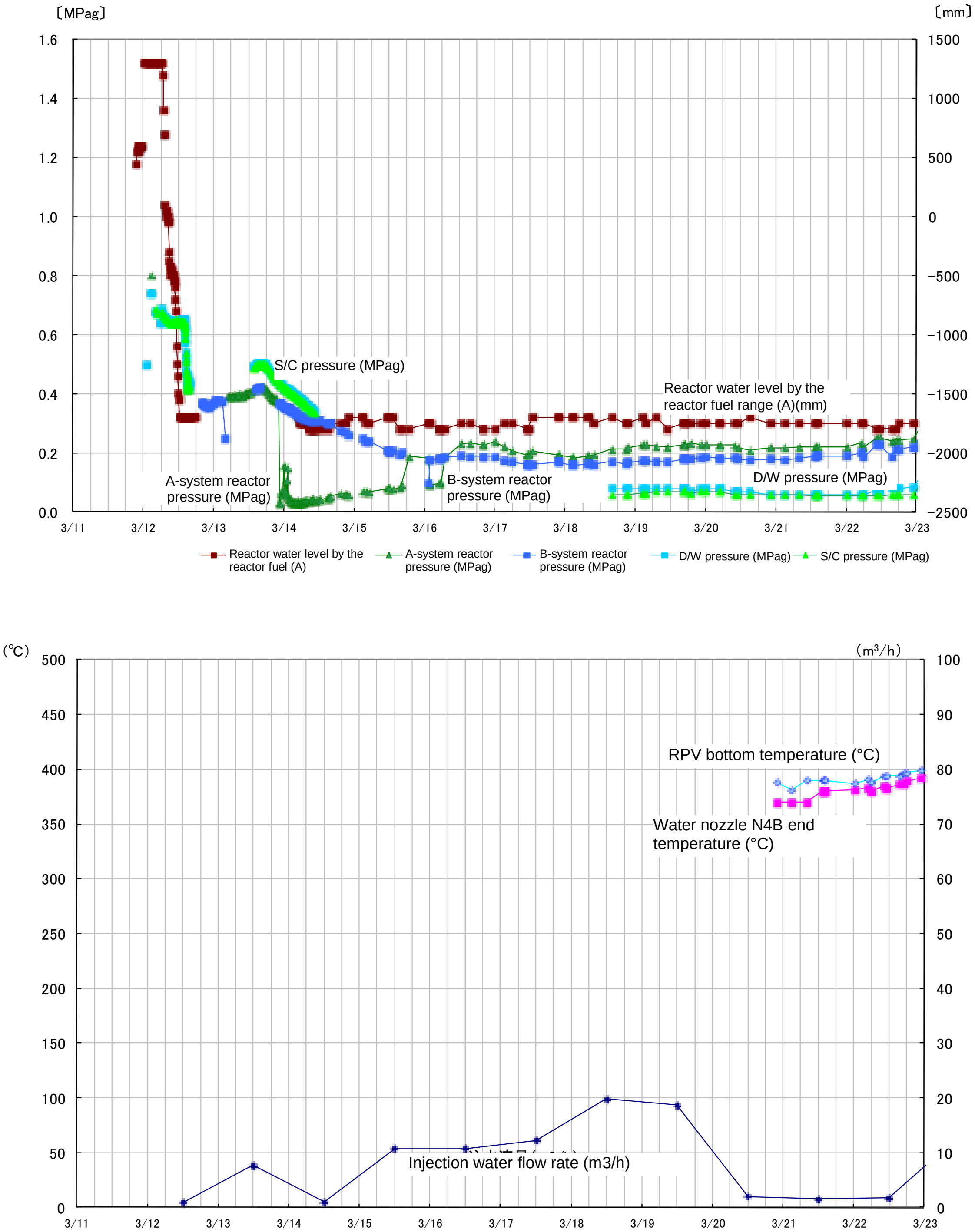
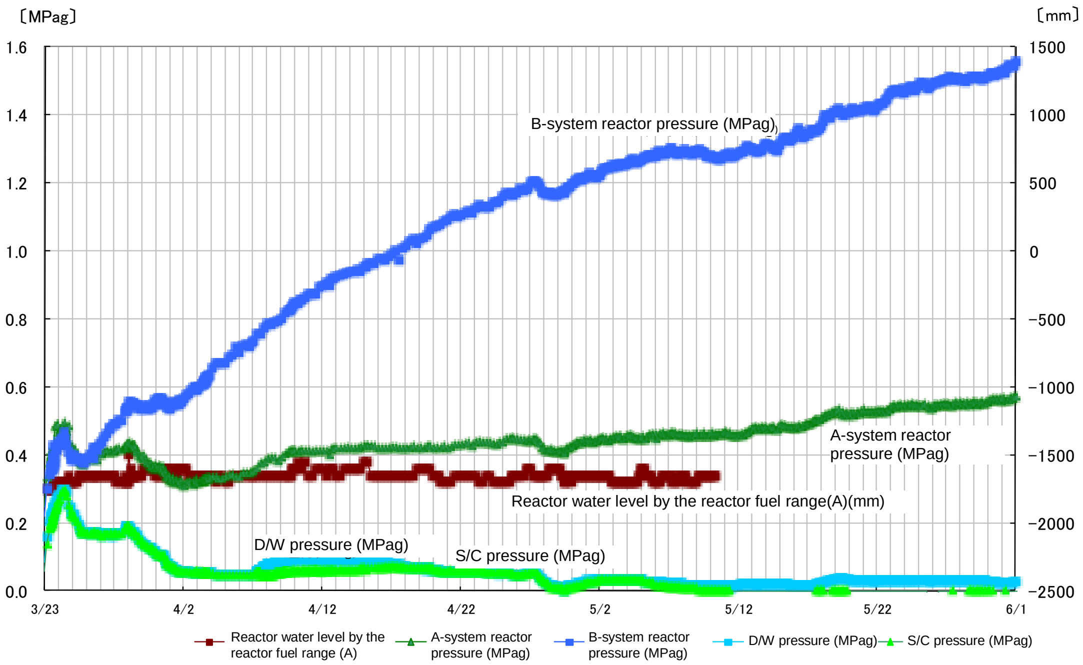


Figure IV-5-2　Changes in major parameters [1F-1] (From March 11 to March 23)



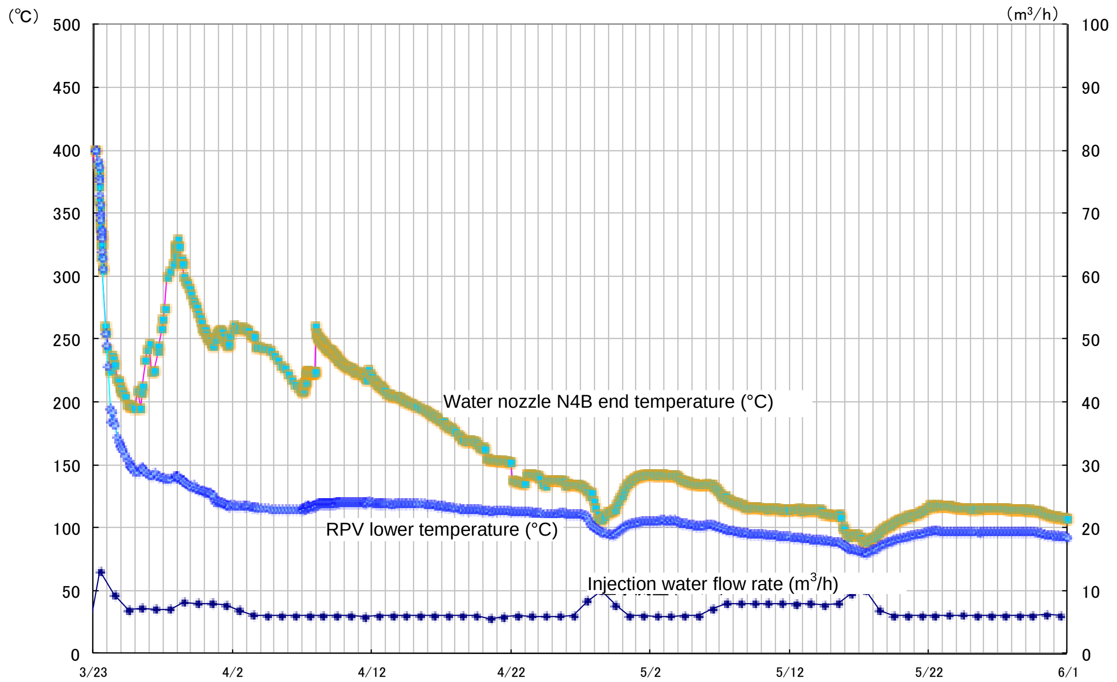


Figure IV-5-3 Changes in major parameters [1F-1] (From March 23 to May 31)

(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, 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. RPV time 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, it cannot be denied that the bottom of the RPV was damaged and part of the fuel 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	Fresh cooling water injection into the Spent Fuel Pool via a temporary motor-driven pump started.
