Examination of Accident at Tokyo Electric Power Co., Inc.'s Fukushima Daiichi Nuclear Power Station and Proposal of Countermeasures (Summary)

October 2011

Japan Nuclear Technology Institute Examination Committee on Accident at Fukushima Daiichi Nuclear Power Station

Introduction

This report is a compilation of the aggregate efforts of the nuclear power industry comprising electric power operators and manufacturers in Japan as concerns the accident at Tokyo Electric Power Company Incorporated's Fukushima Daiichi Nuclear Power Station ("Fukushima Daiichi") which resulted from the Great East Japan Earthquake that occurred on March 11, 2011. This report analyzes the accident based on published facts, knowledge grounded in operational experience accumulated to date, and knowledge developed through plant design, and formulates measures and proposals to be addressed in the future.

We believe that implementing these measures and proposals will ensure that nuclear power stations are even safer.

1. Overview of Fukushima Daiichi Nuclear Power Station and the Accident

1.1 Overview of Fukushima Daiichi Nuclear Power Station

Fukushima Daiichi is located in northeastern Japan (latitude 37 degrees north and longitude 141 degrees east), and looks out over the Pacific Ocean at a distance approximately 225km north of Tokyo.

The first unit commenced operation in 1971, and has a total electrical output of 4,696MW. The principal specifications for each unit are given in the table below.

Unit	Output (MW)	Start of operation	Reactor type	Containment model	General contractor
1	460	March 26, 1971	BWR-3	Mark I	GE
2	784	July 18, 1974	BWR-4	Mark I	GE & Toshiba
3	784	March 27, 1976	BWR-4	Mark I	Toshiba
4	784	October 12, 1978	BWR-4	Mark I	Hitachi
5	784	April 18, 1978	BWR-4	Mark I	Toshiba
6	1100	October 24, 1979	BWR-5	Mark II	GE & Toshiba

1.2 Overview of Accident Following Earthquake off Pacific Coast in the Tohoku Region

At Fukushima Daiichi, as Units 1 thru 3 were operating and Units 4 thru 6 were in the refueling outage, an earthquake occurred off the Pacific coast in the Tohoku [Northeastern] region of Japan at 14:46 on March 11, 2011, and Units 1 thru 3 automatically shut down in accordance with the signal indicating "increasing seismic acceleration." Following the reactor shutdown, generators shut down and, moreover, functionality of any external power source system equipment was also lost. However, AC power for each unit was supplied by emergency diesel generators ("emergency DG").

Subsequently, due to the tsunami which struck the station, all emergency DG except for one air-cooled unit at Unit 6 shut down, and all AC power sources at Units 1 thru 5 were lost.

Furthermore, DC power sources were also lost due to inundation at Units 1, 2 and 4, and such function was also lost at Unit 3 as a result of batteries being depleted, resulting in a situation where all power being supplied to Units 1 thru 4 was lost.

As a result of the loss of AC power sources, existing cooling function for reactors and spent fuel pools was lost, and cooling was attempted using temporary power sources and alternative coolant injection, but the situation escalated into one where fuel in the core was damaged and radioactive material released into the environment.

1.2.1 Earthquake Impact

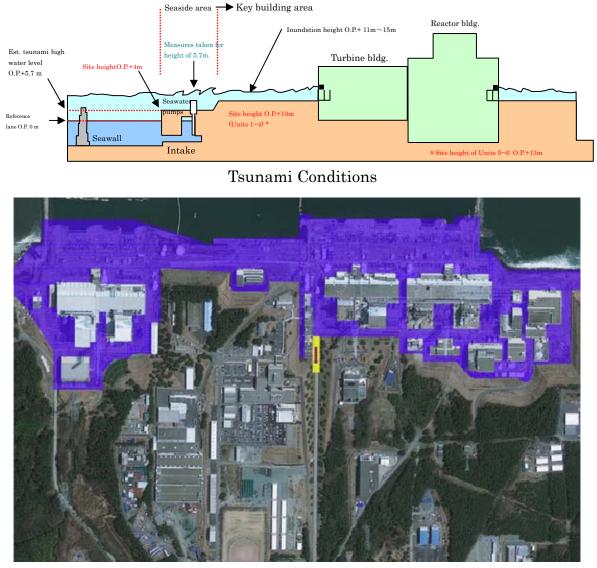
In observation record of the earthquake, although the response spectrum based on standard ground motion Ss was surpassed in some periodic bands, values were equivalent overall. In addition, prior to the tsunami arrival, equipment on safety systems was functioning. The earthquake response analysis which Tokyo Electric Power Company conducted of the reactor building as well as equipment and pipe systems critical for earthquake safety on the basis of observation records, showed that all equipment important for safety maintained its functionality.

1.2.2 Tsunami Impact

The height of the tsunami exceeded the water level designed for tsunami as shown in the diagram below, and almost the entire area around important buildings was inundated. Although there was no significant damage to the structural framework of key buildings, seawater flowed into the buildings through openings and other penetrations, and a broad expanse of the underground levels was also inundated through passageways, stairwells and other such routes.

In addition, many of the emergency DGs and electric power panels which were installed on the lower levels of the reactor and turbine buildings were damaged by tsunami. With the exception of Unit 6, functionality of emergency power sources was lost.

Moreover, all seawater pumps for cooling were damaged by tsunami, and any means of releasing heat from the core or other areas into the sea were lost. Important safety equipment also was damaged by seawater flooding into the buildings.



Scope of Inundation within Power Station (Purple area indicates seawater inundation and yellow area inidcates a run-up point)

2. Analysis of Accident Event Causes and Issues Derived

2.1 Course of Progression of Accident Events

The course along which events progressed is shown in Diagram 2.1-1, using the example of Unit 1.

The reactor at Unit 1 was cooled by the isolation condenser ("IC") in accordance with the shutdown procedures and guided into a cold shutdown, but the tsunami caused a loss of emergency AC and DC power source functionality, and it is possible that most of the valves were in a closed state.

Consequently, it is inferred that the core was not cooled, became damaged and hydrogen was generated which leaked from the containment vessel to the reactor building, leading to the hydrogen explosion.

The reactors in Units 2 and 3 were being cooled using the reactor core isolation cooling system ("RCIC") and other functions in accordance with shutdown procedures.

After the tsunami struck, Unit 2 maintained core cooling using the RCIC even after the loss of emergency AC and DC power sources. However, after the RCIC shut down, time was required until alternative coolant could be injected and the amount of coolant injected was small, so it is inferred that such conditions led to core damage. Also, a rapid decrease in pressure in the pressure suppression chamber and containment vessel was confirmed. Subsequently, it is inferred that hydrogen leaked from the reactor pressure vessel and containment vessel.

