Causes and Countermeasures:

The Accident at TEPCO's Fukushima Nuclear Power Stations

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原子力安全・保安院
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Contents

Accident Overview and Root Causes

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The Accident at Fukushima Dai-ichi NPS

- The accident at Fukushima Dai-ichi NPS was caused by long lasting complete power loss due to common cause failure (CCF) of electrical equipment following tsunami, and insufficient provision against severe accident.
- It is temporarily rated at INES Level 7, and people where lived in the specific areas including those within 20 km radius from the site are still not able to return home.

The moment when tsunami attacked Fukushima Dai-ichi NPS (source: TEPCO)

General View of root causes of the Accident

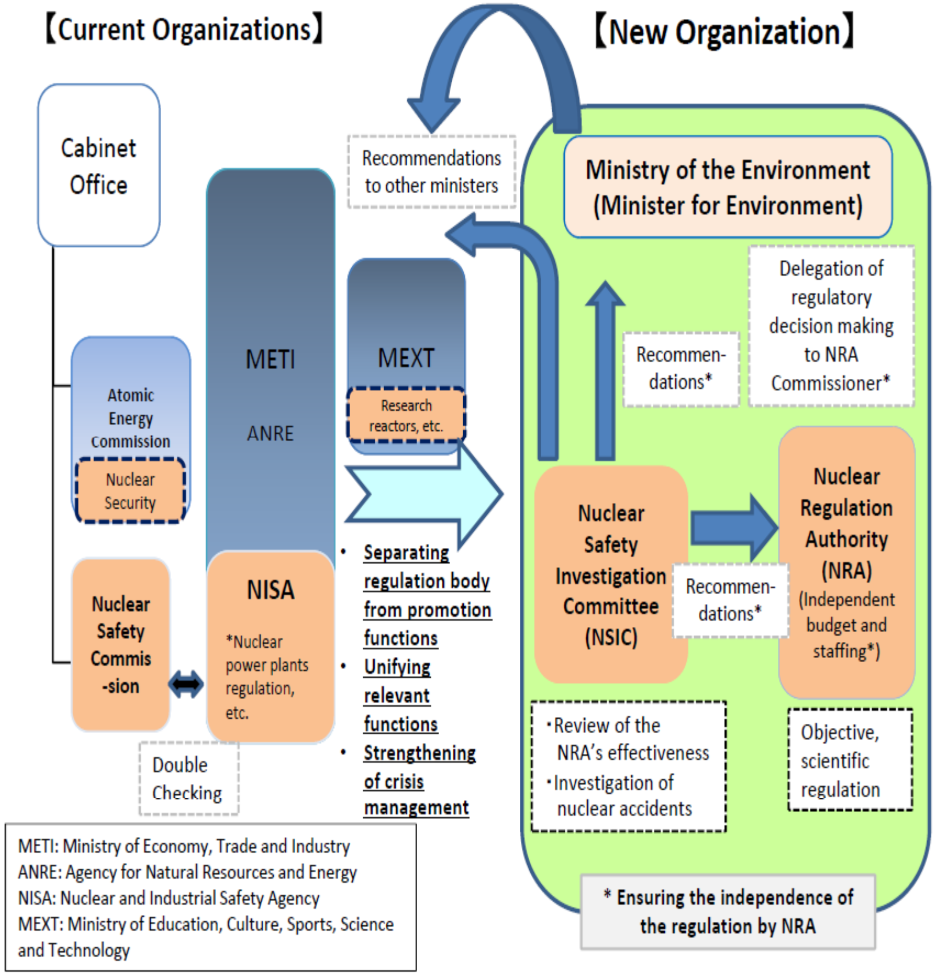
CCF of electric equipment and insufficient severe accident provision were induced by following root causes:

- Too late or missed incorporation of new tsunami knowledge into hazard evaluation,
- The regulatory system not covering severe accident,
- Insufficient application of state-of-the-art technologies and international good practices to the regulatory programs.

New Nuclear Regulatory Organizations

Nuclear Regulatory Authority (NRA) will be established as an external organ of the Ministry of Environment (MOE) by:

- separating the nuclear safety regulatory function of NISA from METI and,
- unifying relevant functions of other ministries (Size: 500 Staff, 50 billion yen Budget).



New Nuclear Regulatory Systems

NRA will implement new regulatory systems stipulated in amended laws, including:

- Regulation taking severe accidents into consideration.
- Regulation applying latest scientific/technical knowledge on safety issues to existing facilities. (backfitting)
- An operation limit of 40 years to deal with aged reactors

Technical Knowledge acquired from the Accident

In order to address root causes in a practical manner, NISA has closely investigated accident sequences from engineering point of view, and extracted technical knowledge as well as corresponding measures in the areas of:

- External power supply systems
- On-site power supply systems
- Cooling systems
- Confinement systems
- Communication, instrumentation and communication systems, and emergency response arrangements

Current Status of Fukushima Dai-ichi NPS

Step 2 Completion in “Roadmap towards Restoration from Accident” (on Dec. 16, 2011)

- Reactors: A condition equivalent to Cold Shutdown
  - ✓ Temperature of RPV bottom is, in general, below 100℃.
  - ✓ Release of radioactive materials from PCV is under control and public radiation exposure by additional release is being significantly held down. (Not exceed 1 mSv/y at the site boundary as a target.)
  - ✓ Mid-term Safety of Circulating Water Injection Cooling System

- Spent Fuel Pools: More stable cooling
  - ✓ Circulating Cooling System by installation of heat exchanger

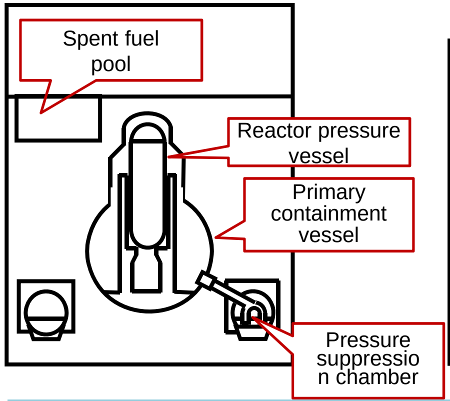
- Radioactive Contaminated Water: Reduction of total amount
  - ✓ Full-fledged processing facilities
  - ✓ Desalination processing (reuse)
  - ✓ Storage
  - ✓ Mitigation of contamination in the ocean

Mid-to-Long-Term Roadmap towards the Decommissioning of Fukushima Nuclear Power Units 1-4

Present（Step 2 Completed）	Within 2 Years	Within 10 Years	After 30-40 Years
Step 1, 2	**Phase 1**	**Phase 2**	**Phase 3**
<Achieved Stable Conditions> ・Reactors: A condition equivalent to Cold Shutdown ・Spent Fuel Pools: More stable cooling ・Radioactive Contaminated Water: Reduction	**Period to the commencement of the fuel removal from the Spent Fuel Pools (Within 2 years)**	**Period to the commencement of the removal of fuel debris (Within 10 years)**	**Period to the end of the decommissioning (In 30-40 years)**
	-Commence the removal of fuels from the spent fuel pools (Unit 4 in 2 years) -Reduce the radiation impact due to additional emissions from the whole site and radioactive waste generated after the accident (secondary waste materials via water processing and debris etc.) Thus maintain an effective radiation dose of less than 1 mSv/yr at the site boundaries caused by the aforementioned. -Maintain stable reactor cooling and accumulated water processing and improve their credibility. -Commence R&D and decontamination towards the removal of fuel debris -Commence R&D of radioactive waste processing and disposal	-Complete the fuel removal from the spent fuel pools at all Units -Complete preparations for the removal of fuel debris such as decontaminating the insides of the buildings, restoring the PCVs and filling the PCVs with water Then commence the removal of fuel debris (Target: within 10 years) -Continue stable reactor cooling -Complete the processing of accumulated water -Continue R&D on radioactive waste processing and disposal, and commence R&D on the reactor facilities decommission	-Complete the fuel debris removal (in 20-25 years) -Complete the decommission (in 30-40 years) -Implement radioactive waste processing and disposal

Actions towards systematic staff training and allocation, improving motivation, and securing worker safety will be continuously implemented.