	13:07	Fresh cooling water injection into the Spent Fuel Pool via a temporary motor-driven pump ended (about 70 t).
4/5	14:15	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.
	around 17:00	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	It was confirmed that the outflow of contaminated water from the pit crack had stopped.
	13:15	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	Fresh water injection into the Spent Fuel Pool via the Spent Fuel Cooling Line using a motor-driven pump started.
	14:34	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	Fresh cooling water injection into the Spent Fuel Pool using a temporary motor-driven pump started
	12:38	Fresh cooling water injection into the Spent Fuel Pool using a temporary motor-driven pump stopped (about 60 t).
4/11	About 17:16	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.
	17:56	External power supply restored
	18:04	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	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.
	11:00	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)
	11:00	Transfer of pooled water from the trench to H/W ended
	13:15	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a motor-driven pump started
	14:55	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a motor-driven pump stopped
	15:02	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.
	17:04	Transfer of the accumulated water in the trench of the turbine building to the Hot Well of the Condenser stopped
4/14	7:45	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.
	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 stopped.
4/15	10:19	As a countermeasure against possible tsunamis, transfer of the distribution boards for the water injection pumps to higher ground started.
	17:00	As a countermeasure against possible tsunamis, transfer of the distribution boards for the water injection pumps to higher ground ended.
4/16	10:13	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump started.
	11:54	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	The work of replacing the hose that had been used for injecting water to the reactor core with a new one started.
	12:37	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.
	13:42	A survey by an unmanned robot to check the conditions in the reactor building started.
	14:33	A survey by an unmanned robot to check the conditions in the reactor building ended.
4/19	10:08	The transfer of contaminated water from the trench to the Radioactive Waste Treatment Facility started.