At Unit 3, core cooling was secured through operation of the RCIC and high pressure coolant injection system ("HPCI") even after the loss of emergency AC power sources, but depletion of the batteries led to a loss of the DC power source, and the RCIC and HPCI lost functionality. Time was required until alternative coolant could later be injected and the amount of coolant injected was small, so it is inferred that the core was damaged and hydrogen generated, and that the hydrogen leaked into the containment vessel and reactor building, which led to the hydrogen explosion.

Unit 4 was in the refueling outage and all of the fuel was stored in the spent fuel pool. From the results of fuel observations with a camera and the results of analysis of nuclides in the pool water, it is inferred that there was no significant damage to the fuel. It is possible that hydrogen which exploded in Unit 4 was hydrogen which generated in Unit 3 and seeped into Unit 4 through the standby gas treatment system exhaust to then build up inside the reactor building.

In order to clarify the factors in the progression of events above, the particulars

divaricating convergence and expansion of events have been arranged and consolidated into the event tree shown in Diagram 2.1-2.

The subsequent progression of events differs depending on (1) the circumstances entailed in loss of power source functions due to the earthquake and tsunami, (2) condition of core cooling function, and (3) success or failure of measures to mitigate events after core damage, as well as other factors.

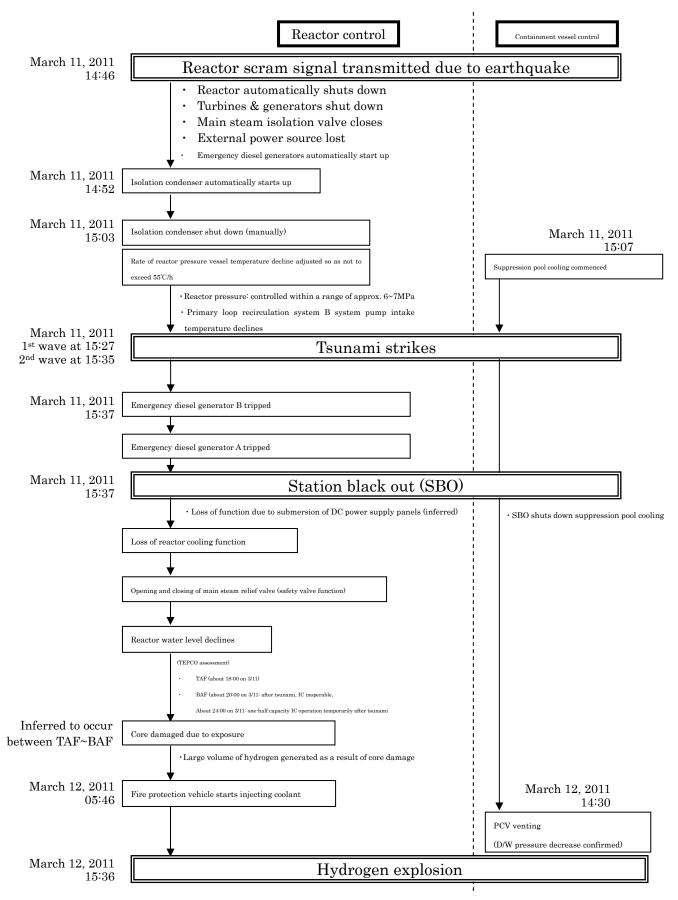
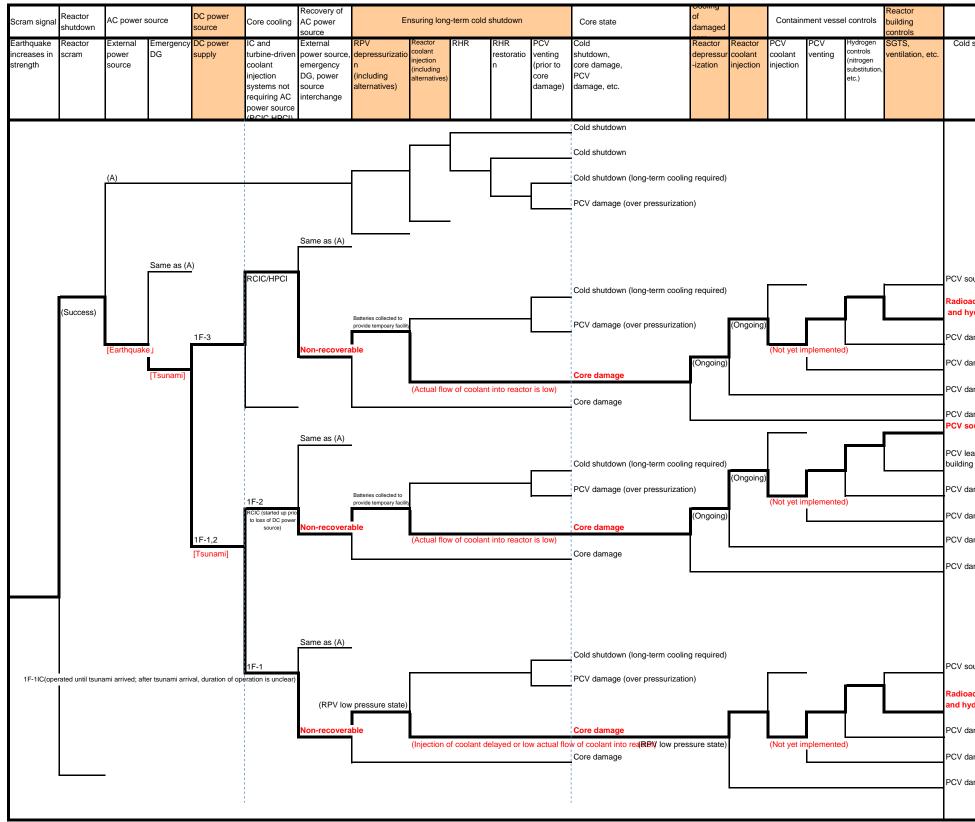


Diagram 2.1-1 Course of Accident Event Progression at Fukushima Daiichi Unit 1 Nuclear Power Station after Earthquake





Final state
shutdown, core damage, PCV damage, etc.
ound or PCV leakage (over heating)
activity release (PCV leakage (over heating) ydrogen burning in building)
amage (hydrogen explosion Accident sequence
amage (over pressurization presumed to have
Accident sequence presumed to have occurred at 1F-2
amage (DCH, etc.) Cocurred at 1P-2
akage (over heating) and hydrogen burning in g
amage (hydrogen explosion)
amage (over pressurization)
amage (MCCI, etc.)
amage (DCH, etc.)
ound or PCV leakage (over heating)
activity release (PCV leakage (over heating) drogen burning in building)
amage (hydrogen explosion Accident sequence
amage (over pressurization)
amage (MCCI, etc.)

