

# Fukushima Nuclear Accident Analysis Report

## ( Interim Report ) -Summary-

### 1. Report Objective

The objective of this report is to investigate the causes of the accident at the Fukushima Daiichi Nuclear Power Station (hereinafter referred to as the “Fukushima accident” ) based on the facts known to date and the results of several analyses and to put forward necessary measures to improve the safety at other existing nuclear power plants.

Primary measures are identified as countermeasures in order to cope with several technical issues, which were clarified through the investigation that mainly focused on the sequence of events of the accident.

Since the investigation is still under way, further investigation results will be compiled and released. (Further investigation will mainly focus on the release of radioactive materials, radiation control, human resources, material procurement, disclosure of information, etc.)

### 2. Overview of the Fukushima Nuclear Accident (Full Version Report 【2】 )

### 3. Overview of the Tohoku - Chihou - Taiheiyo - Oki Earthquake (Full Version Report 【3】 )

#### Scale of the Earthquake and Tsunami (Full Version Report 【3.1】 )

- On March 11, 2011 at 14:46 the 9.0-magnitude Tohoku - Chihou - Taiheiyo - Oki Earthquake occurred. This was the largest magnitude earthquake in the recorded history of Japan.
- This massive quake was caused by the combination of several earthquakes whose focal area ranged approximately 500km in length and 200km in width extending from the offshore of Iwate Prefecture to the offshore of Ibaraki Prefecture. All of this seismic activity led to the occurrence of the largest tsunami in Japanese history.
- The ground motion that the power station experienced (intensity “6 upper” of 7 level on the Japanese scale) was nearly equivalent to the Design Basis Seismic Ground Motion per the plant design.

#### Height of the Tsunami (Full Version Report 【3.3】 )

- Fukushima Daiichi Nuclear Power Station (hereinafter referred to as “Fukushima Daiichi”): The height of the tsunami was approximately 13m\*. The whole area surrounding the major buildings of Units 1 to 4 was flooded to a depth of approximately 1.5m to 5.5m. The depth of the water surrounding the major buildings of Units 5 and 6 was less than 1.5m (Detailed information is provided in the table below).
- Fukushima Daini Nuclear Power Station (hereinafter referred to as “Fukushima Daini”): The height of the tsunami was approximately 9m\*. The tsunami ran up the southeast road along the major buildings of Unit 1. The tsunami did not

appear to have gone over the slope running alongside the main buildings facing the seaside.

\* Measurements of the tidal level and wave height were not possible due to the impact of the tsunami. These values were analytically obtained based on the observed flood height.

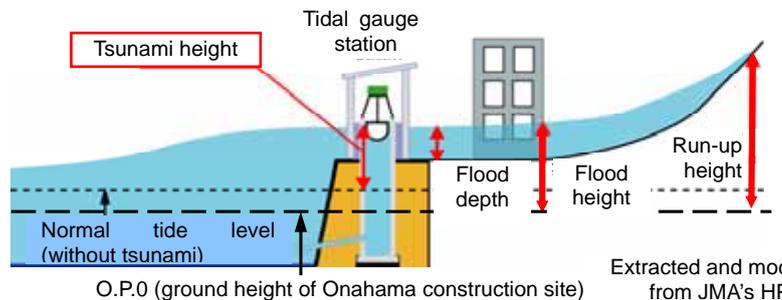
Flood height and depth at Fukushima Daiichi		
	Area surrounding major buildings (Units 1 to 4)	Area surrounding major buildings (Units 5 and 6)
Ground Level (a)	O.P. <sup>*1</sup> +10m	O.P.+13m
Flood Height (b)	O.P. approx.+11.5~+15.5m <sup>*2</sup>	O.P. approx.+13~+14.5m
Flood Depth (b)-(a)	Approx.1.5~5.5m	Less than approx. 1.5m
Flooded Areas	Almost all of the seaside area and the surroundings of the major buildings	
Note	Height of the tsunami (Estimate based on the tsunami analysis): approx. 13m <sup>*3</sup> Analysis result based on the assessment method introduced by the Japan Society of Civil Engineers (latest): O.P.+5.4~6.1 m	

\*1 : O.P. refers to the ground height of the Onahama Port construction site serving as the point of reference (lower than that of Tokyo Bay's mid-sea level by 0.727m).

\*2 : There were indications that the tsunami height reached levels of approximately O.P. +16~17m in some southwest areas (approximately 6~7m in flood depth)

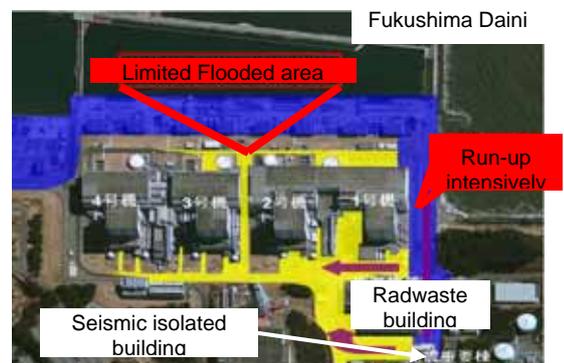
\*3 : Near tidal gauge station

Ground deformation caused by the earthquake is not reflected in the flood level and run-up height



(c) GeoEye

Flooded area of Fukushima Daiichi



Flooded area of Fukushima Daini

Tsunami Evaluation (Full Version Report 【3.4】)

1966-1972 [When establishing permits were obtained]

Establishing permits were obtained between 1962 and 1972. At that time, there

was no guideline for setting a design basis for a tsunami. Hence, the site designs were based on the maximum height of historical records. The design basis tsunami height (O.P. +3.122m) was determined based on the highest earthquake tidal wave level measured following the 1960 earthquake in Chile.

2002- [the JSCE's tsunami assessment methodology]

In 2002, the Japan Society of Civil Engineers (JSCE) published the "Tsunami Assessment Method for Nuclear Power Plants in Japan" This document has since then been used as the standard method of tsunami evaluation at nuclear power stations in Japan. Utilizing this method, the design basis tsunami height for Fukushima Daiichi Nuclear Power station was set to O.P. +5.4 to 6.1m and the necessary measures were taken by TEPCO.

2002 [Opinion of the Headquarters for Earthquake Research Promotion]

In the same year, a national institute for research and investigation known as the Headquarters for Earthquake Research Promotion (hereinafter referred to as the "Earthquake Headquarters") expressed the view that "there is the possibility that an approximately 8.2-magnitude earthquake could occur anywhere in the area offshore from Sanriku to Bousou along the ocean trench".