Current Status of Fukushima Dai-ichi NPP



Unit 1

TEPCO

Unit 2

Ministry of Defense

Unit 3

Air Photo Service

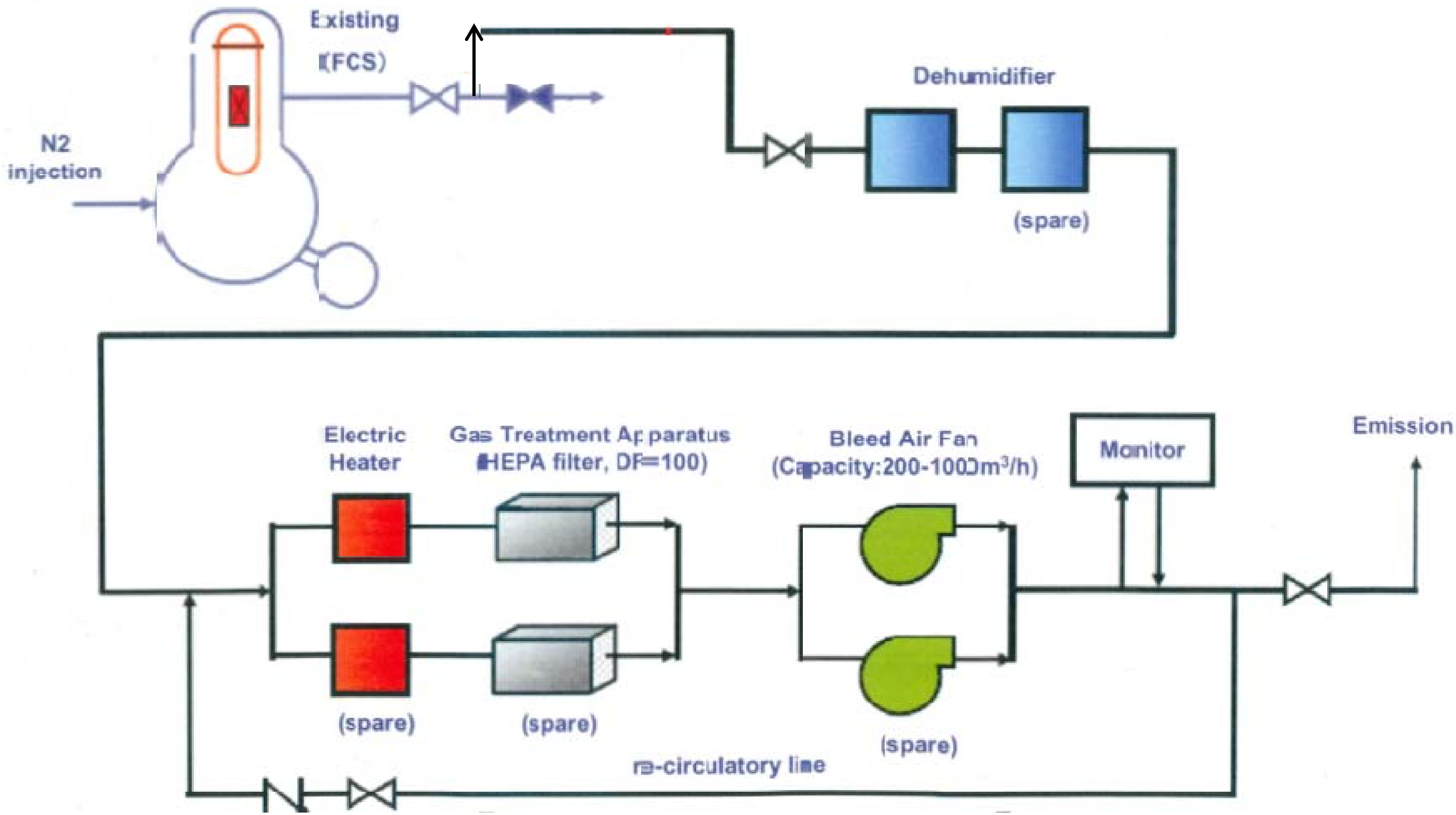
Unit 4

Air Photo Service

	Unit 1	Unit 2	Unit 3	Unit 4
Reactor Pressure vessel Temperature at reactor vessel bottom*	Circulating water injection cooling 24.3℃	Circulating water injection cooling 47.1℃	Circulating water injection cooling 51.4℃	No fuel
Primary Containment vessel Temperature of air in PCV*	Nitrogen injection 25.4℃	Nitrogen injection 54.3℃	Nitrogen injection 44.4℃	—
Fuel pool Temperature of pool water*	Circulation cooling 26.5℃	Circulation cooling 14.2℃	Circulation cooling 14.4℃	Circulation cooling 26℃
Highly-contaminated water in R/B and T/B**	14,100 m^3	22,000m^3	23,800 m^3	18,300 m^3

* As of 12:00 on February 24, 2012 ** As of February 21, 2012

Diagram of PCVs Gas Control System for Unit 3



(Source: TEPCO)

Result of Gas Sampling at PCVs Gas Control System

Nuclides	Concentration of sample (Bq/cm3) Unit 1 (Sampled on Mar. 8, 2012) Gas vial container	Detection limits of Unit 1 (Bq/cm3)	Concentration of sample (Bq/cm3) Unit 2 (Sampled on Mar. 7, 2012) Gas vial container	Detection limits of Unit 3 (Bq/cm3)	Concentration of sample (Bq/cm3) Unit 3 (Sampled on Mar. 1, 2012) Gas vial container	Detection limits of Unit 3 (Bq/cm3)
I-131	N.D.	1.3×10^{-1}	N.D.	1.2×10^{-1}	N.D.	1.3×10^{-1}
Cs-134	3.5×10^{-1}	3.0×10^{-1}	5.9×10^{-1}	3.0×10^{-1}	4.0×10^{-1}	3.2×10^{-1}
Cs-137	5.5×10^{-1}	3.6×10^{-1}	8.1×10^{-1}	3.6×10^{-1}	7.2×10^{-1}	3.8×10^{-1}
Kr-85		2.5×10^{-1}	N.D.	2.5×10^{-1}	N.D.	2.5×10^{-1}
Xe-131m		2.9×10^{0}	N.D.	3.0×10^{0}	N.D.	3.3×10^{0}
Xe-133		2.4×10^{-1}	N.D.	2.7×10^{-1}	N.D.	2.2×10^{-1}
Xe-135		1.1×10^{-1}	N.D.	1.0×10^{-1}	N.D.	1.0×10^{-1}

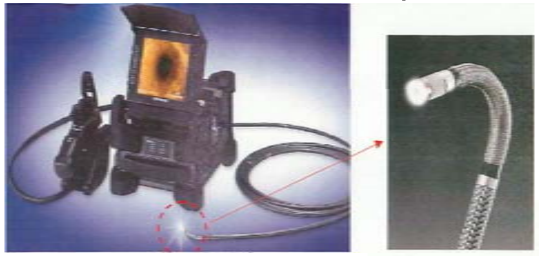
N.D. : not detected

(Source: TEPCO)