2.2 Analysis of Accident Event Causes and Issues Derived

2.2.1 Analysis of Causes from the Progression of Accident Events

From an analysis of the accident using the course of accident event progression (event tree) 2.1, three major factors, which formed significant turning points in the progression of the accident and escalated the accident, have been deduced ((1) inability to supply AC power to the station, (2) inability to remove heat from the reactor, and (3) leakage of hydrogen into the building and the hydrogen explosion), and issues pertaining to these factors have been derived.

The results of a factor analysis regarding the "inability to supply any AC power source" are shown in Diagram 2.2.1.

(1) Inability to Supply AC Power to the Station

The inability to supply power attributable to the external power source, the inability to supply power using emergency diesel generators, the inability to interchange power sources, and the inability to restore power at an early stage have been cited as factors from an equipment and operational aspect as to the inability to supply AC power to the station.

(2) Inability to Remove Heat from Reactor

The inability to depressurize using the main steam safety relief valve, the inability to remove heat using the core spray and residual heat removal system, the inability to remove heat using accident management equipment (alternative coolant injection equipment), and the inability to vent the containment vessel have been cited as factors from an equipment and operational aspect that failed to remove heat from the reactor.

(3) Leakage of Hydrogen into Building and Hydrogen Explosion

The factor which led to hydrogen leaking into the building has been given to be hydrogen leaking from the containment vessel and circulating into and around the common exhaust equipment, and one of the causes of the hydrogen explosion has been cited as the inability to detect hydrogen leaking into the reactor building.

2.2.2 Consolidation of Issues Confirmed as Functional Aspects

The basic safety functions of a nuclear power station are "stopping," "cooling," and "confining," and the factors which caused these respective functions to malfunction were analyzed. In addition, the basic requirements necessary for implementing "stopping," "cooling," and "confining" operations (main control room heating, ventilating and air conditioning system, communication equipment and other equipment environments) were also analyzed.

Moreover, the common factors which impeded the achievement of each function were the "inability to supply electric power" and "inoperability of auxiliary cooling," and these factors were analyzed and issues derived.

The results of an analysis of accident factors according to function for Unit 1 and the issues consolidated are shown in Table 2.2.2.