2003-2008 [Efforts on updating tsunami evaluation]

In 2005 and 2007, the JSCE published a paper regarding the advanced study on the probabilistic approach to tsunami evaluation that had been conducted since 2003.

During that period, TEPCO was carefully observing the JSCE's study. Based on the results of JSCE's study between 2003 and 2005, TEPCO submitted a report in 2006 regarding the results of experimental analysis that was carried out using the Fukushima sites as an example. This study was conducted in order to verify the applicability, etc. of the probabilistic tsunami hazard analysis method that was under development at that time.

In 2007 and 2008, it was confirmed that the tsunami height estimated by the Fukushima Prefecture did not exceed TEPCO's tsunami evaluation height. It was also confirmed that the tsunami height calculated from an estimated wave source, which was defined by the Ibaraki Prefecture, did not exceed TEPCO's tsunami evaluation height.

[Trial calculation based on the opinion of the Earthquake Headquarters]

For its internal investigation on how to handle the "Opinion of the Earthquake Headquarters" (which was published in 2002 as the results of a long-term evaluation) in the seismic qualification back checks based on a deterministic approach, from April to May, 2008, TEPCO conducted trial calculations as a reference. It should be noted that these trial calculations were based on hypothetical assumptions for the following reasons: First, the JSCE's "tsunami assessment methodology" did not take into consideration the tsunami along the ocean trenches offshore Fukushima. Second, the wave source model necessary for tsunami assessments had not yet been determined at that time. Therefore, in June 2009, TEPCO requested the JSCE to discuss the formulation of a specific wave source model in order to conduct tsunami assessments.

[Trial calculations based on the Jogan tsunami wave source model and field survey

of the tsunami deposits]

In December 2008, since the proposed Jogan tsunami wave source model was presented (although it was not fixed), TEPCO conducted trial calculations based upon such wave source model. TEPCO requested the JSCE to discuss this issue together with the opinion of the Earthquake Headquarters in June 2009. In addition, TEPCO conducted a survey of the tsunami deposits on the coast of Fukushima prefecture, which was considered to be necessary. Tsunami deposits were found in the northern area of the Fukushima Prefecture, while they could not be found in the southern area (from Tomioka to Iwaki). Because of the result of such survey, etc., it was considered that further investigation would be necessary in order to establish an accurate Jogan tsunami wave source model.

[Territorial scope of analysis at the Central Disaster Prevention Council]

In January 2006, a report of the Central Disaster Prevention Council's "Special Investigation Committee on the Subduction Zone Earthquake around Japan Trench and Chishima Trench" was issued. According to this report, past repeated earthquakes would be considered for disaster prevention measures. With respect to the area along the Japan Trench, although the possibility of offshore Sanriku earthquake was assumed, the 2002 opinion of the Earthquake Headquarters concerning the area offshore from Fukushima to Bousou was not reflected in the report.

[Scale of the earthquake on March 11]

The earthquake on March 11 can be considered neither as one premised on the opinion by the Earthquake Headquarters nor as that of the Jogan earthquake. It was a massive earthquake, the focal area of which covered a much broader area.

#### 4. Preparations for Accidents in power stations (Full Version Report 【4】)

##### Facility Design (Full Version Report 【4.2】)

- Human errors and mechanical malfunctions are assumed to occur when designing nuclear power facilities. Hence, various emergency cooling facilities were installed consisting of redundant systems and diverse functions that are able to operate independently in the case of an accident caused by a single failure.
- Vital functions, such as a reactor scram, are designed based on the philosophy of operating on the safe side in the case of failure. Taking these concepts into consideration, among others, TEPCO has obtained the establishing permit in accordance with the law, on the premise that the structure and equipment, etc. of the reactor facility does not hinder the prevention of disaster.

##### Preparations of Accident Management (AM) (Full Version Report 【4.4】)

###### 1992-2002 [Implementation of AM measures]

In May 1992, the Nuclear Safety Commission (NSC) decided the "Accident Management for Severe Accidents at Light Water Power Reactor Installations." Per the request for AM preparations (July 1992) from the Ministry of International Trade and Industry (MITI), AM measures were prepared in order to enhance the

multiplicity and diversity so that the “shutting down,” “cooling down” and “Confining inside” functions would not be lost even in the event of multiple failures during the period between 1994 and 2002. The specific contents of the preparations were reported to and confirmed by the government as appropriate, and the preparations were put into practice together with the government.

[AM measures in terms of the facility]

Design changes have been implemented in order to maximize the potential capabilities of the existing facility. Design changes were implemented for alternate water injection, primary containment vessel (PCV) hardened vents, power source cross-ties, etc. Specific design changes that have been made are as follows:

- Connecting piping and motor-operated valves were installed in order to enable the injection of water into the reactors from the existing make-up water condensate system (MUWC) and the fire protection system via the core spray system (for Fukushima Daiichi Unit 1) or via the residual heat removal system (RHR) (for Fukushima Daiichi Units 2 to 6 and Fukushima Daini Units 1 to 4), which can be implemented by operations at the main control room. (alternate water injection)
- New vent lines that are able to withstand high pressure were installed and connected to the existing line in preparation for the excessive PCV pressure due to failed PCV heat removal. This allowed an operator to release pressure inside the PCV from the main control room. (PCV hardened vent)

Alternate power source cross-ties were installed to adjacent units in preparation for the total loss of emergency diesel generators (EDGs) and DC power sources.

[AM measures in terms of plant operations]

In addition to preparations for multiple failures, existing manuals etc. were revised in order to accurately implement AM measures, and new standard operational procedures (SOP) for accident (severe accident) were established. Furthermore, plant operators and emergency response team members had been taking training courses etc. periodically on the AM procedures.

AM measures and the Fukushima Accident (Full Version Report 【4.5】 )

- In the Fukushima accident, the destruction caused by the tsunami resulted in the loss of almost all equipment and power source functions expected to be activated in case of accidents, including those for AM measures prepared together with the government. As a result, workers on the site were forced to adapt to sudden change of circumstances such as injecting water into the reactors using fire engines, and the accident management became extremely difficult. The situation on the site was far beyond the originally estimated accident management conditions, and as a result, the expansion of the accident could not be prevented under the framework of the prepared safety measures.