	10:23	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.)
	16:08	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump started.
	17:28	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	Fresh water injection into the Spent Fuel Pool started via the Spent Fuel Cooling Line using a temporary motor-driven pump started.
	17:40	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		

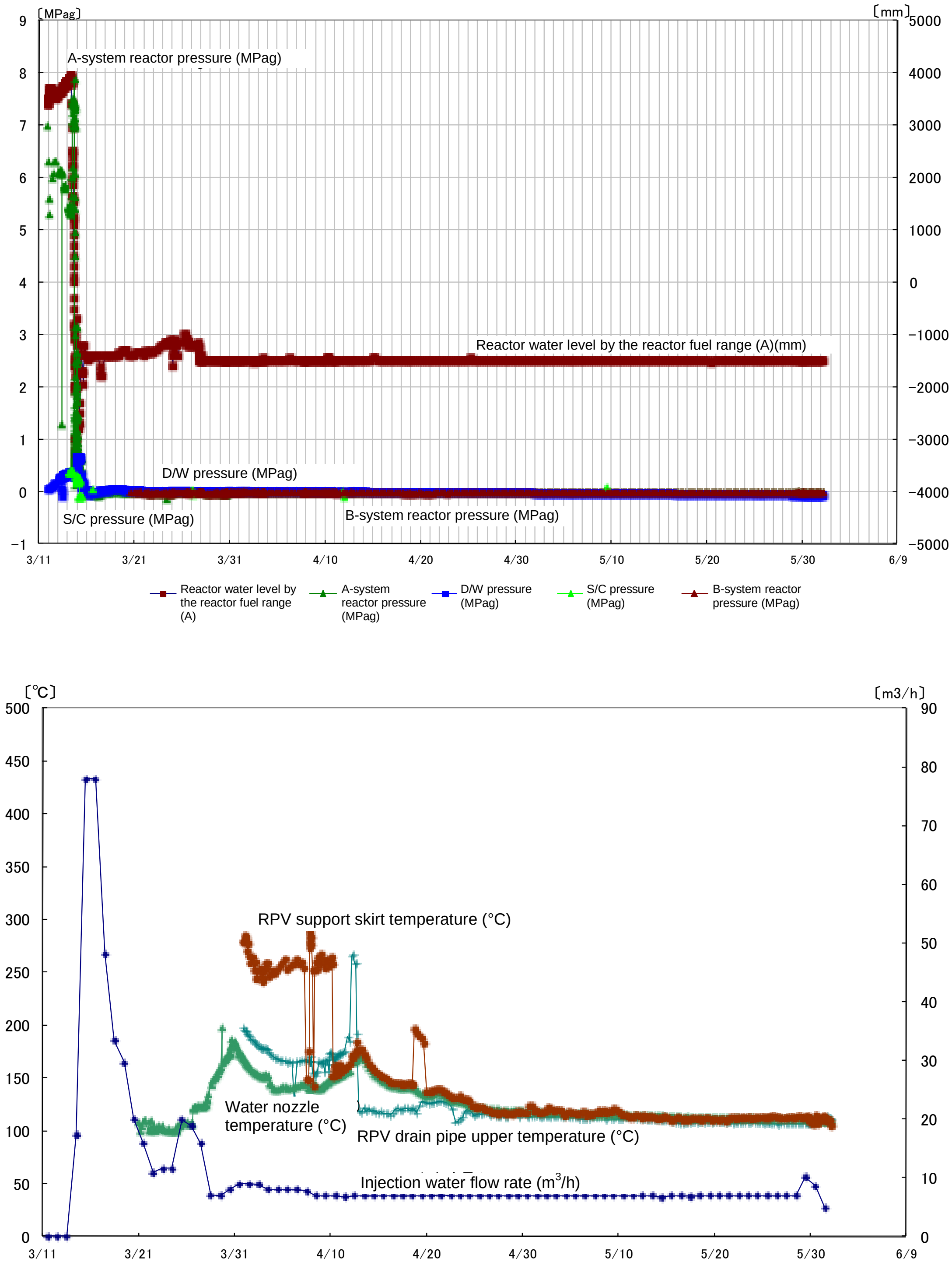
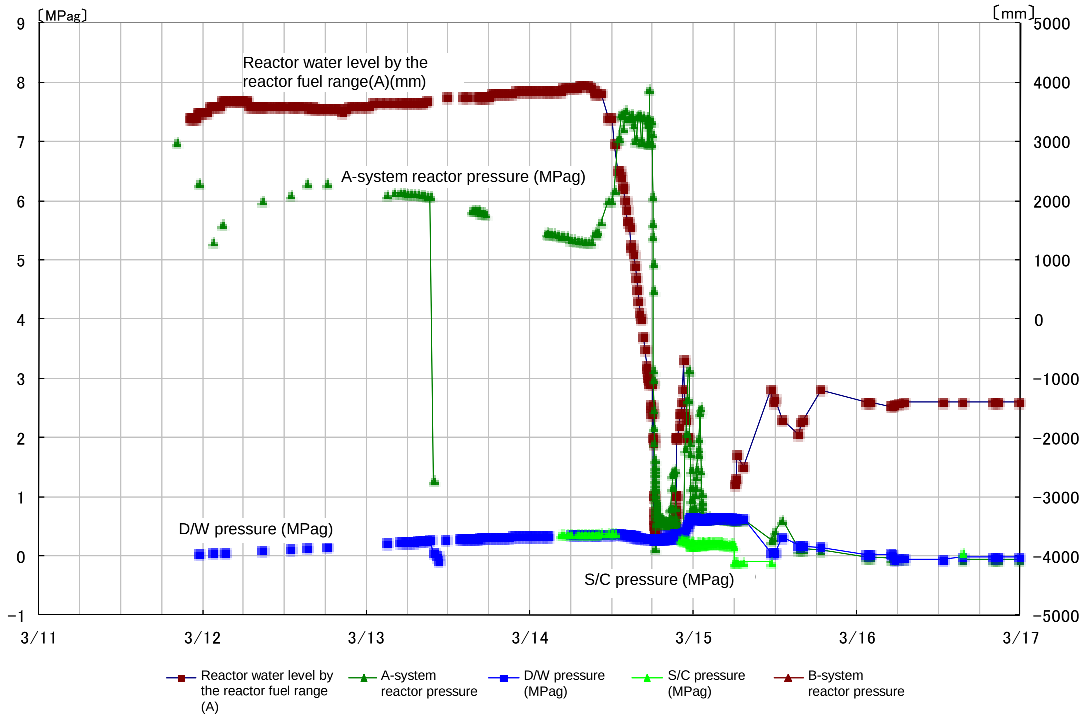


Fig. IV-5-4 Changes in key parameters [1F-2] (From March 11 to May 31)



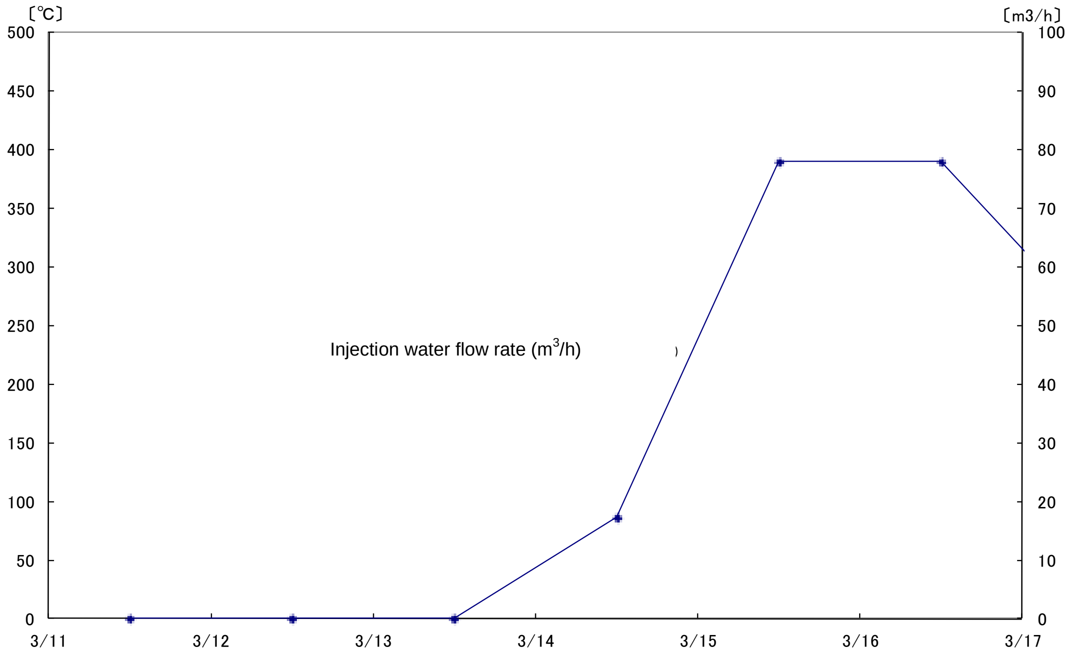
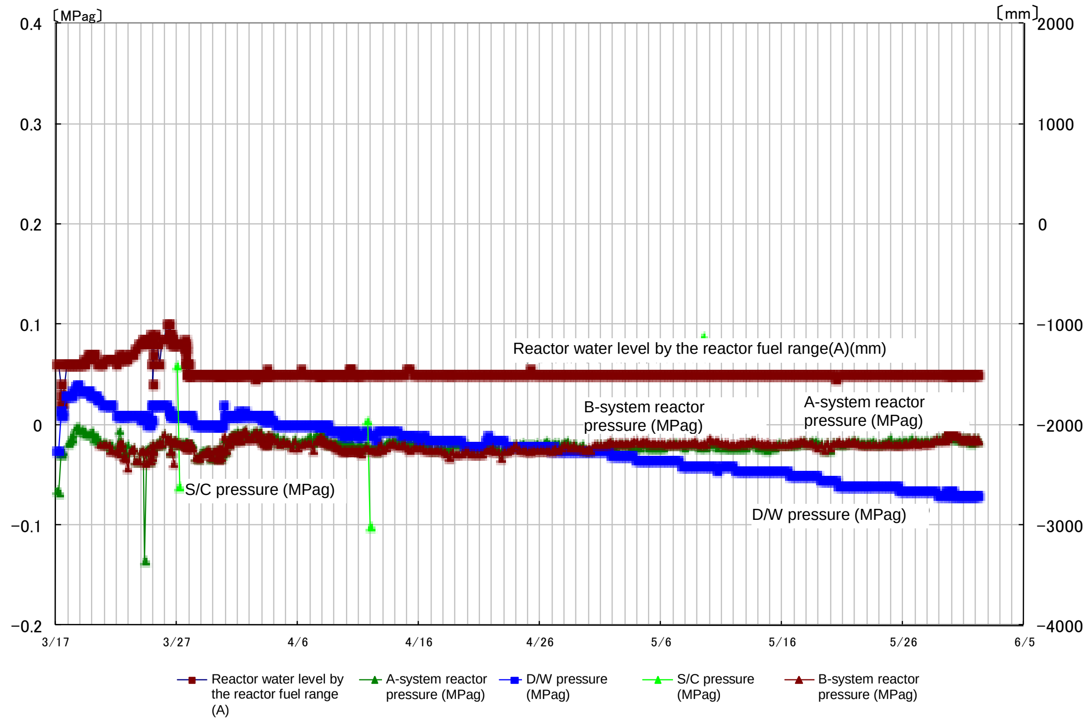


Fig. IV-5-5 Changes in key parameters [1F-2] (From March 11 to March 17)



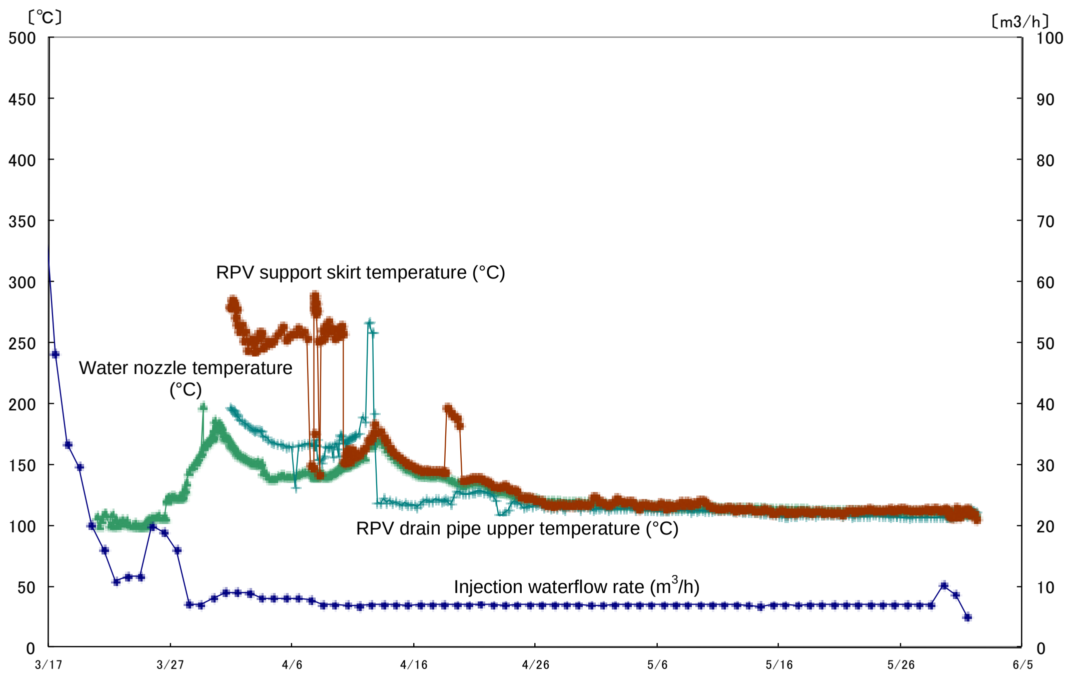


Fig. IV-5-6　Changes in key parameters [1F-2] (From March 17 to May 31)