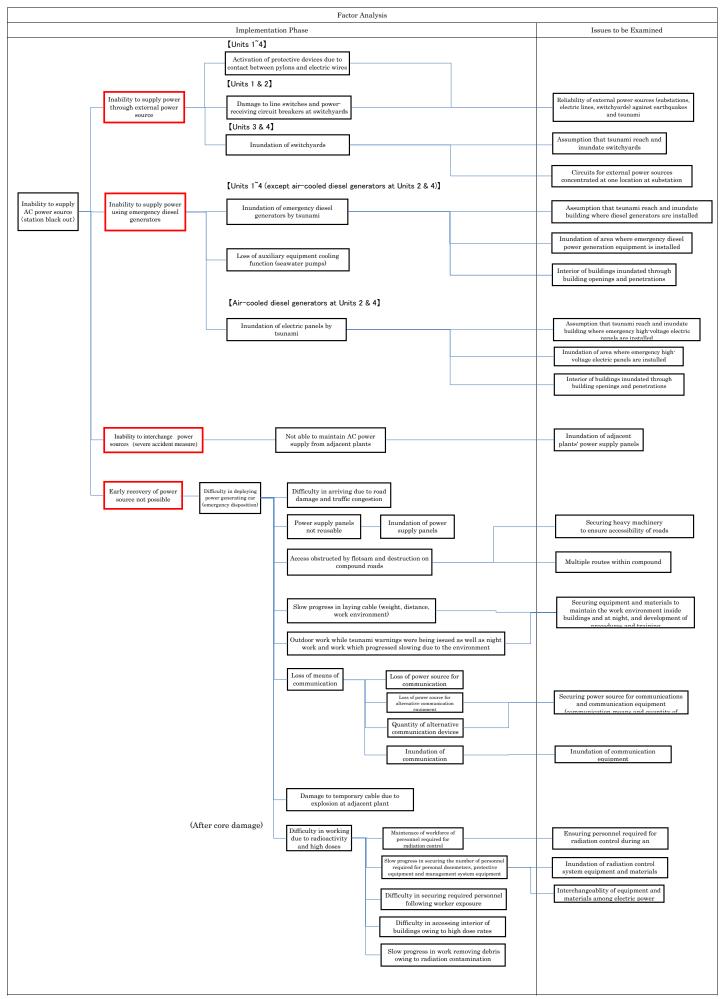


Diagram 2.2.1 Analysis of Factors Leading to Inability to Supply AC Power

	Safety Functions	Rolated For	uipment, etc.		2.2. Analysis of the 1F U1 accident factors Function or State of Deteriorated Function	Factor Analysis	
			ction systems,	Loss of	r unction or State of Deteriorated Function	ractor Analysis	+
	Emergency shutdown function for reactor	control rods a	and control rod systems	0	(Operated normally during earthquake)	_	
Stopping	Alternative reactivity	Recirculation p	pump trip (AM)	_	(Not necessary due to scram success)	_	
	control	Alternative	rod insertion	_	(Not necessary due to scram success)	_	
	Subcriticality maintenance function	Standby liquid	l control system	_	(Not necessary due to scram success)	-	
		External p	ower source	×	Loss of external power source due to earthquake	Earthquake damaged Okuma line 1L receiving-line circuit breaker at switchyard for Units 1 & 2	① F
			iesel generator	×	Loss of function due to inundation	Inundation of emergency diesel generator by tsunami	
			voltage power oply	×	Loss of function due to inundation	Inundation of 6.9kV high-voltage power supply panels by tsunami	3 ^I
	Power supply function	480V low-voltage power			Loss of function due to loss of 6.9kV high-voltage power supply	Inundation of 6.9kV high-voltage power supply panels by tsunami	
		sur	pply	×	Loss of function due to inundation	Inundation of 480V low-voltage power supply panels by tsunami	Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: constraint of the second symbol Image: consecond symbol <t< td=""></t<>
		125V DC p	ower supply	×	Loss of function due to inundation	Inundation of 125V DC power supply panels by tsunami	(5) I
		Power supply interchange		×	Power supply from adjacent plant not able to be	Tsunami caused loss of station power supply at adjacent plant	
					Difficulty in arriving at site	Difficulty in arriving due to road damage and traffic	
						Connection not possible due to inundation of Unit 1 AC power supply panels	
Support	Alternative power supply					Difficulty with work laying cable (weight, distance and work environment)	8 I
systems	function	-	erating car deployment)	×	Tie-in work progressed slowly	Intermittant aftershocks and continuously issued tsunami warnings	(1) R (2) In (3) In (3) In (3) In (3) In (4) In (5) In (5) In (7) F ower (5) In (7) F ower (7) F ower (8) L ni (8) L (9) S (9) C (9) S mi (10) In symmi (11) In SS mi (11) In SS mi (11) In SS mi (11) In SS (11) In SS (12) S In (12) S In (12) S
						Loss of communication means due to loss of AC power supply	9
					No capacity to supply electric power	Automatic shutdown of power generating car and damage to	
		Containment cooling service				cable due to explosion at Unit 1 reactor building Inundation of containment cooling service water system	I
			system	×	Loss of function due to inundation	pumps by tsunami	② In ③ In ③ In ③ In ⑤ In ⑤ In ⑦ F ☞ ⑦ F ③ In ⑦ F ⑨ ⑨ ⑦ S ⑨ ⑨ ⑧ S ⑨ ⑨ ⑧ S ⑨ ⑨ ⑧ S ⑨ ⑨ ⑧ S ⑨ ⑨ ⑧ S ⑨ ⑨ ⑧ S ⑨ ⑨ ⑧ S ⑨ ⑨ ⑧ S ⑨ ⑨ ⑧ S ⑨ ⑨ ⑧ S ⑨ ⑨ ⑧ S ⑨ ⑨ ⑧ S ③ ⑨ In S S S S S S ③ S ③ S ③ ⑤ S ⑤ S
		Auxiliary cooling seawater system			Loss of function due to loss of AC power source	Inundation of 6.9kV high-voltage power supply panels by	
				×	Loss of function due to inundation Loss of function due to loss of AC power source	Inundation of auxiliary cooling seawater pumps by tsunami	
	Auxiliary cooling function			~	Loss of function due to loss of AC power source	Inundation of 6.9kV high-voltage power supply panels by Inundation of 125V DC power supply panels by tsunami	
		Reactor building cooling			Loss of function due to loss of DC power source	Inundation of auxiliary cooling seawater pumps by tsunami	
				~	seawater system		5
		water	system	×	Loss of function due to loss of AC power source	Inundation of 6.9kV high-voltage power supply panels by	
		r Main steam safety relief			Loss of function due to loss of DC power source	Inundation of 125V DC power supply panels by tsunami	S
	Pressure relief function for reactor coolant pressure boundary	Main steam safety relief valve (safety valve function) High pressure coolant		-	(Controlled by isolation condenser)	-	
	Doundary			×	Loss of function due to loss of DC power source	Inundation of 125V DC power supply panels by tsunami	Ę
					Functionality deteriorated due to loss of DC power	Inundation of 125V DC power supply panels by tsunami	
		Isolation	condenser	Δ	source (remote operation not possible) Isolated due to transmission of isolation signal		
		(main unit)		(Operated temporarily)	(inner isolation valve halfway open due to loss of AC power supply)	Operation of pipe rupture detection circuit due to loss of DC power supply	
	High-pressure core cooling function	Isolation	water purified	×	Loss of function due to loss of AC power source	Inundation of 480V low voltage power supply panels by tsunami	
		condenser (support	Fire	Δ	Electric motor pumps unusable due to loss of external power source	Earthquake damaged Okuma line 1L receiving-line circuit breaker	s
		system) protection system	-	(Operated temporarily)	Shutdown of diesel driven fire protection pump	Mechanical failure (presumed)	
		Standby liquid control system			Loss of function due to loss of AC power source	Inundation of 480V low voltage power supply panels by	5
	Alternative coolant injection			×	Slow progress made in operation to restore power supply	[Non-recoverable]Automatic shutdown of power generating car and damage to cable due to explosion at Unit 1 reactor	
	function				Loss of function due to loss of AC power source	Inundation of 480V low voltage power supply panels by	5
	(high pressure)	Conrol rod drive hydraulic system (AM)		×	Loss of function due to loss of DC power source	Inundation of 125V DC power supply panels by tsunami	
	. 3 F				Loss of function due to loss of auxiliary cooling seawater system	Inundation of auxiliary cooling seawater pumps by tsunami	
	Reactor depressurization function	va (relief	i satety reliet live f valve automatic	×	Loss of function due to loss of DC power source	Inundation of 125V DC power supply panels by tsunami	s

	Issues to be addressed
	_
	_
	① Reliability of switchyard circuit breakers
	2 Inundation of emergency diesel generators 3 Inundation of 6.9kV high-voltage power supply
	3 panels
	Same as ③
	Inundation of 480V low-voltage power supply panels
	5 Inundation of 125V DC power supply panels
ant	6 Inundation of power supply panels at adjacent
	⑦ Furnishing alternative electricity from outside
ver	Same as ③ and ④
rk	(8) Laying of cable for alternative power supply
	_
oly	(9) Communication means during loss of AC power
	(9) supply
io.	-
	$_{f 10}$ Inundation of containment cooling service water
	system pumps by tsunami
	Same as ③
i	① Inundation of auxiliary cooling seawater pumps
	Same as ③ Same as ⑤
i	Same as (1)
	-
	Same as ③ Same as ⑤
	—
_	Same as ⑤
	Same as 5
~	
C	¹ Suitablity of design of isolation signal to handle
	loss of DC power supply
	Same as ④
	Same as $①$
	_
	Sama as A
or .	Same as (4)
g	-
	Same as ④ Same as ⑤
i	
-	Same as (1)
	Same as 5

Safety Functions		Related Equipment, etc.	Loss of	Function or State of Deteriorated Function	Factor Analysis	Issues to be addressed
Cooling			×	No capacity to inject coolant due to inablity to depressurize reactor	Inundation of 125V DC power supply panels by tsunami	Same as (5)
Cooning	Low-pressure core cooling	Core annou austam		Loss of function due to loss of AC power source	Inundation of 6.9kV high-voltage power supply panels by	Same as ③
	function	Core spray system		Loss of function due to loss of DC power source	Inundation of 125V DC power supply panels by tsunami	Same as (5)
				Loss of function due to loss of containment cooling	Inundation of containment vessel cooling seawater pumps by	Same as 🔟
				service water system	tsunami	Same as w
		Make up water condensate	×	No capacity to inject coolant due to inablity to	Inundation of 125V DC power supply panels by tsunami	Same as (5)
		system (AM)	~	Loss of function due to loss of AC power source	Inundation of 480V low voltage power supply panels by	Same as ④
				No capacity to inject coolant due to inablity to depressurize reactor	Inundation of 125V DC power supply panels by tsunami	Same as ⑤
		Containment vessel cooling	×	Loss of function due to loss of AC power source	Inundation of 6.9kV high-voltage power supply panels by	Same as ③
		system (AM)	*	Loss of function due to loss of DC power source	Inundation of 125V DC power supply panels by tsunami	Same as 5
				Loss of function due to loss of containment cooling	Inundation of containment vessel cooling seawater pumps by	Same as 🔟
				service water system	tsunami	
		Fire protection system (AM)	×	No capacity to inject coolant due to inablity to	Inundation of $125V$ DC power supply panels by tsunami	Same as (5)
		The protection system (AW)	~	depressurize reactor Shutdown of diesel driven fire protection pump	Mechanical failure (presumed)	_
	Alternative coolant injection			No capacity to inject coolant due to inability to		
	function			depressurize reactor	Inundation of 125V DC power supply panels by tsunami	Same as (5)
	(low pressure)			Difficulty in securing coolant flow required	Difficulty in ensuring capacity of fire control cisterns used as water sources	(13) Depletion of fresh water supply
		Fire protection vehicle	Δ (Insufficient		Obstructions resulting from earthquake and tsunami	Obstructions resulting from earthquake and tsunami
		(support during Chuestsu-oki	flow, and work		High dose debris and evacuation of site due to explosion at	Worsened working environment due to rise in
		earthquake)	progressed		Unit 1 reactor building	dosage and hydrogen explosion
		-	slowly)	Work progressed slowly	Seawater injection hose damaged and relaid due to explosion	Same as 🚯
			-		at Unit 1 reactor building	
					Intermittant aftershocks and continuously issued tsunami	_
					warnings	
					Loss of communication means due to loss of AC power supply	Same as (9)