5. Preparation for Emergency Response (Full Version Report 【5】 )

6. Status of Fukushima Daiichi Nuclear Power Station (Full Version Report 【6】【7】 )

Plant status before the earthquake (Full Version Report 【6】 )

[Units 1 to 3: in operation      Units 4 to 6: in annual outage]

Units 1 to 3 were in operation at the rated power output. Units 4 to 6 were shutdown and had been in outage for periodic inspection. At Unit 4, all fuels were stored and cooled in the SFP for the shroud replacement work.

Plant Status following the Earthquake (Full Version Report 【6】 )

[Safe shutdown and successful start up of emergency diesel generators]

After the earthquake, all control rods were inserted into the reactors as designed and all reactors automatically shutdown. While the external power source that supplies the necessary electricity was lost due to the earthquake, EDGs started up properly and the other instruments also functioned as designed.

[Impact on facilities due to the earthquake]

Based on the data recorded between the earthquake and the tsunami, no abnormality was found such as ruptures to the piping located inside the PCV which has an impact on the plant safety. The result of the seismic response analysis confirmed that all the vital equipment and piping met the evaluation standards.

As for Units 1 to 3, 5, and 6, visual investigations were conducted for the equipment to the extent possible. As a result, no damage to safety-related equipment was found. It was also confirmed that even for equipment that has lower seismic resistance, only minor damage was found.

Regarding instruments on the field, many instruments have been damaged. Although the result of the visual investigation of the facilities in the field can not completely deny the impact by the earthquake, it is considered that the majority of the damage in the field was mainly caused by the tsunami.

[Condition of Unit 1 isolation condenser system (IC) and Unit 3 high-pressure coolant injection system (HPCI)]

Visual investigation of the Unit 1 IC was conducted outside of the PCV that was able to be confirmed. The result found no damage to the vessels or piping, and no evidence of leaks of large volumes of high-pressure steam caused by piping ruptures was found. Regarding Unit 3 HPCI, based on interviews with operators who went to the field, it was concluded that damage such as piping ruptures did not occur.



Seawater facility in the field, Unit 1  
(Main seawater pump)



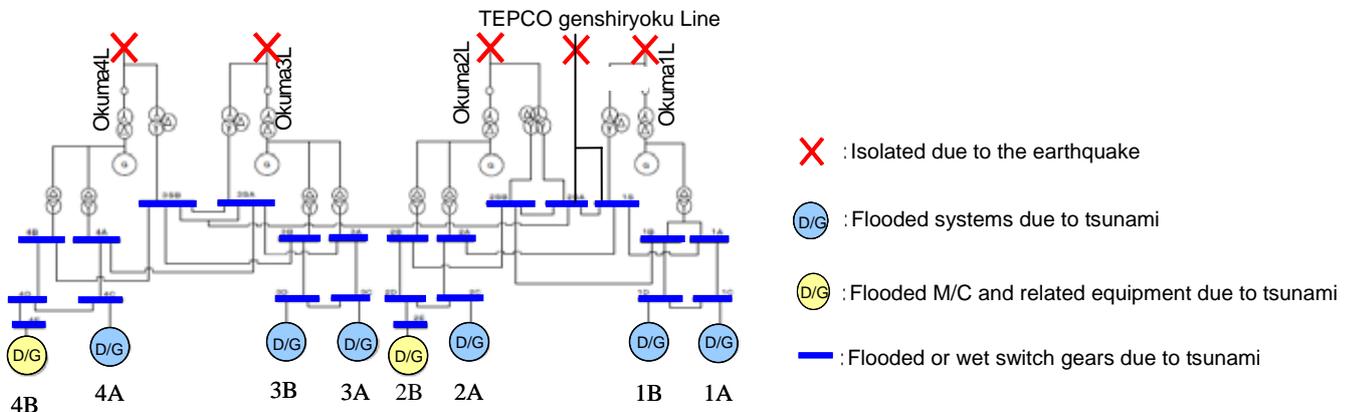
Isolation Condenser (B), Unit 1



Turbine auxiliary cooling system  
pump, Unit 3

## 7. Direct Damage to the facilities from the tsunami (Full Version Report 【7】 )

- All AC power sources for Units 1 to 6, except for one EDG for Unit 6 lost their functions because of the tsunami and it resulted in all motor-driven pumps and motor-driven valves being inoperable. Numerous switchgears became wet or flooded and became unusable. It turned out that there were almost no operable switchgears to connect to in order to activate the equipment even though external electricity sources (e.g. power supply cars) could be prepared.
- Units 1, 2 and 4 lost their DC power sources resulting in the monitoring instruments being out of use.
- Seawater facilities necessary for heat removal from reactors and various equipments were also wet or flooded. This resulted in inoperability of large pumps and other equipments that required cooling of motors.



Single line diagram of Units 1 to 4, Fukushima Daiichi

## 8. Event Summary after the tsunami (Full Version Report 【8】 )

### Event sequence on Unit 1 (Full Version Report 【8.1】 )

- The earthquake occurred at 14:46 on March 11. The plant was automatically shutdown and all control rods were inserted. Subsequently, tsunamis struck the plant at around 15:30 while operators were engaged in shutdown procedures, such as controlling the reactor pressure via the ICs in line with limitations not to exceed a cool-down rate of 55 degree C/hr in order to mitigate the impact on the reactor pressure vessel.
- Due to the impact of these tsunamis, all AC and DC power was lost. It resulted in