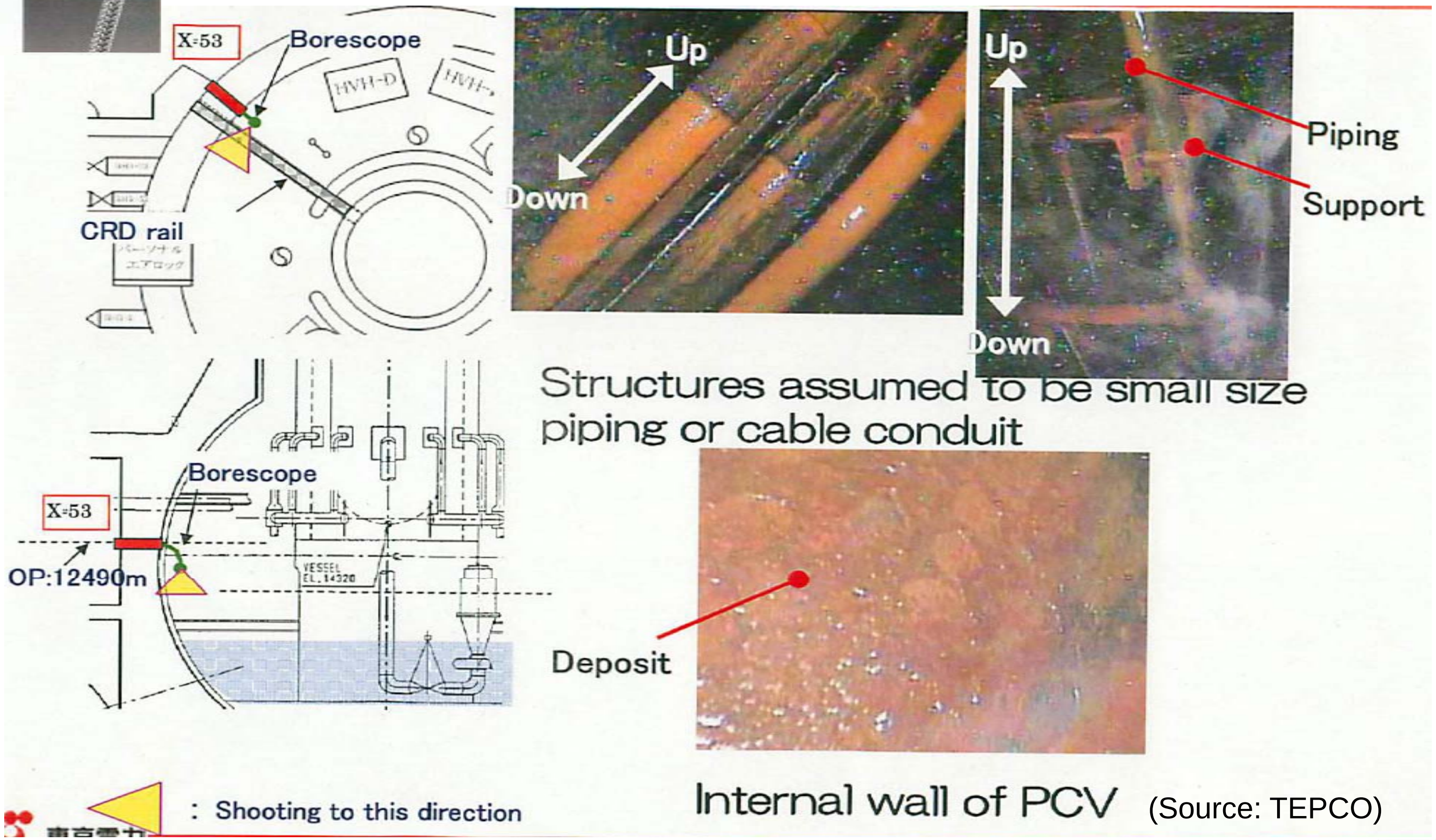
Investigation Result of the Inside of PCV of Unit 2 (on Jan. 19, 2012)

- Photos were taken inside the PCV by an industrial endoscope (length:10m).

<Industrial endoscope>



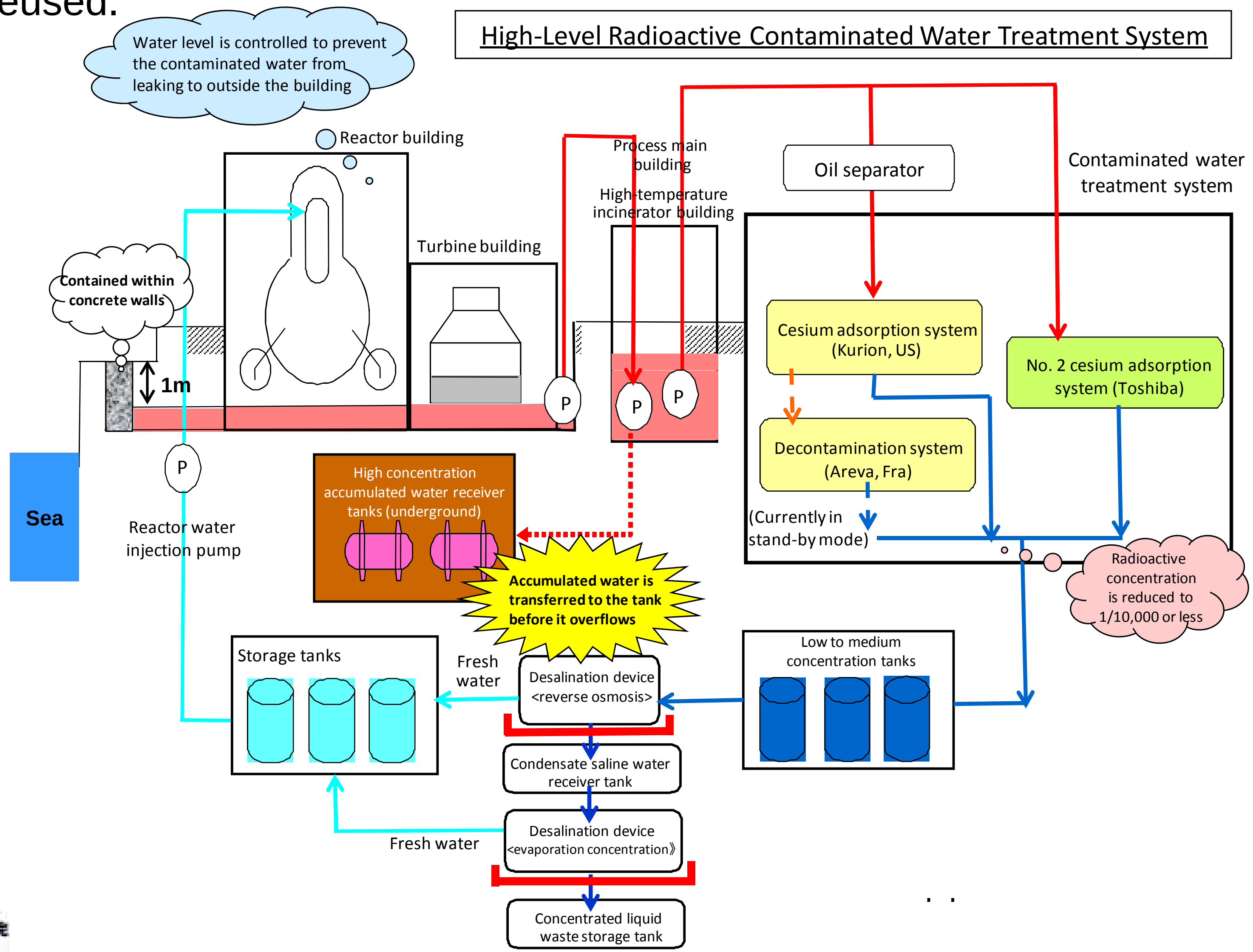
< Photos inside the PCV of Unit 2 >



(Source: TEPCO)