2.3 Summary of Analysis of Causes

The number one cause as to why the accident at Fukushima Daiichi escalated was that the loss of power sources for driving safety system equipment brought about a secondary loss of a number of safety system equipment functions.

With regard to power sources, if electric power generation shuts down, power is first supplied from an external power source. The system is designed so that, if the external power source loses functionality, an emergency DG supplies power to safety system equipment. This time, functionality of the external power source was lost due to the earthquake, and then tsunami submerged emergency DGs and inundated electric power panels. Because access to power source connections was lost due to inundation of the panels, rapid restoration was not possible, which led to the accident escalating.

The essence of the problem is that preparations assuming a contingency brought about by tsunami strike were ineffectual. What was necessary to prevent an accident from escalating was that provisions be made to implement profound measures for ensuring safety where the preparations undertaken assuming an escalating accident scenario would be expressed as: "If a tsunami floods the site, electric power panels and various important safety equipments will be submerged. In response, necessary countermeasures will be identified and the required equipment provided for in advance. Furthermore, all needed preparations will be made beforehand on the chance that such equipment does not function."

The fact that external power sources, emergency DGs, electric power supply panels and other equipment related to power supply lost functionality, and that preparations were ineffectual for a situation in which function of such facilities was lost due to a tsunami are considered to have been significant factors leading to escalation of the accident.

The issues deduced in 2.2 have been arranged and consolidated into the following five categories.

- · Preparations for earthquakes and tsunami (natural hazards)
- Preparation of power sources
- Measures to counter heat sink loss
- Hydrogen countermeasures
- Preparations for emergency situations

Category Deduced issues

Category	Deduced issues		
Preparations for	• Loss of function of external power sources due		
earthquakes and	to earthquake or tsunami		
tsunami	• Loss of function of switching stations due to tsunami		
	· Loss of function of seawater facilities due to		
	tsunami		
	• Inundation of seawater pump rooms		
	\cdot Loss of function of emergency DG due to		
	tsunami		
	\cdot Infiltration of seawater through building		
	openings		
Preparation of power	• Incoming lines for external power sources at		
sources	one location		
	• Submersion of power supply equipment due to		
	tsunami		
	• Depletion of DC power supplies		
	• Securing storage battery capacity		
	• Furnishing of power source externally (power		
	generating cars, etc.)		
	• Responding to secure supply of AC power		
	Laying of cable for alternative power sources		
Measures to counter	 Inundation of seawater pumps 		
heat sink loss	• Not all equipment is damaged at once in the		
	face of a tsunami		
	• In preparation for damage by tsunami, means		
	are provided that are not impacted by tsunami		
	• Transmitting a signal to isolate the isolation		
	condenser in response to a loss of DC power		
	source		
	• Securing materials and equipment to respond		
	to a loss of driving source for valves		
	• Development of procedures and training		
	• Depletion of fresh water supplies		
	• Maintaining function of fire protection pipes		
	against the occurrence of earthquake or		
	tsunami		
	• Furnishing fuel for fire protection vehicles		
	• Enhancing driving source for pressure vent line		
	valves		
	• Inoperability of ruptured disks at low pressure		

Category	Deduced issues
	• Securing compressed air for maintaining containment vessel vent valves in an open state
Hydrogen countermeasures	 Enhancing seals on penetrations and containment vessel gaskets Circulation of hydrogen gas into and around buildings from pressure vent lines Circulation of hydrogen gas into and between units having a common exhaust stack Retention of hydrogen inside reactor building Hydrogen detection
Preparations for emergency situations	 Securing personnel for radiation control Tsunami protection measures for radiation control equipment Obstructions resulting from earthquakes and/or tsunami Communication means when AC power sources are lost Materials and equipment for supporting night and outdoor work Materials and equipment for securing accessibility of roads Securing multiple routes within the station grounds Interchange system between electric power operators Worsening environment due to hydrogen explosions and rising doses

For some of the aforementioned issues, such as enhancing seals on penetrations and containment vessel gaskets, securing storage battery capacity, and transmitting a signal to isolate the isolation condenser in response to a loss of DC power source, it has been determined, having taken into account the feasibility and effectiveness of measures, that these issues be covered by measures to address other issues and not measures directly responding to such issues.

3. Proposed Measures

After examining the extracted issues intently, the facts were arranged once again in line with the course along which the same accident progressed and countermeasures based on the issues were deduced.

All measures deduced have been arranged in a diagram and are shown in Diagram 2.4-1.

Also, as shown in Table 2.4-1, safety functions, that is measures directly related to power supplies, heat sinks (coolant injection and cooling), measures to prevent a hydrogen explosion, maintaining the water level in the spent fuel pool (SFP) as well as ensuring other functions have been arranged in accordance with the deep protection approach, and high priority measures have been selected from among all the countermeasures. From the standpoint of preventing a recurrence of the accident (giving depth to preparations assuming a scenario in which an accident escalates), even more measures have been put in place in the fourth tier.

The measures have been selected in combination, giving consideration to the safety of the whole plant, and various combinations of these measures are conceivable depending on the conditions at respective power stations and strategies for ensuring safety.

It is necessary to have effective measures sufficient to prevent and mitigate severe accidents by putting in place measures in a multitiered manner so that safety is able to be ensured, even if the measures readied, which are a combination of the various steps detailed here plus those taken into account since the design and construction stages, lose functionality in succession.

Keeping the aforementioned point in mind, the following measures are those which are particularly recommend for adoption by all companies.