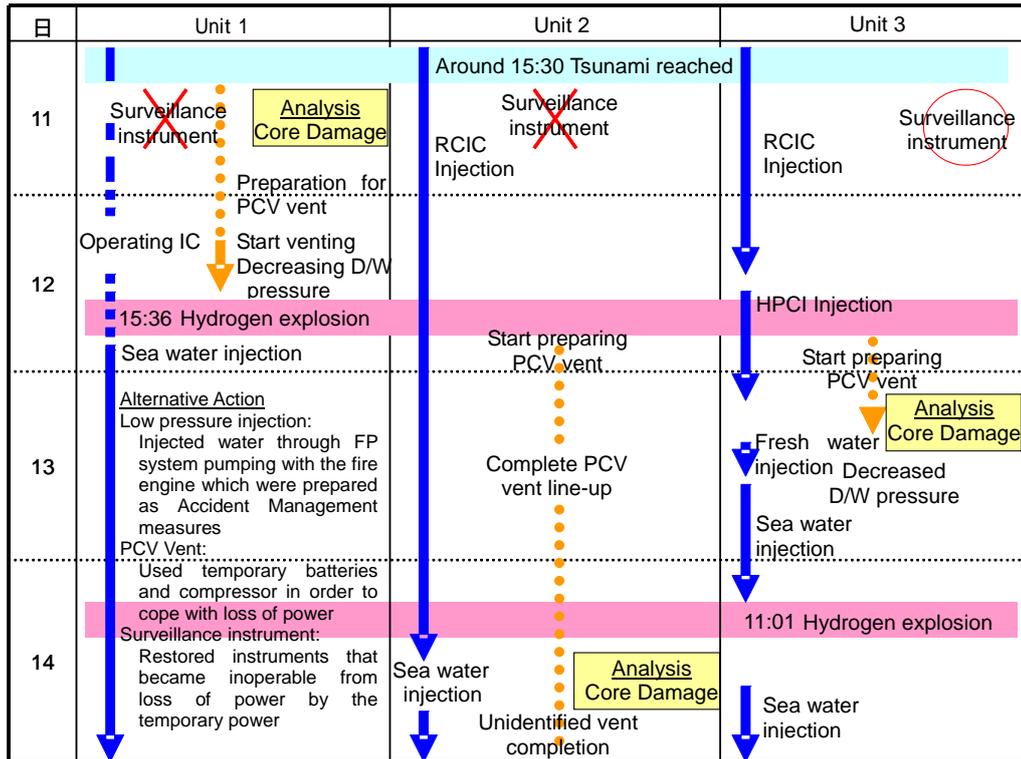
the loss of all functions for injecting cooling water and cooling the reactor. The lost functions included steam-driven high-pressure cooling water injection systems and motor-driven cooling facilities.

- Under such situation, fire protection lines, which were originally prepared as one of the accident management measures, and fire engines were utilized for alternative water injection.
- The work was made very difficult due to scattered debris caused by the tsunami and frequent aftershocks. Under such circumstances, a water source and a connection point for the hoses were maintained and water injection was commenced early in the morning of March 12, at 5:46. The work conditions further deteriorated due to the increase of on-site radiation levels and a hydrogen explosion inside of the Unit 1 reactor building occurred at 15:36. Finally, injection of seawater started in the evening of March 12, at 19:04.
- The necessity of venting the PCV was recognized at an early stage and an immediate review of venting procedures was conducted. In the midst of all this, an increase of the pressure inside the PCV (Dry Well: D/W) was found. Since then, preparations for venting were proceeded with, such as estimating the radiation dose rate inside and outside the building.
- PCV venting was conducted using temporary equipment and manual actions in the field amid increasing radiation dose rate since remote operations were not possible due to a loss of power. Since it was necessary to take into account the status of local personnel evacuation, this PCV venting was implemented after confirming the evacuation of the area's residents.
- The D/W pressure was confirmed to have decreased, and it was determined that the "release of radioactive materials" had been conducted through the venting (14:30 on March 12)

#### Sequence of events for Units 2 and 3 (Full Version Report 【8.2】【8.3】)

- Even after the tsunami, steam-driven cooling water injection pumps, such as the reactor core isolation cooling system, were used to inject cooling water into the reactors. However, these pumps eventually stopped working. Cooling water injection into the reactor was essential to cool down the reactors; thus, the depressurization of the reactors was inevitable. However, since no power sources were available in order to operate valves, workers had to conduct complicated works; as an example, they had to use temporary car batteries for operating the valves.
- The preparations of the PCV venting for Units 2 and 3 were implemented using temporary equipment under harsh conditions after such events as the Unit 1 hydrogen explosion.

## Major Event Progression and Timeline



### Status of Unit 4 Spent Fuel Pool (SFP) (Full Version Report 【8.4】【8.9】)

- All of the fuel assemblies had been removed from the reactor prior to March 11 and placed in the SFP for the outage. The cooling function for the SFP was lost due to the loss of all the electrical power caused by the tsunami. Consequently, at 4:08 on March 14, the SFP temperature was confirmed to have risen to 84 degrees C due to decay heat from the spent fuel.
- On the morning of March 15, a loud explosive sound was heard and the upper part of the Unit 4 reactor building was found to be damaged. At first, the concern was that the SFP might have been damaged. However, an overhead visual inspection conducted by a helicopter revealed that there was still water remaining in the pool after the explosion, and that the spent fuel had not been exposed. Furthermore, a radionuclide analysis of the SFP water did not show any indication of fuel damage. Currently the water injection and cooling functions have been recovered for the SFP to date.

### Radionuclide Analysis Results in Unit 4 Spent Fuel Pool



Inside the Unit 4 Spent Fuel Pool

Detected nuclide	Half life	Concentration (Bq/cm <sup>3</sup> )					
		Unit 4 Spent Fuel Pool water					(reference) Stagnant water on basement of unit 4 T/B Mar.24
		Sampled on Apr.12	Sampled on Apr.28	Sampled on May 7	Sampled on Aug. 20	(reference) Sampled on Mar.4	
Cs-134	About 2 yrs	88	49	56	44	ND	31
Cs-137	About 30 yrs	93	55	67	61	0.13	32
I-131	About 8 days	220	27	16	ND	ND	360

## 9. Evaluation of the Hydrogen Explosions (Full Version Report 【9】)

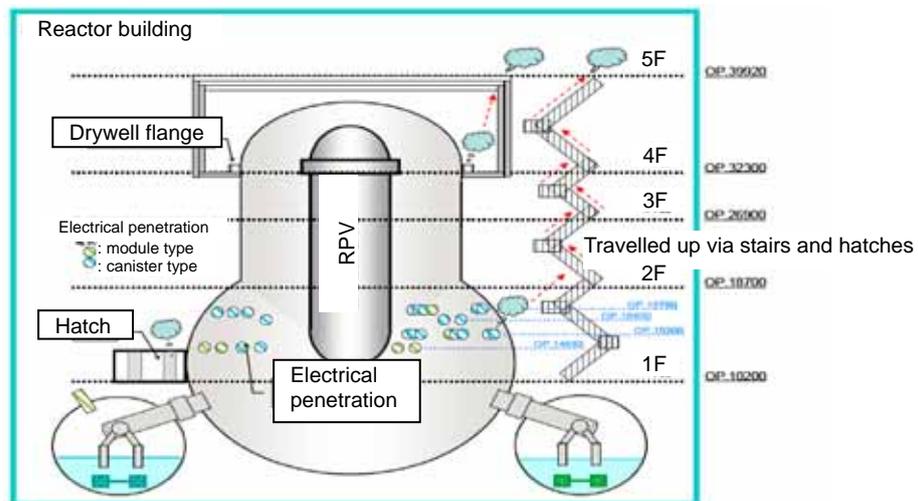
### Causes of the Hydrogen Explosions at Units 1 and 3 (Full Version Report 【9.2】)

#### [Cause of the hydrogen explosion]

- It is considered that hydrogen was generated due to the zirconium-water reaction following the reactor core damage, and that hydrogen leaked out and accumulated within reactor buildings, resulting in a series of explosions.