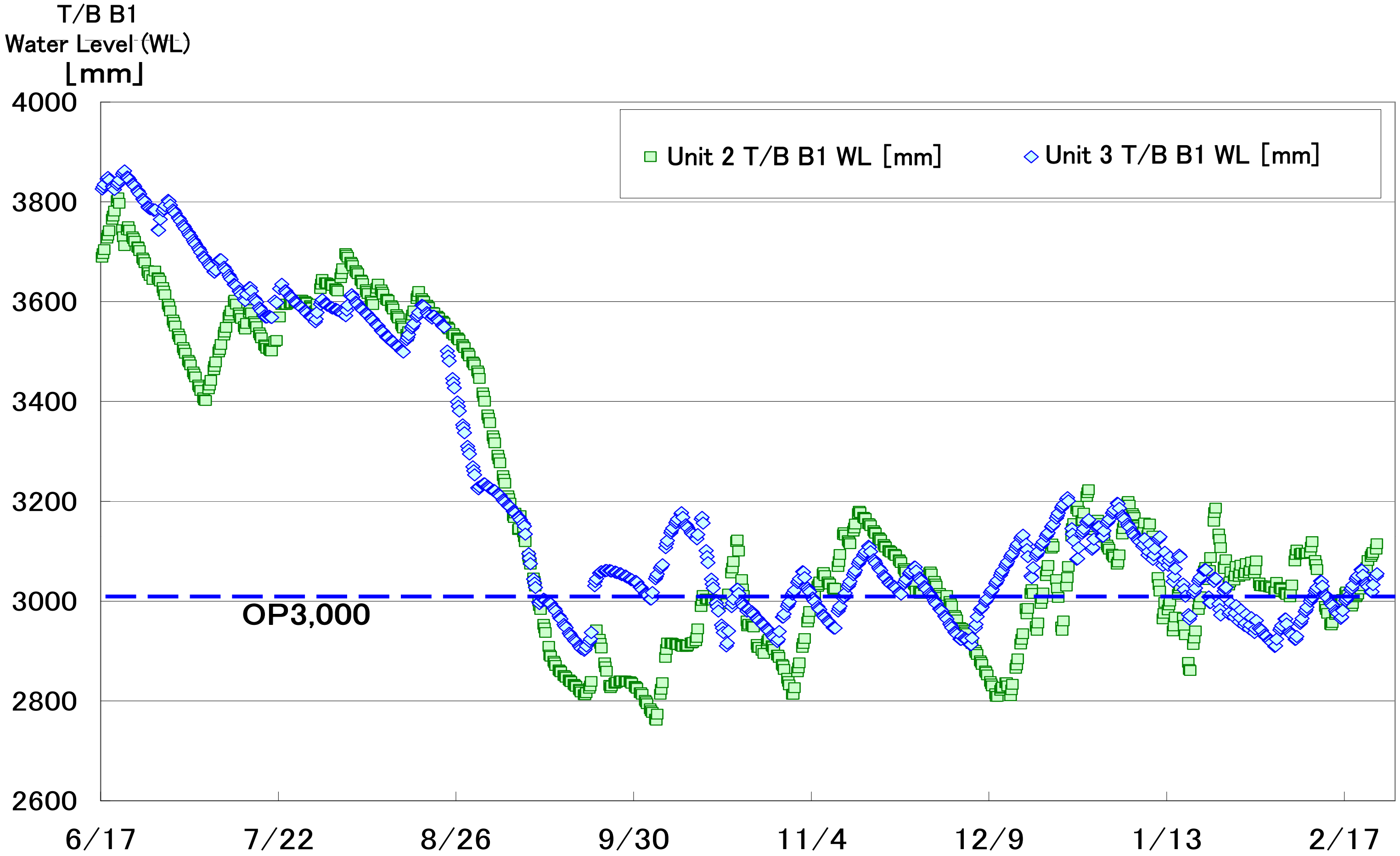
Treatment of High Level Radioactive Contaminated Water

- Highly-radioactive contaminated water accumulated in the reactor building and turbine buildings is treated to reduce the concentrations of radioactive materials and reused.



Trend of Amount of Accumulated Water

- Total amount of the accumulated water level has been decreased around the tentative target level of O.P. 3000 during STEP 2 and maintained.



Result of Nuclide Analysis of Accumulated Water in Turbine Building

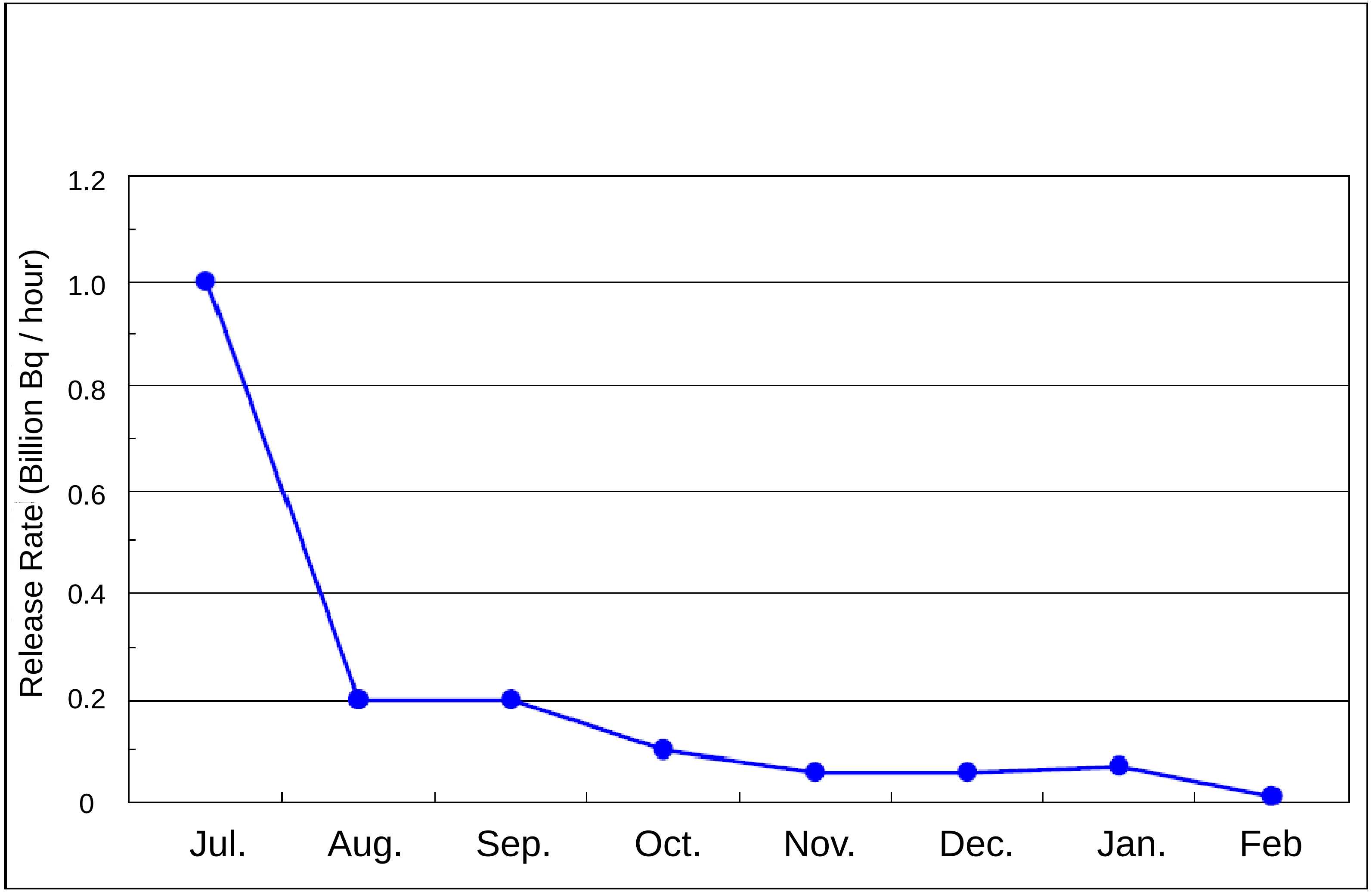
nuclide	Density of sample (Bq/cm3)							
	Unit 1		Unit 2		Unit 3		Unit 4	
	Sampled on Mar. 27, 2011	Sampled on Jan. 20, 2012	Sampled on Mar. 24, 2011	Sampled on Jan. 12, 2012	Sampled on Mar. 24, 2011	Sampled on Feb. 12, 2012	Sampled on Mar. 24, 2011	Sampled on Feb. 12, 2012
I-131	3.0E+04	ND	2.0E+06	ND	1.2E+06	ND	3.6E+02	ND
Cs-134	1.2E+05	2.2E+04	2.6E+06	2.2E+05	1.8E+05	8.5E+04	3.1E+01	2.1E+04
Cs-137	1.6E+05	3.0E+04	2.8E+06	3.0E+05	1.8E+05	1.1E+05	3.2E+01	2.8E+04
Y-91		ND		ND		ND		ND
Mo-99		ND		ND		ND		ND
Tc-99m		ND		ND		ND		ND
Te-129m		ND		ND		ND		ND
Te-132		ND		ND		ND		ND
I-132		ND		ND		ND		ND
Cs-136		ND		ND		ND		ND
Ba-140	<560	ND	2.4E+05	ND		ND		ND
La-140	<300	ND	2.2E+05	ND		ND		ND

* In the case the measurement is under the detection threshold, "ND" is marked.