-Power sources

- Installation of seawalls or tide embankments for important safety equipment
- Preventing against inundation of sections where important safety equipment is installed
- Preventing against inundation including improving seals around penetrations and air inlets and other openings in proportion to the height of inundation
- Development of watertight locations for deployment of power receiving transformers and switchyards or measures to prevent against inundation of equipment
- Development of watertight locations for deployment of DC power supply equipment or measures to prevent against inundation of equipment

- Deployment of power generating cars or large capacity power supplies (gas turbines and diesel generators), and development of procedures for emergencies
- Development of routes for recharging DC power supplies by means of backup power sources
- Improving reliability through measures to prevent against inundation of equipment for interchanging power sources between units (severe accident measure)

-Heat sinks (coolant injection and cooling)

- Bulkheads around seawater pumps and other inundation protection measures
- Deployment of spare parts for seawater pump motors
- Deployment of mobile seawater pumps
- Preventing against inundation of sections where the emergency core cooling systems and other safety system equipment are installed
- Measures to prevent against inundation of equipment for severe accident measures
- Backup power supplies, standby air cylinders and other preparations for SRV drives (BWR)
- Ensuring core cooling via SG by means of the main steam relief valve (PWR)
- Deployment of backup power sources and driving sources for venting operations (BWR)
- Improving reliability of existing coolant injection systems through deployment of backup power generating cars or large capacity power supplies
- Movable pumps, hoses, etc. not dependant on existing equipment
- Securing water supplies
- Releasing heat into the atmosphere through containment vessel venting (BWR)

-Measures to protect against hydrogen explosion

- Releasing and reducing retained hydrogen
- Measures to prevent against inflow from pressure strengthened venting lines
- Preventing hydrogen from circulating around between units having a common exhaust stack

Since the accident at the Fukushima Daiichi Nuclear Power Station, all sorts of measures have been adopted by companies, and these which are shown in

Table 2.4-1 along with the approach at a typical plant. At the present stage, it is able to be confirmed that necessary measures have been adopted at each stage from the standpoint of deep protection, and a substantial improvement in safety has already been achieved.

- Preparations Against Earthquakes and Tsunami 1, 6, 7, 9, Power Supply Arrangements 3, 5, Responding to Loss of Heat Sink (BWR) 2, 4, 8, 10, 11

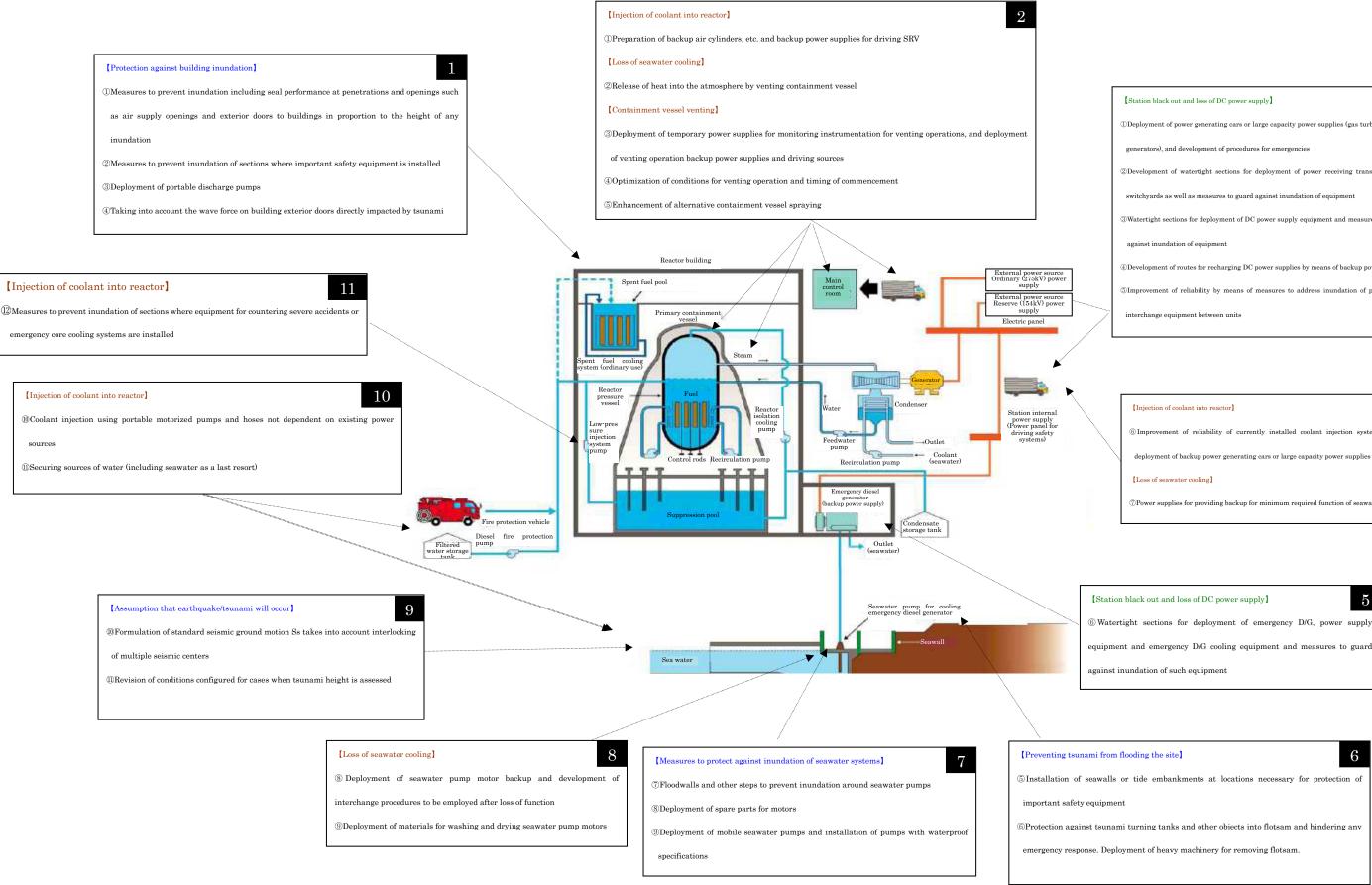
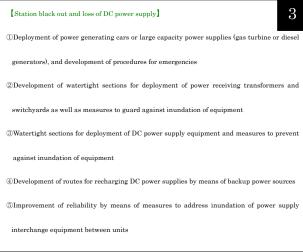
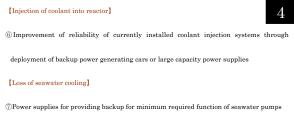


Diagram 2.4-1 Typical Measures 1/3





ation black out and loss of DC power supply] 5
atertight sections for deployment of emergency D/G , power supply
oment and emergency D/G cooling equipment and measures to guard
nst inundation of such equipment