#### [Hydrogen's leakage path]

- Although the leakage path to the reactor buildings remains unknown, there is a hypothesis that the joint at the PCV head and the seals (sealed by silicone rubber) at the joints of the hatches used for the entrance/exit deteriorated due to the high temperatures.



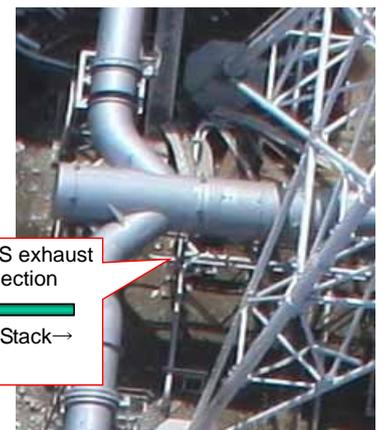
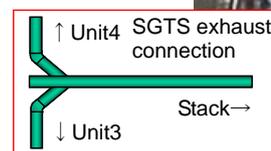
Unit 1 and 3 Estimated leaking path of Hydrogen

### Cause of the Hydrogen Explosion at Unit 4

(Full Version Report 【9.1】【9.2】)

#### [Source of hydrogen generation]

- The filter train of the standby gas treatment system (SGTS) at Unit 4 was investigated and it was found that the radioactive concentration accumulated at the outlet was higher than that at the inlet. This implies that contaminated gas flowed into the Unit 4 SGTS pipe from the outlet to the inlet.
- Another field investigation revealed that the main explosion at Unit 4 occurred near the SGTS duct on the 4th floor
- The above-mentioned findings are consistent with the hypothesis that the ventilation flow from Unit 3 travelled into the 2nd floor of Unit 4 and then into various areas of the Unit 4 reactor building via pipes and the SGTS ducts.



[Explosion sound at around 6:00 on March 15]

- On March 15 at around 6:00 the sound of an explosion was heard from the Unit 2 area almost at the same time as the Unit 4 explosion. Later investigation on the on-site seismometer vibration data revealed that the explosion had actually occurred only at Unit 4 and no explosive phenomenon had occurred at Unit 2. The observed decrease of the pressure to 0 MPa[abs] in the suppression chamber is likely due to an instrument malfunction.

Measures to Prevent Explosions (Full Version Report 【8.3】【9.1】)

- At Unit 3, measures to prevent hydrogen explosions were being considered, but were not actually implemented because of the high possibility of inducing explosion by spark discharge. (Arrangements were made to prepare tools for boring a hole through the wall of the reactor building using a water jet machining device. However, the tools did not arrive before the explosion of Unit 3.)
- At Unit 2, the blow-out panel on the top floor of the Unit 2 reactor was opened at the time of the explosion at Unit 1. It is considered that the explosion was averted since this opening prevented hydrogen from accumulating in the building.

#### 10. Analysis of the Accident and Major issues (Full Version Report 【10】)

Plant Conditions at the Time of the Accident (Full Version Report 【10.1】)

The plant correspondence was evaluated with the up-to-date collected information and post-accident analysis results based on those data.

For Fukushima Daiichi Units 1 to 3, the core conditions were evaluated using the accident analysis code (Modular Accident Analysis Program (hereinafter referred to as "MAAP")) based on the plant condition right after the earthquake and operating logs and so on. The figure below shows an example of an output of the MAAP analysis.

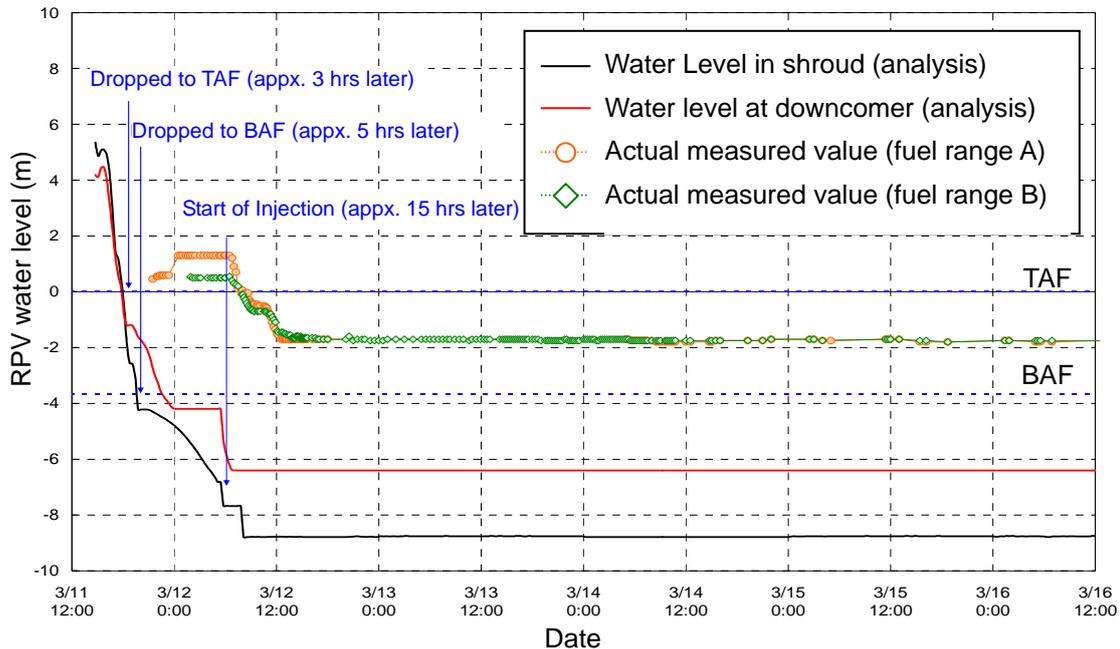
[Fukushima Daiichi Unit 1]

- The IC lost its function due to an automatic isolation signal caused by loss of power. The reactor water level is considered to have decreased within a short period of time and thereafter, which led to the exposure of the reactor core and the core damage.
- On March 12 at around 15:00 the reactor pressure decreased despite there being no actions taken to decrease the pressure. On the other hand, the pressure in the PCV increased. This implies the possibility that the pressure in the reactor pressure vessel could not be maintained due to the damage to the vessel, and that the core damage had advanced to a considerable extent within a short period of time.