(Source: TEPCO)

Release Rate of Radioactive Materials from PCVs of Units 1-3

- Current total release rate of Cesium 134 and 137 from PCVs of Units1-3 is estimated to be approx. 0.01 billion Bq/h at the maximum. (1/77,000,000 of early stages of the accident)



Installation of Reactor Building Cover (on Oct. 28, 2011)

- A cover was installed in the Unit 1 building to restraint release of radioactive materials.
- Rubble is being removed from the upper part of the reactor buildings for Units 3 and 4 before installation of the covers.

Installation of the Unit 1 Cover

Start of steel framing

Completion of steel framing

Building wall panels

The Covering was completed

Debris removal at Unit 3

On Sep. 10, 2011

On Feb. 21, 2012

Debris and girder removal at Unit 4

Covering of SFP

Debris removal at the top

Removal works of the girder of overhead traveling crane on Mar. 5, 2012

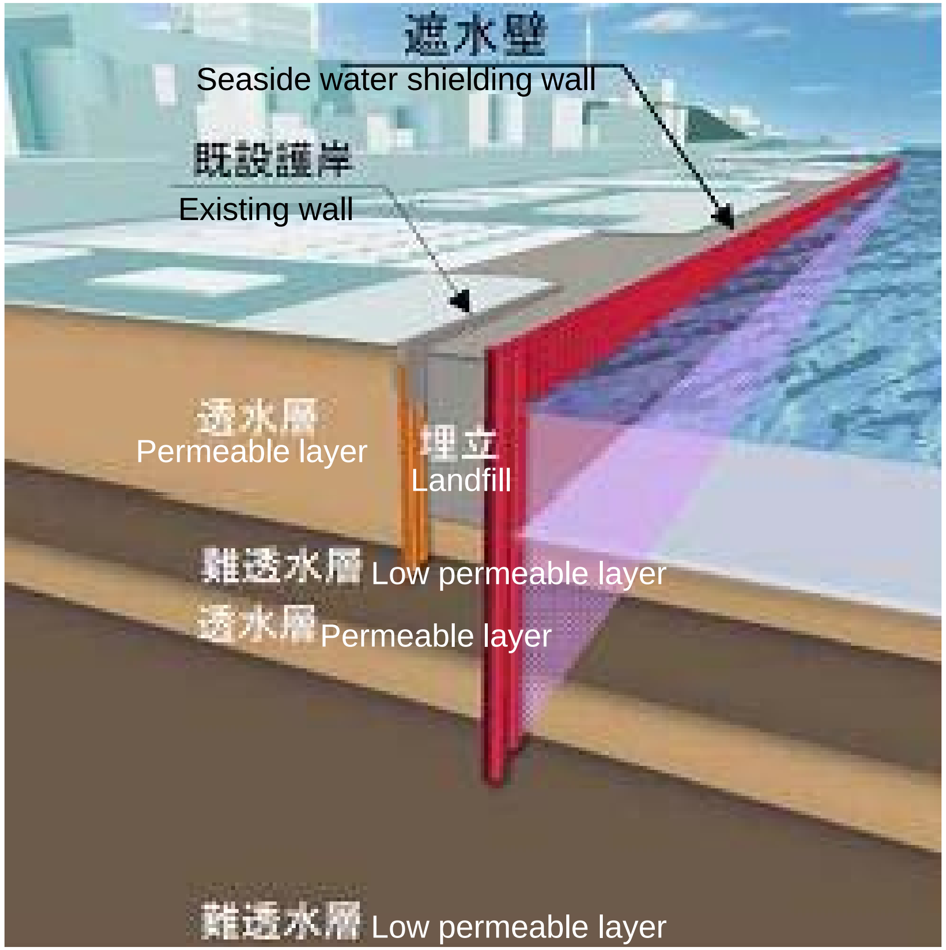
(Source: TEPCO)

Construction of Water Shielding Wall

- A measure to prevent contamination of the ocean via the underground water.