— Hydrogen Countermeasures 14, Preparations for Emergencies 12, 15, 16, 17, 18, 20, 21, Ensuring Soundness of Spent Fuel 13, 19 —

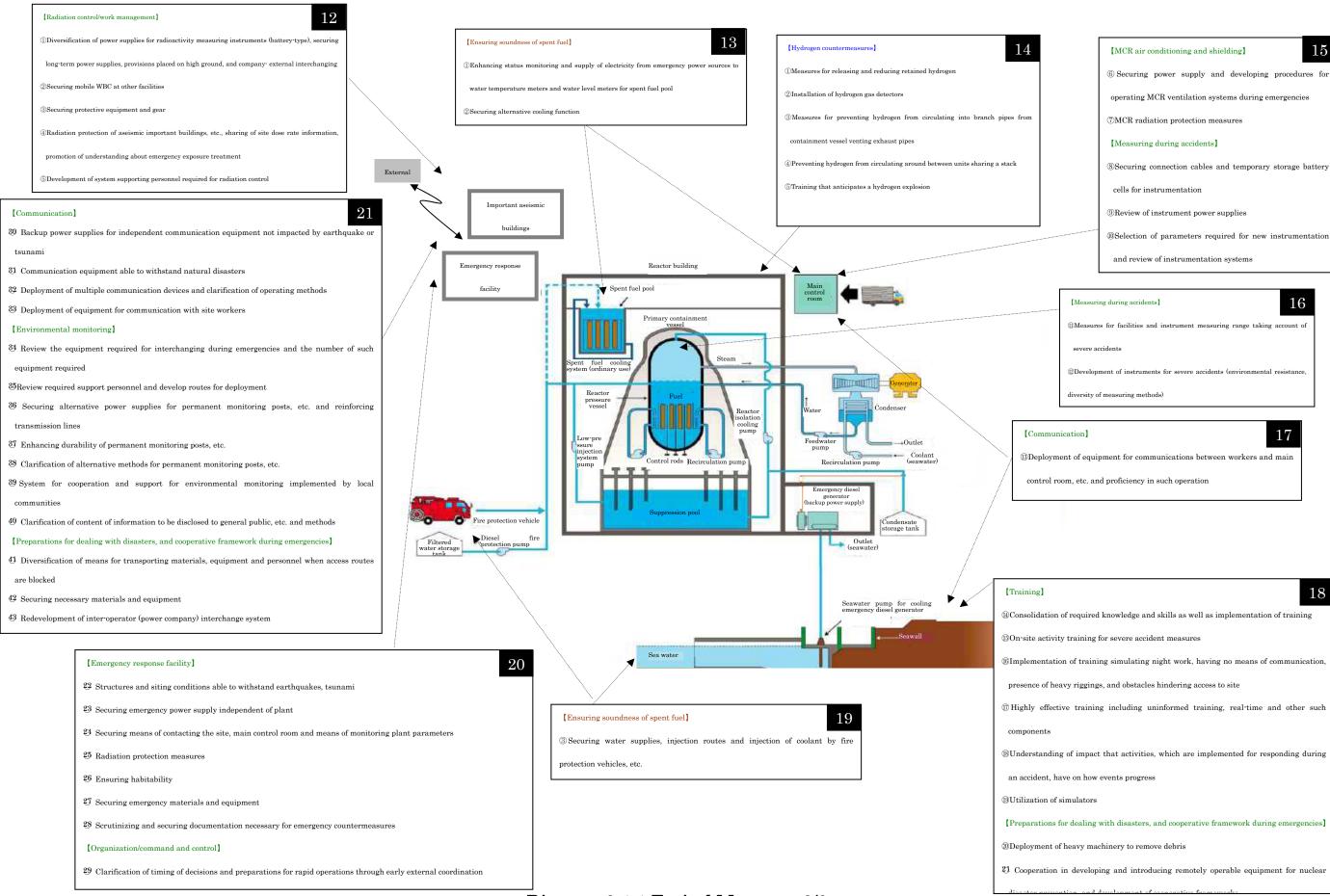
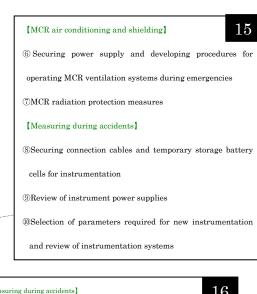


Diagram 2.4-1 Typical Measures 2/3



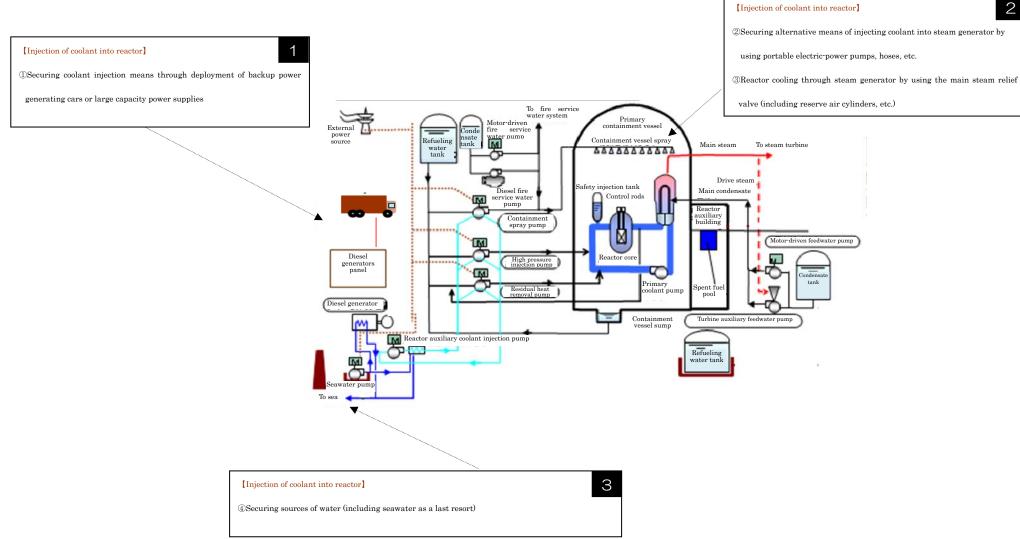


Diagram 2.4-1 Typical Measures 3/3



Table 2.4-1 Checklist Arranged from the Standpoint of Deep Protection (Status of Commitment at Typical Plant)