[Fukushima Daiichi Unit 2]

- The reactor water level started to decrease after the reactor core isolation cooling system stopped. Prior to the depressurization by safety relief valves, a fire engine's pump was started and the low pressure water injection was ready to be operated. However, the safety relief valve could not immediately be opened during the reactor depressurizing operation. Hence the low pressure water

injection did not start quickly. This caused further deterioration of the cooling function and the amount of water in the reactor sharply decreased following the pressure decrease, which led to the core damage. (A similar event sequence of events is considered to have occurred at Unit 3.)



Example of an analysis result of RPV water level at Fukushima Daiichi Unit 1

Fukushima Daini Unit 1's event progress is evaluated as a case that succeeded in cold shutdown by utilizing functions prepared as a part of AM countermeasures.

[Fukushima Daini Unit 1]

- Since both the power source and the MUWC pump were intact, low pressure water injection via the MUWC was activated while the high pressure cooling water injection via the reactor core isolation cooling system (RCIC) was active. Thereafter, while maintaining the water level via high pressure cooling water injection, the reactor pressure was reduced via main steam safety relief valve operations to a level where the low pressure cooling water injection became possible.
- While maintaining the reactor water level via the low pressure cooling water injection, the power source for the residual heat removal system was restored. The cold shutdown of the reactor was achieved by using the heat removal function of the system using seawater.

Identification of the Key Issues (Full version report 【10】)

Some issues are identified from the following viewpoint regarding the plant behavior, system function, and the factors impacting worker's performance during the accident recovery activities.

[Plant behavior]

- Several issues are identified from updated collectable information and post-accident

analysis results based on the information.

(e.g.) To ensure an injection measure by high pressure injection system promptly.  
[System function]

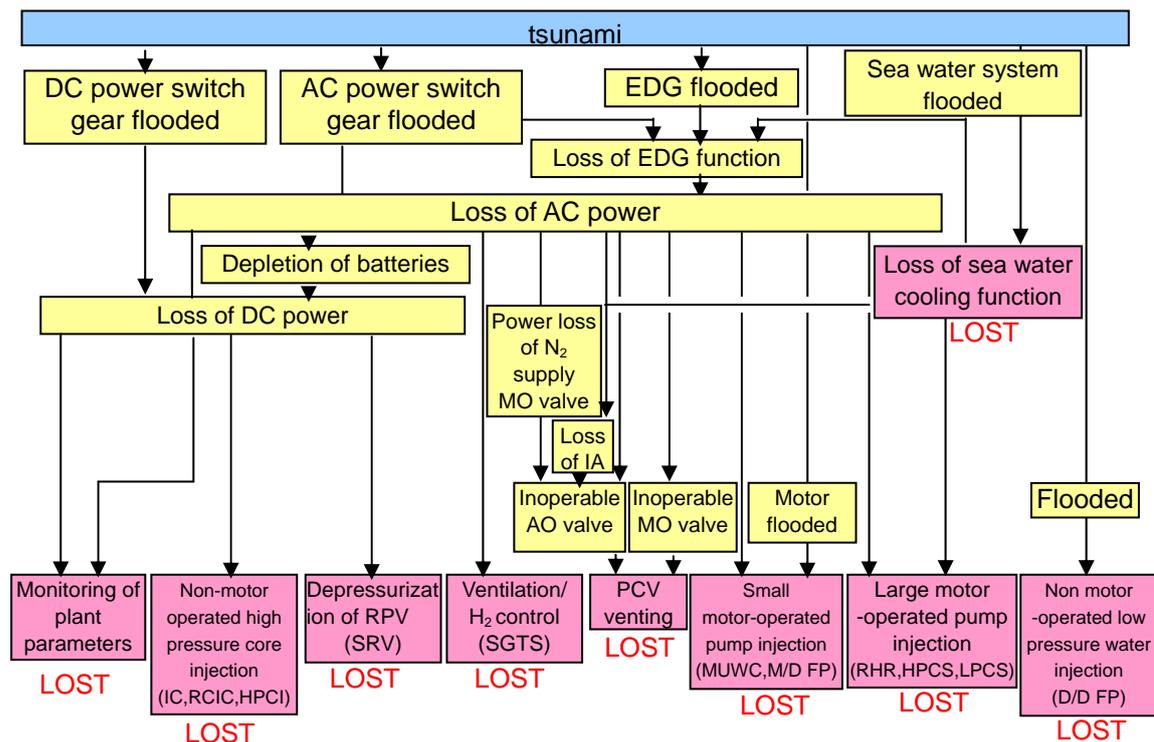
- Several issues are identified regarding each event sequence, such as ensuring the post-earthquake cooling, ensuring the high pressure injection, and etc.

(e.g.) To ensure DC power supply for maintaining system function.  
[Factors impacting worker's performance]

- Several issues are identified which impacted worker's performance during important accident management operations, such as the reactor water injection and the PCV venting.

(e.g.) To consider deteriorated working condition by the debris, loss of lighting, release of radioactive materials, and etc.

Based on the accident progress at Fukushima, the correlation of primary factors resulting in the loss of vital functions is shown in the following figure. "Simultaneous power loss of AC and DC power for an extended period of time" and "residual heat removal function of the emergency sea water system for an extended period of time" are two of the primary factors that caused a simultaneous loss of multi-safety function due to flooding by tsunami in this accident.



Causes Leading to the Loss of Critical Functions to Prevent Core Damage and Mitigate Effects

## 11 . Countermeasures on the Accident Causes (Full version report 【11】)

### Strategy for preventing Core Damage ( Full version report 【11.1】)

Based on the issues identified from the accident, in order to prevent similar accidents from occurring again, the strategies below have been identified.

Strategy 1 <Thorough Tsunami Countermeasures>

: To take countermeasures for mitigating the impact of tsunami hazard, which is the direct cause of the Fukushima accident. In addition, to implement thorough tsunami countermeasures for protecting vital facilities necessary for reactor cooling water injection and cooling based on the lessons learned from the accident operations and plant behavior at Fukushima.