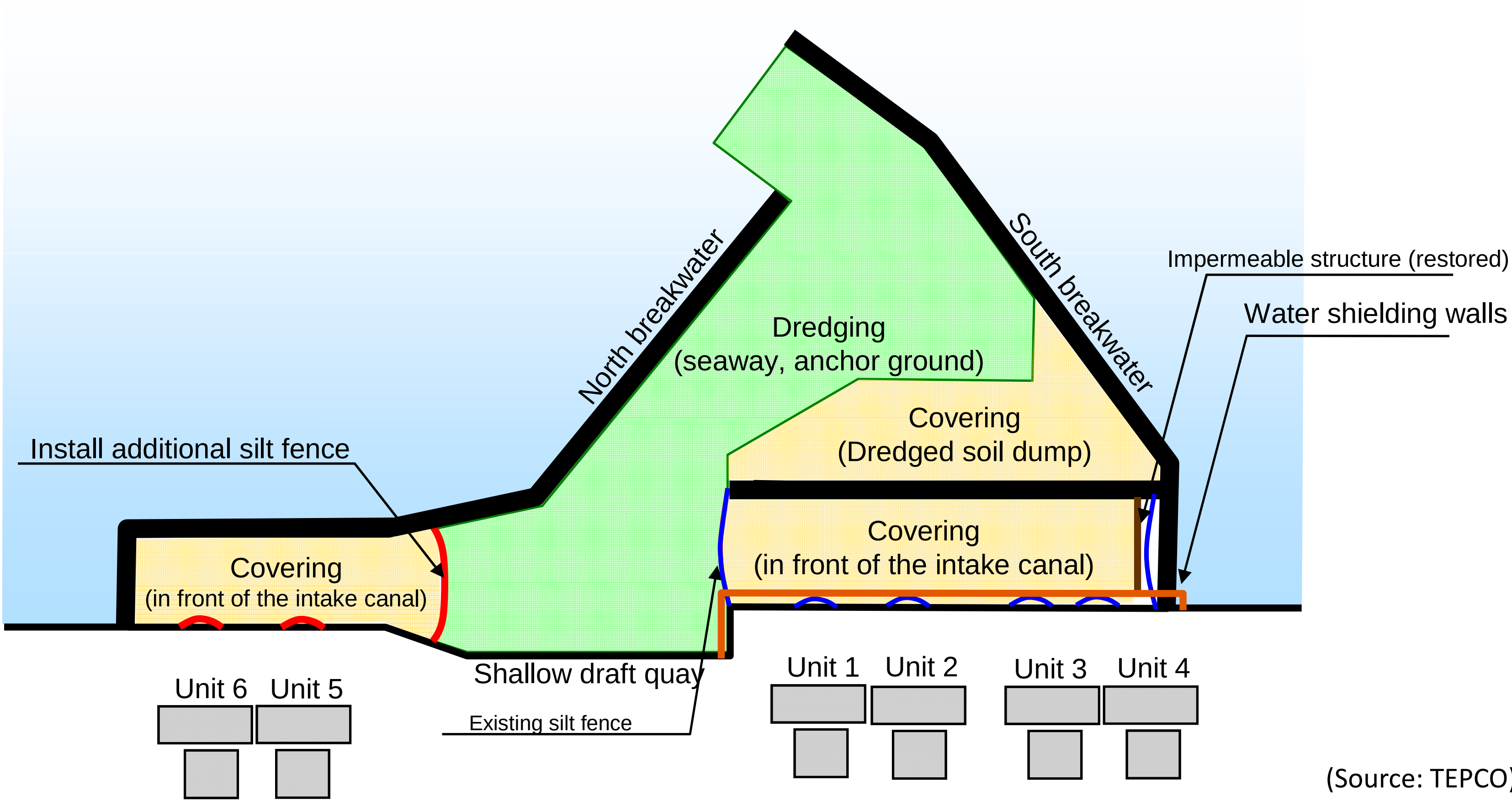
Image of water shielding walls

Cross-section view



Start of Marine Soil Covering Construction at Inside Port

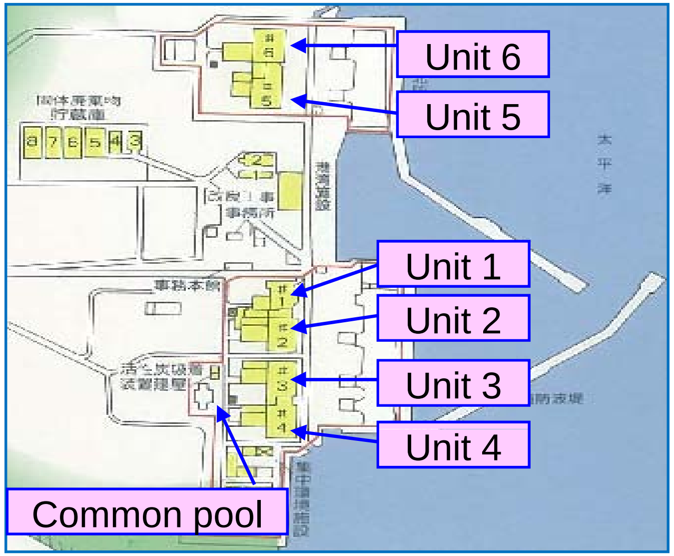
- High concentrated radioactive materials were detected from marine soil sampled at inside of the port
- To prevent contamination of the ocean outside of the port, marine soil in front of the intake canal is planned to be covered with solidified soil.



(Source: TEPCO)

Overview of Spent Fuel Pools (SPFs)

<Overview of location of spent fuel storage facilities>



<Status of stored fuel in SFPs>

	Number of stored fuel assemblies (Number of new fuel assemblies)	Capacity of storage
Unit 1 SFP	292 (100)	900
Unit 2 SFP	587 (28)	1240
Unit 3 SFP	514 (52)	1220
Unit 4 SFP	1331 (204)	1590
Common pool	6375	6840

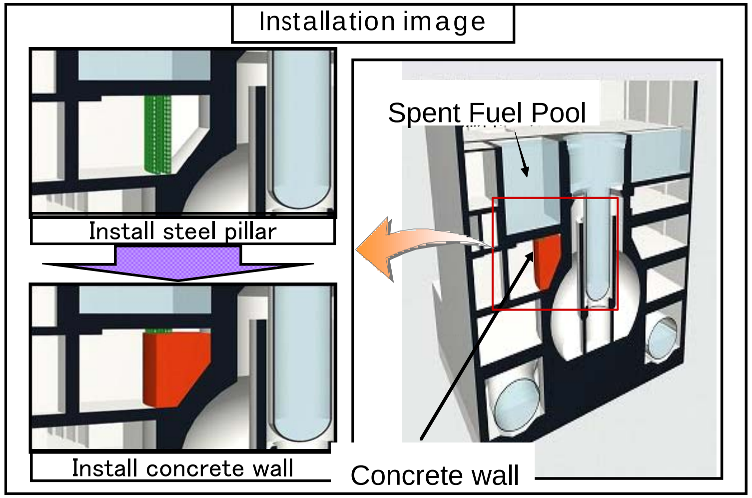
<Decay heat of SFPs>

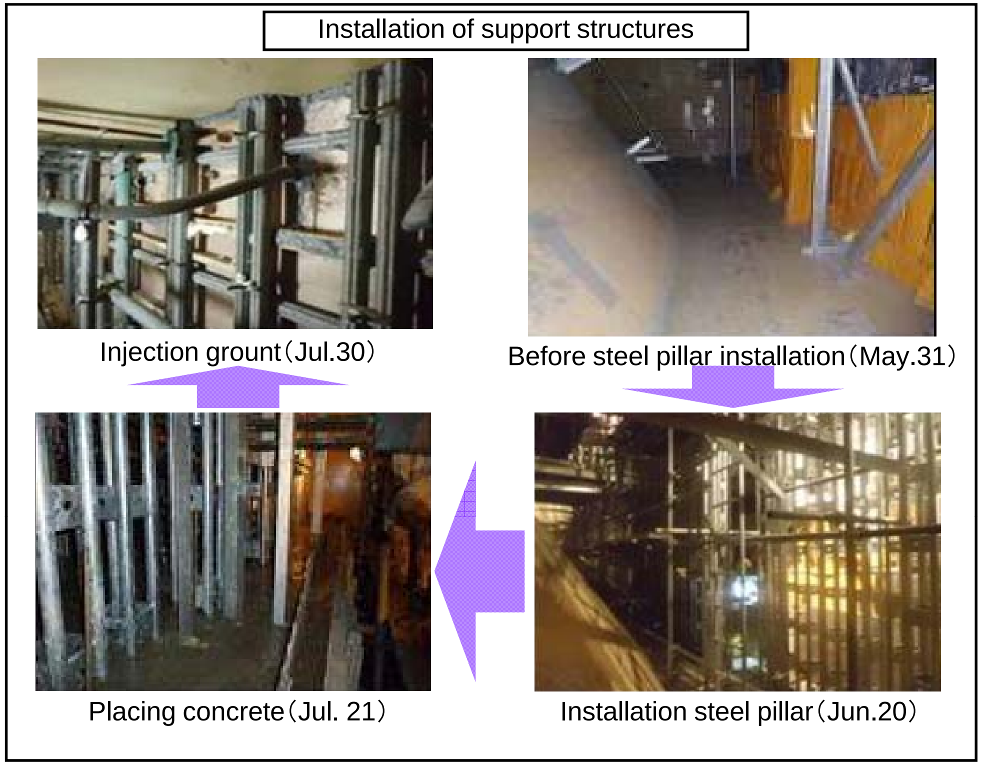
	Decay heat (MW)	
	As occurrence of accident (3/11)	3 months after the accident (6/11)
Unit 1 SFP	0.18	0.16
Unit 2 SFP	0.62	0.52
Unit 3 SFP	0.54	0.46
Unit 4 SFP	2.26	1.58
Common pool	1.13	1.12

(Source: Added to "The impact of Tohoku-Chihou Taiheiyo-Oki Earthquake to Nuclear Reactor Facilities at Fukushima Daiichi Nuclear Power Station" (Sep.9, 2011, revised Sep.28, 2011, TEPCO))

Installing Support Structures at Bottom of SFP of Unit 4

- It has been confirmed that the seismic resistance is sufficient without any reinforcements.
- Nevertheless, support structures at the bottom of the pool has been installed in order to further improve the safety margin.

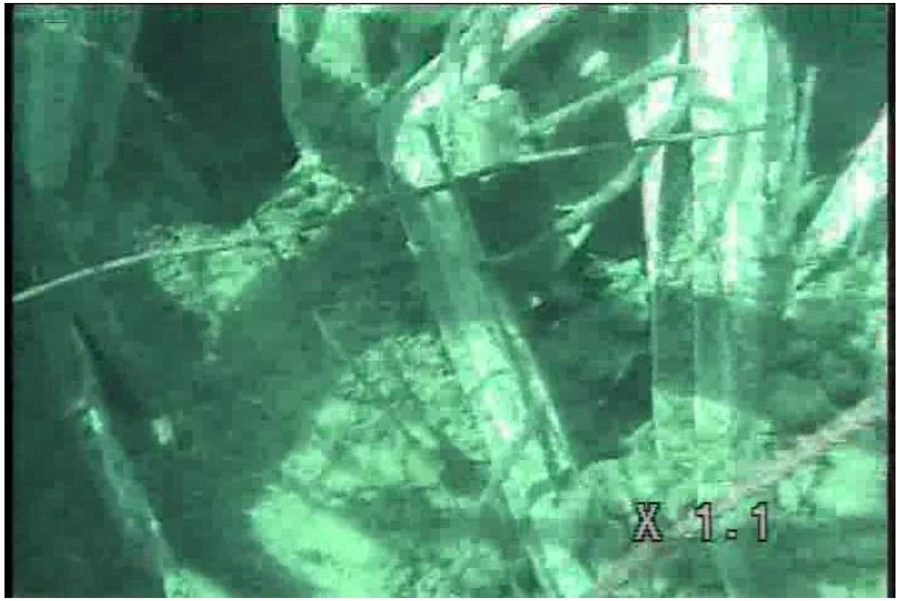




The latest condition of the upper floor of Unit 4
(Mar. 5, 2012) (source: TEPCO)