			First Tier	Preventing accidents from Second Tier	m occurring / Mitigatin Third Tier	ng the effects of accidents Fourth Tier	Fourth Tier
	Multiple Protection Levels		(Preventing abnormalities from occurring)	(Preventing abnormalities from spreading and developing into an accident)	(Preventing the extraordinary release of radioactive material)	(Preventing severe accidents from occurring)	(Mitigating the impact of a severe accident)
	Objective		Preventing abnormal operation and accidents	Controlling abnormal operation and detecting failures	Controlling accidents to within design standards	Preventing an accident from progressing	Mitigating the impact of SA
				lanures			
			Conservative design and construction High quality in operation	Control, confining and protection systems	ECCS and accident procedures	Supplementary means and severe accident measures	Supplementary means and severe accident measures including protecting the PCV
	Power sources	Prior to the disaster	Based on past records, the aseismatic class is configured using a sufficiently conservative design premise and the site height is designed by estimating twice the margin necessary · Inundation through building air supply, exhaust and other openings due to tsunami not taken into account · When a plant's power generation shuts down, electric power is supplied by an external power source · Redundant emergency DGs are set up, and if the external power source fails, backup is provided by the emergency DG · Restoration is assumed in a short period even if the power shuts down · The diversity and multiplicity of power sources across multiple systems using external power systems, emergency DG, and DC · Activity and power systems, emergency DG, and DC · Activity and Source is a sume of the power systems is a sume of the power sources across multiple systems using external power systems, emergency DG, and DC · Activity an	Emergency DG automatic startup from detection of low voltage signal on high-voltage power source bus Along with the automatic startup of emergency DG, related equipment starts up sequentially	On receipt of the automatic startup signal for the ECCS pump, the emergency DG automatically starts up despite supply from an external power source Power supply is secured by DC batteries and emergency DG which have redundancy	The restoration of AC power source is anticipated at an early stage (8 hours) and long- term power outage is not assumed After the failure of AC power sources, core cooling is done using DC-driven euipment and the recovery of AC power source is expected Development of recovery procedures	Power source interchange developed between units as a severe accident measures. However, loss of power sources simultaneously at multiple units not assumed.
		measures	 Seawalls and bulwarks are installed for equipment important for safety Preventing against inundation of sections where important safety equipment is installed Oreventing against inundation including improving seals around penetrations and air inlets and other openings in proportion to the height of inundation Development of watertight locations for deployment of power receiving transformers and switchyards and measures to prevent against inundation of equipment Development of CDC wer supply equipment and measures to prevent against inundation of compared to the same statistical sections for installation of DC power supply equipment and measures to prevent against inundation of compared sections for installation of the same section section sections for the same section section section section section sections for the same section section section section sections for the same section section section sections for the same section section section section section section sections for the same section sectio			 Deployment of power generating cars or large capacity power supplies (gas turbines and diesel generators), and development of procedures for emergencies Development of routes for recharging DC power supplies by means of backup power sources Deployment of portable drainage pumps, etc. 	 Improving reliability through measures to prevent against inundation of equipment for interchanging power sources between units (severe accident measure)
Core	Heat sinks (Coolant injection and cooling)	Prior to the disaster	 Based on past records, the aseismatic class and site height are designed using a sufficiently conservative design premise Heat removal systems are installed which have redundancy Multiplicity or diversity and independence are ensured for heat removal systems 	 In response to transient events, capability to respond through operations even if ECCS and other safety system equipment cannot be hoped for Due to inundation of seawater pumps and power supply panels, the simultaneous loss of function of all units is not assumed When the seawater pump is tripped, the backup automatically starts up Detectors having to do with the safety of the reactor are designed so that they can be tested even during operation of the reactor and maintenance of soundness and multiplicity can be confirmed 	 ECCS and other safety systems are installed along multiple systems Even when external power sources cannot be used, power is supplied by the emergency DG Systems (IC,HPCI,RCIC) are installed which function on power supplied from DC batteries even when the AC power source fails for a short time Ensuring diversity for driving sources through the installation of steam-driven equipment Although there are the HPCI and RCIC for which seawater cooling systems for cooling oil and bearings are not needed, their functions fail if DC power is lost 	 Severe accident measures (accident management) were developed. Existing equipment used as alternative cooling equipment as necessary Inundation or loss of power source for a long period not assumed No different alternative types of drive sources for valve types 	•Development of connections to fire protection vehicles or other fire fighteing system pipes
			○Bulkheads around seawater pumps or other measures to prevent inundation ●Preventing against inundation of sections where the emergency core cooling systems and other safety system equipment are installed		 Improving reliability of existing coolant injection systems through deployment of backup power generating cars or large capacity power supplies Deployment of backup power sources and driving sources for venting operations (BWR) Backup power supplies, standby air cylinders and other preparations for SRV drives (BWR) 	• Deployment of washing and drying materials for seawater pump motors • Deployment of mobile seawater pumps • Preventing against inundation of equipment for severe accident measures • Movable pumps, hoses, etc. not dependant on existing equipment • Securing water supplies (including seawater as a final means) • Releasing heat into the atmosphere through containment vessel venting (BWR) • Ensuring core cooling via SG by means of the main steam relief valve (PWR)	containment vessel venting (guaranteeing soundness of containment vessel) (BWR) oDeployment of backup power sources and driving sources for venting operations (BWR)
	Hydrogen	Prior to the disaster			 Installation of combustible gas concentration control systems to control the concentration of hydrogen and oxygen which is generated when there is a cooling failure accident Preventing hydrogen from being generated by cooling the core using the ECCS, etc. By filling the PCV with nitrogen, an inert environment is created which controls the concentrations of hydrogen and oxygen inside the containment vessel when there is an accident environment to keep it below the flammability threshold 	Gas circulating between units not taken into account	If core is damaged, hydrogen may leak from containment vessel.
		Proposed measures				 Releasing and reducing retained hydrogen Preventing hydrogen from circulting from pressure strengthened venting lines Preventing hydrogen from circulating around 	Releasing and reducing retained hydrogen

© Suide to column for typlical measures : •→Items for which implementation is completed or which have been taken into account initially due to factors characteristic of the site ○→Items being implemented or such capability is being planned

In Closing

In this report, the nuclear power industry, which is comprised of Japan's electric power companies and manufacturers conducted an examination focused mainly on analyzing factors as to why a core meltdown was not able to be prevented after tsunami struck the Fukushima Daiichi Nuclear Power Station and on formulating measures to counter such a situation.

The causes of the accident were that tsunami strikes inundated station electric installations, particularly the emergency AC and DC power supply panels, which caused cooling, control and monitoring functions to be lost, that time was required to establish means for cooling the core which were not dependent on permanent electric power sources, and that the core was not able to be maintained in a submerged state.

In this review, in keeping with the progression of the accident, we focused on whether the functions expected at each stage worked or not, analyzed causes and factors, and deduced issues and countermeasures. We looked at all measures in combination with existing equipment and countermeasures, arranged the measures from the standpoint of deep protection having the capability to ensure safety, and deduced those with high priority to be multitiered measures.

In addition, we have confirmed that safety has been substantially improved by the emergency safety measures already implemented by each company.

As new information about the accident is obtained, we plan to conduct further studies and review this report.