Strategy 2 <Securing Functions by adopting Flexible Countermeasures>

: To implement practical and flexible countermeasures for preventing core damage even under the accident condition with multiple equipment failures and loss of multiple functions like Fukushima (Multiple facility failure and function loss due to both the long-term station black out condition and the loss of long-term heat removal functions using seawater)

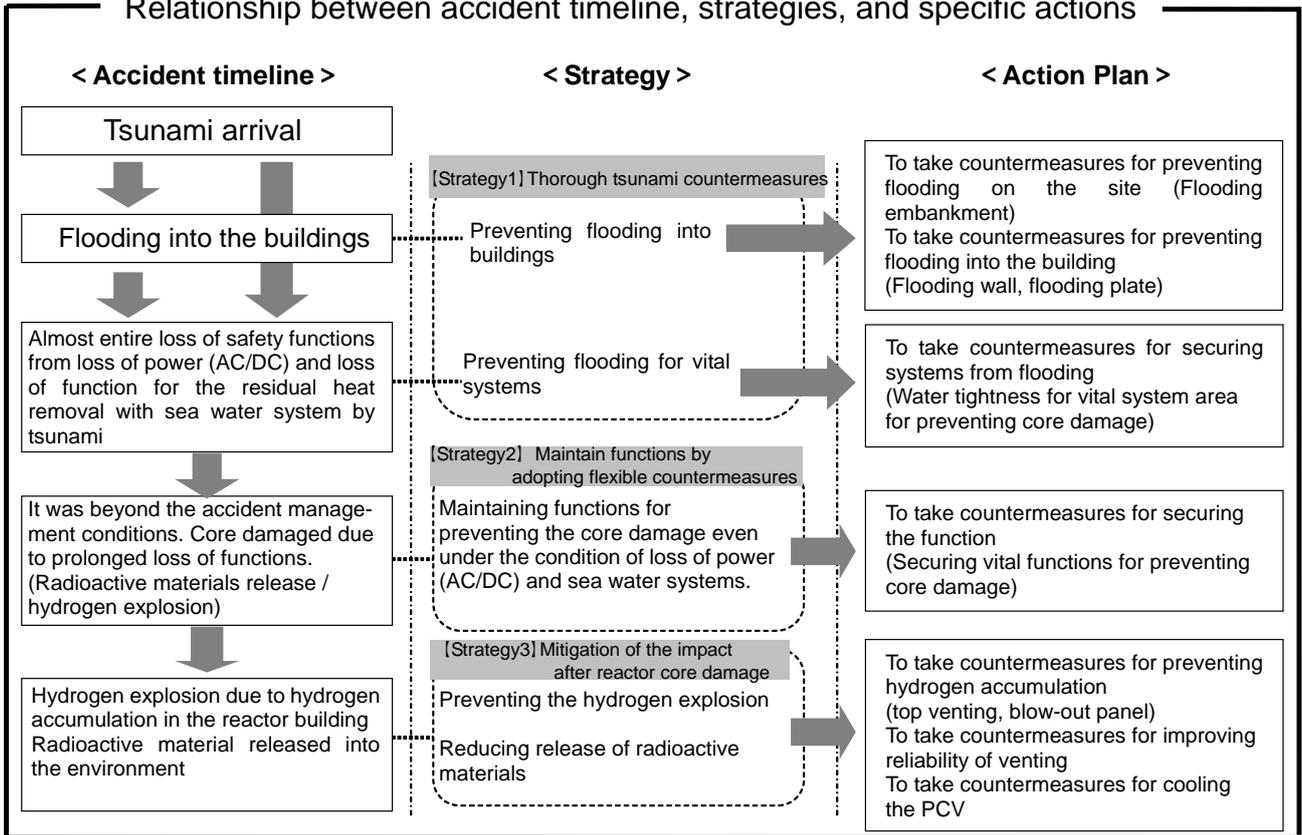
Strategy 3 <Mitigation of the Impact after Reactor Core Damage>

: Although top priority should be placed on the prevention of core damage, implement additional countermeasures to mitigate the impact that occur in case of core damage.

Specific Actions related to the Strategies ( Full version report 【11.2】)

In order to apply the lessons of the Fukushima accident to the nuclear industry, specific actions are proposed based on the above-mentioned strategies. For effective application of the lessons, it is important that management aspects, such as procedures, training, and drills, are improved. The following figure describes the relationship between the accident timeline, strategies, and examples of specific actions. Furthermore, see attachment 1 for more detailed countermeasures.

## Relationship between accident timeline, strategies, and specific actions



## 12 . Conclusions ( Full version report 【12】)

## Countermeasures for protecting Core Damage

### (1) Flooding Protection Countermeasures for sites and buildings

Installation of tidal embankment, board, and wall and flood protection of door and penetration

### (2) High Pressure Cooling Water Injection Facilities (Required within 1-hour)

#### Concepts

-High pressure injection is initially required due to high reactor pressure in the case that the plant experiences an abnormal shutdown.

-During the accident, some motor-driven equipments were inoperable due to the station black out (SBO). Hence, a steam-driven high pressure facility is the key issue.

-Furthermore, when choosing motor-driven high pressure cooling water injection facilities, it is important to select equipment with minimum operating requirements.

RCIC	steam-driven	
SLC or CRD	motor-driven	x
HPCS		

### (3) Depressurizing Equipment (Within 4-8 hours)

#### Concepts

-Depressurization of the reactor pressure vessel is essential in order to remove heat and bring it to a cooling stage

-During the Fukushima accident, the DC power necessary to operate the main steam safety relief valve for depressurizing was insufficient. In addition to securing N2 for valve operations, securing a power source is necessary.

### (4) Low Pressure Water Injection Facilities (Within 4-8 hours)

#### Concepts

-Low pressure cooling water injection equipment consists of an emergency system, a make-up water condensate system (MUWC) and a fire protection system. In the case of the SBO, only the diesel-driven fire pumps (DDFP) of the FP will be operable.

-Preparing reliable low pressure injection equipment is important including the fire-engine used.

DDFP	diesel-driven	
MUWC	motor-driven	x

### (5) Heat Removal/Cooling Facilities

#### 1) PCV venting (Within 1-2 days)

##### Concepts

-In the case that seawater cannot be used as a cooling source, suppression chamber venting that utilizes air as a cooling source is necessary.

-In order to conduct suppression chamber venting, opening motor-operated (MO) valves as well as air-operated (AO) valves are necessary.

#### 2) Heat removal via Shutdown Cooling Mode (Within 3-7 days)

##### Concepts

-Shutdown cooling mode procedures by residual heat removal system (RHR) that utilizes sea water as a cooling source is necessary.

-Thus, in addition to ensuring a power source, restoring the seawater system utilized as the ultimate heat sink for preparing alternative pumps, or motor repairs is necessary.