Situation of SPF

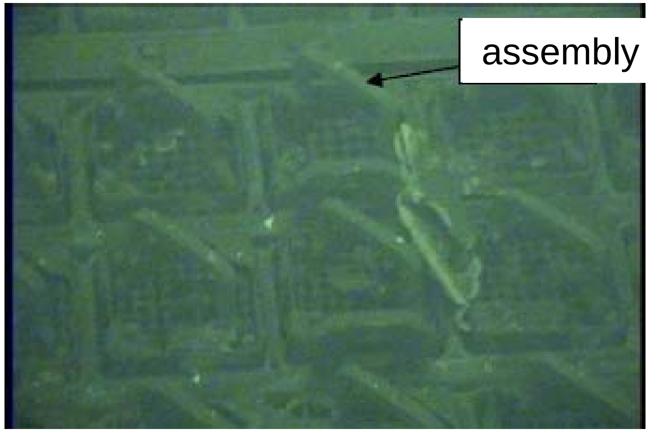
- Unit 3: Due to Much debris from the explosion of the reactor building the status of the fuel can not be confirmed.
- Unit 4: The fuel is usually confirmed to be stored in the racks and not severely damaged.



Situation of SFP of Unit 3

(Source: “The impact of Tohoku-Chihou Taiheiyo-Oki Earthquake to Nuclear Reactor Facilities at Fukushima Daiichi Nuclear Power Station” (Sep.9, 2011, revised Sep.28, 2011, TEPCO))

(Source: “The impact of Tohoku-Chihou Taiheiyo-Oki Earthquake to Nuclear Reactor Facilities at Fukushima Daiichi Nuclear Power Station” (Sep.9, 2011, revised Sep.28, 2011, TEPCO))



(Source: TEPCO (Shot on Feb.9, 2012))

Situation of SFP of Unit 4

Situation of SFP (cont.)

- The water analysis results show that the detected radioactive materials came from the damaged core and that there is little possibility of large-scale damage of spent fuels.

Unit 1

Detected nuclide	Half-life	Concentration (Bq/cm^3)		
		Sampled 6/22	Sampled 8/19	Sampled 11/5
cesium134	~2 years	1.2×10^4	1.8×10^4	1.3×10^4
cesium137	~30 years	1.4×10^4	2.3×10^4	1.8×10^4
iodine131	~8 days	68	lower than detection limit	lower than detection limit

Unit 2

Detected nuclide	Half-life	Concentration (Bq/cm^3)		
		Sampled 4/16	Sampled 8/19	Sampled 11/5
cesium134	~2 years	1.6×10^5	1.1×10^5	9.5×10^4
cesium137	~30 years	1.5×10^5	1.1×10^5	1.1×10^5
iodine131	~8 days	4.1×10^3	lower than detection limit	lower than detection limit

Unit 3

Detected nuclide	Half-life	Concentration (Bq/cm^3)			
		Sampled 5/8	Sampled 7/7	Sampled 8/19	Sampled 11/5
cesium134	~2 years	1.4×10^5	9.4×10^4	7.4×10^4	6.0×10^4
cesium137	~30 years	1.5×10^5	1.1×10^5	8.7×10^4	7.4×10^4
iodine131	~8 days	1.1×10^4	lower than detection limit	lower than detection limit	lower than detection limit

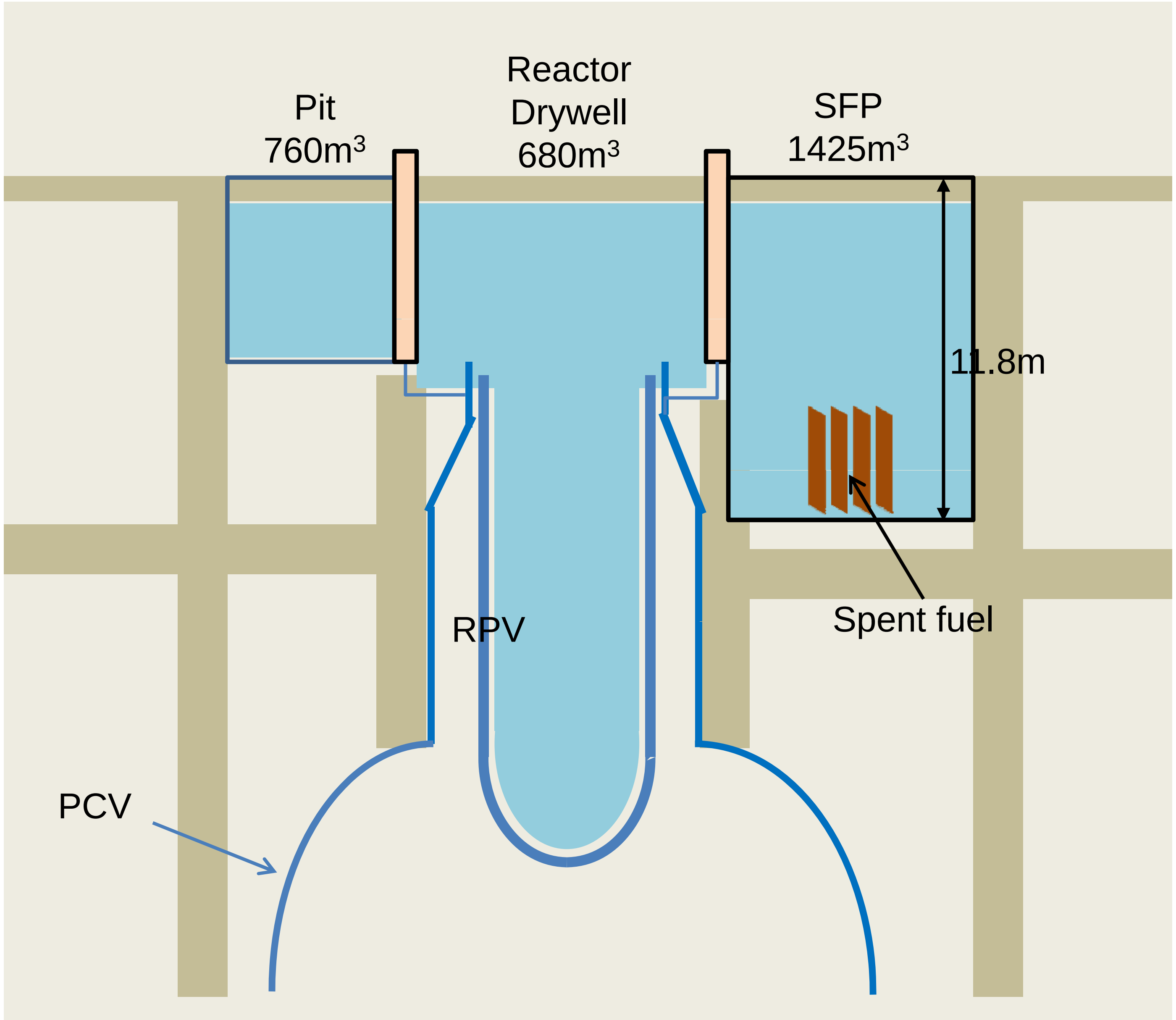
Unit 4

Detected nuclide	Half-life	Concentration (Bq/cm^3)				
		Sampled 4/12	Sampled 4/28	Sampled 5/7	Sampled 8/20	Sampled 11/5
cesium134	~2 years	88	49	56	44	3.5
cesium137	~30 years	93	55	67	61	5.1
iodine131	~8 days	220	27	16	lower than detection limit	lower than detection limit

Red : sampled SFP water using a concrete pumper Blue : sampled SFP water overflow into a skimmer surge tank from FPC sampling piping