#### Reactor Core Isolation Cooling System (RCIC)

Necessary Equipment	Flooding Countermeasure for system	Countermeasure in a flexible manner
Pump/Turbine	Flood protection for the RCIC Room	Establishing manual activation procedures
DC Power Supply (Battery, switchgears, etc.)	Flood protection for the battery room and the area where the main bus panel is located or considering rearrangement	Preparing Power-Supply cars

#### Stand by Liquid Control System (SLC) or Control Rod Drive (CRD)

Necessary Equipment	Flooding Countermeasure for system	Countermeasure in a flexible manner
SLC pump or CRD pump	-	Flooding protection for the pump area
Water Source	-	Establishing water supply procedure from the purified water tank
AC Power	-	Flooding protection for power supply equipment, including Emergency D/G(EDG), deploying power-supply car, securing an outside power source as an alternative to the EDG

Necessary Equipment	Flooding Countermeasure for system	Countermeasure in a flexible manner
N2 tanks	-	Preparing spare tanks
DC power supply (Battery, switchgears, etc.)	Flood protection for the battery room and the area where the main bus panel is located (or considering rearrangement)	Preparing portable batteries

#### Fire Protection System (FP)

Necessary Equipment	Flooding Countermeasure for system	Countermeasure in a flexible manner
Diesel-driven fire pumps	Flood protection for the pump room	Preparing fire engines and constructing water transfer lines, and establishing procedure for seawater injection
Batteries	Flood protection for the battery room	Preparing portable batteries
Diesel fuel	Fuel deployment (including delivery logistics)	-

#### Make-up Water Condensate system (MUWC)

Necessary Equipment	Flooding Countermeasure for system	Countermeasure in a flexible manner
MUWC pump	Flood protection for the pump room	Establishing procedures for supplying of water among tanks
AC power	Flood protection for power supply equipment, including EDG or considering rearrangement	Preparing power-supply cars, securing an outside power source as an alternative to the EDG

Necessary Equipment	Flooding Countermeasure for system	Countermeasure in a flexible manner
AC power (MO-valve, solenoid valve for AO-valve)	Flood protection for power supply equipment including EDG or considering rearrangement	Preparing power-supply cars, portable AC generator or portable batteries
Compressed air (For AO-valve operation)	Portable air compressor (or tank preparation)	Remodeling AO-valve so that it can be operated manually

Necessary Equipment	Flooding Countermeasure for system	Countermeasure in a flexible manner
AC power (RHR pump)	Flood protection for power supply equipment including EDG or considering rearrangement	-Preparing alternative pump -Preparing mobile heat exchangers
RCW/RSW pump	Preparing spare motor	
AC power (RCW/RSW)	Flood protection for power room	Preparing Power-Supply cars, maintaining an outside power source as an alternative to the EDG

### 3) Heat removal from spent fuel pool (Within 7-10 days: Depending on decay heat from spent fuels)

#### Concepts

-Spent fuel pool cooling and cleanup system (FPC) is basically tsunami-resistant since it is located inside the reactor building. Hence it is important to maintain the power source.

-Furthermore, in light of having a sufficient amount of time to respond, monitoring utilizing the instruments is important.

### (6) Ensuring power supply to the monitoring instruments (Required within 1 hour)

#### Concepts

-During the Fukushima accident, the monitoring instruments were rendered inoperable and restoring power to the instruments took time.

-Thus ensuring immediate power supply for instruments is important.

### (7) Mitigation measures following reactor core damage

#### Concepts

-During the accident, not only was the containment function lost, but also restoration efforts were seriously hampered due to the hydrogen explosion caused by the possible leak of hydrogen from the primary containment vessel to the building.

-In light of defense in depth, it is important to establish countermeasures in the case of the reactor core damage, which happened at Fukushima Daiichi

### (8) Common Countermeasures

-In addition to implementing each countermeasure, it is important to reinforce the supporting work and auxiliary equipment for safe and efficient activity in order to achieve the aforementioned countermeasures effectively.

### Other mid and long-term Technical Issues

-In this study, the aforementioned core damage countermeasures have been established. In addition, mid and long-term technical issues such as those listed in the right-hand table should be considered

-These technical issues will be considered separately.

Necessary Equipment	Flooding Countermeasure for system	Countermeasure in a flexible manner
FPC pump	Flooding protection for the pump room Installation of water level detection instruments or a thermometer inside the pool	-Preparing fire engines -To establish redundancy with fire protection piping
AC power	Flooding protection for power supply equipment or considering rearrangement	Preparing Power-Supply cars

Necessary Equipment	Flooding Countermeasure for system	Countermeasure in a flexible manner
DC power	Waterproofing the battery room and the area where the main bus panel is located (or considering rearrangement)	-Preparing portable batteries -Preparing Power-Supply cars and portable battery chargers

Items	Countermeasure
Hydrogen Accumulation Prevention	Installing equipment or establishing procedures for drilling holes through the roof or opening the blow-out panels in order to improve reactor building ventilation.
Mitigation of Radioactive Material release	Establishing the water injection procedures to the PCV via fire engines etcetera as is being done with the suppression chamber venting. (Established for smooth venting via water filtering)

Items	Countermeasure
Outside Power Source	Reviewing the seismic improvement for the substation facilities, assessing the destruction of the embankment that could lead to transmission tower damage, and setting up facilities that will contribute to power transmission reliability.
Debris Removal Equipment	Preparing equipment to remove debris hampering restoration activity.
Securing communication tools	Establishing flexible communication measure such as the preparation of walkie-talkies or satellite phones as well as ensuring a power source
Securing Lighting Equipment	Preparing high power lighting equipment and headlights that will allow workers free use of both hands so that they will be ready to respond safely, quickly and precisely.
Health Protection Equipment	An abundant supply of protective gear, masks, APDs, portable air refreshers, etc. should be on hand along with the deployment of the power supply car in order to ensure that workers will be able to restore the main control room ventilation system promptly.

Items	Action Plan
Isolation Signal Review	During the Fukushima accident, the loss of the isolation condenser cooling function was caused by the valve closing up due to loss of DC power. Hence, the concept concerning the isolation signal should be reviewed.
Venting line improvement	In order to improve venting that is able to significantly filter out radioactive materials, measures such as the aggressive activation of the Rupture Disk will be looked into while taking the accidental release of radioactive materials into consideration
Mitigation measures for radioactive material release during venting	The design of a filter vent to mitigate the release of radioactive materials will be considered
Surveillance Instrument Improvements	Given that the water level gauge measurements deviated greatly from the actual value at the power station, research and development in this area will be developed.