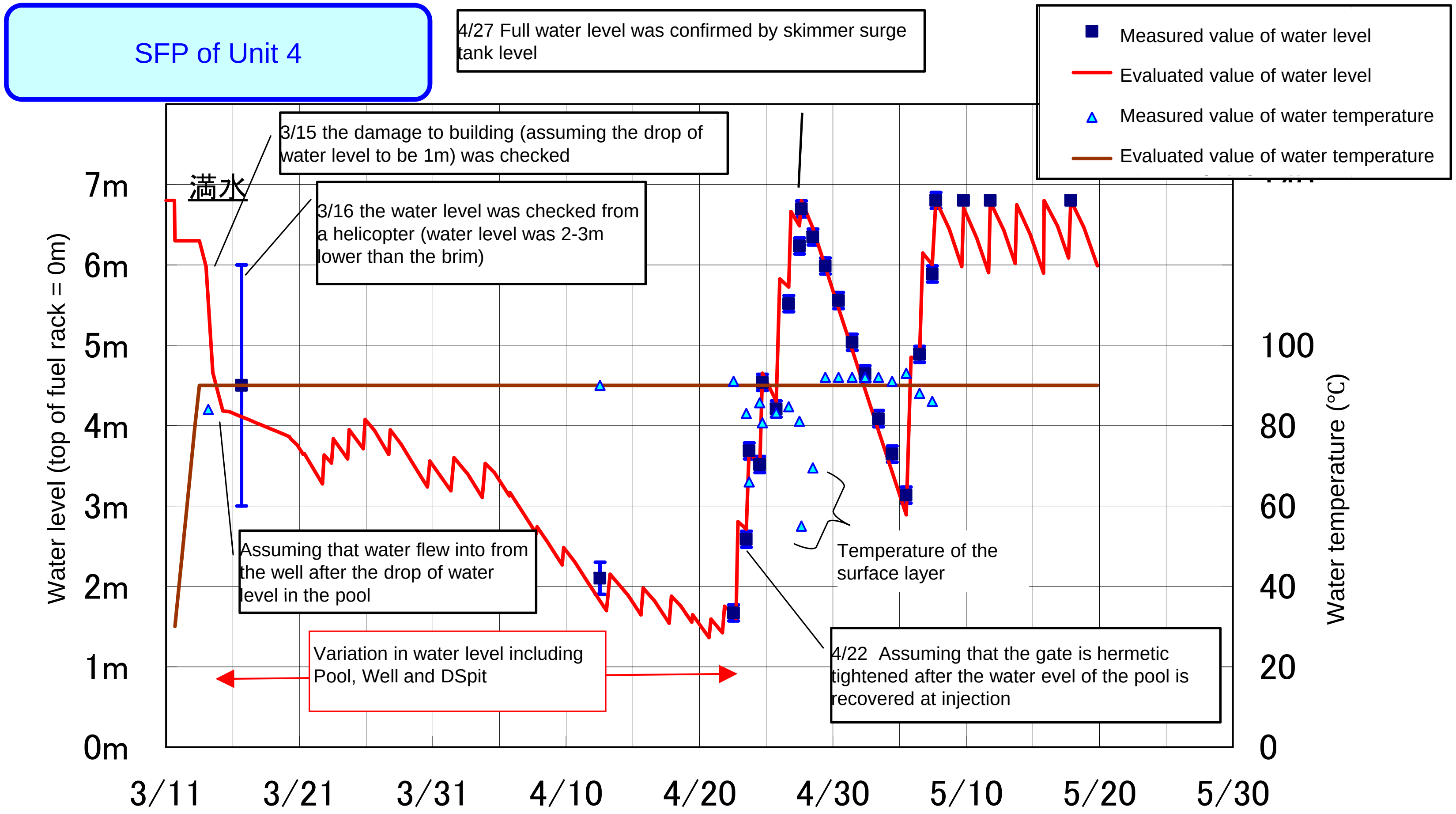
Source: Added to "The impact of Tohoku-Chihou Taiheiyo-Oki Earthquake to Nuclear Reactor Facilities at Fukushima Daiichi Nuclear Power Station" (Sep.9, 2011, revised Sep.28, 2011, Tokyo Electric Power Co., Inc.)

Amount of water around the SFP of Unit 4



Trend of Water Level and Temperature of SFP

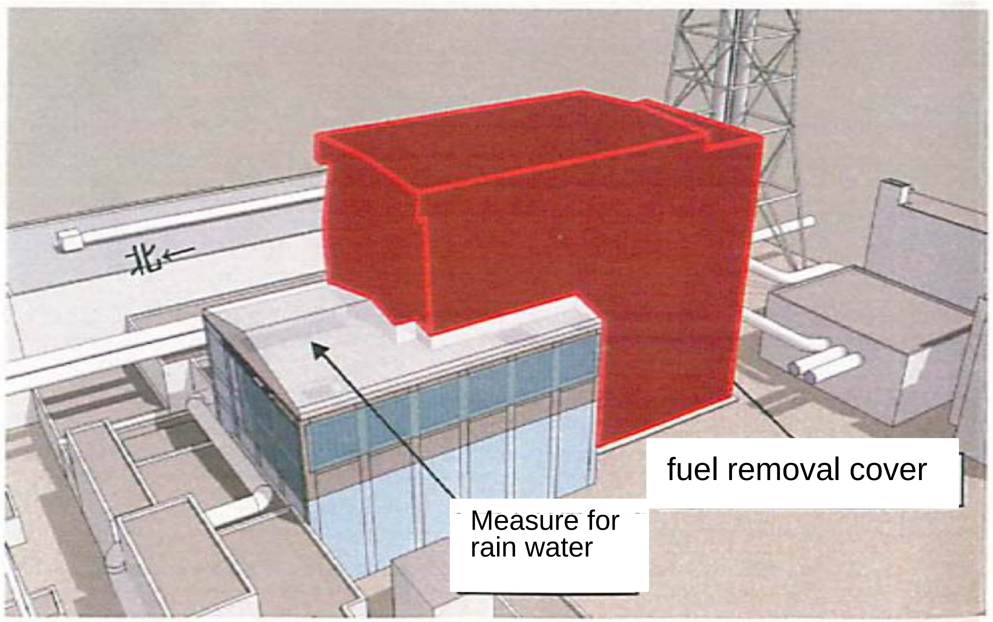
- Since March 17, water was supplied to Units 1-4, by fire engines and concrete pumpers. The decay heat evaluation shows the fuel has never been exposed.
- As for Unit 4, water in the reactor well filled for annual inspection could flow into the SFP when the water level of SFP decreased.



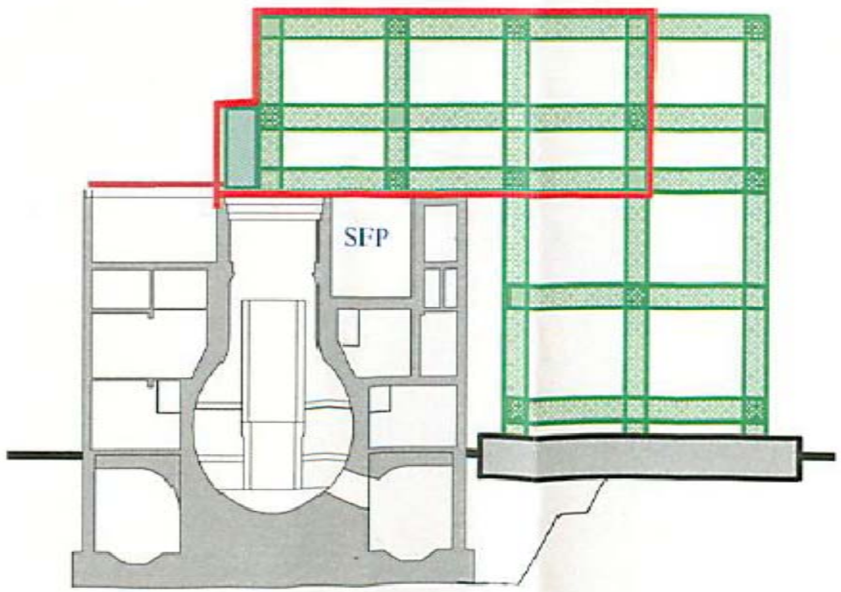
Source: Added to "The impact of Tohoku-Chihou Taiheiyo-Oki Earthquake to Nuclear Reactor Facilities at Fukushima Daiichi Nuclear Power Station" (Sep.9, 2011, revised Sep.28, 2011, Tokyo Electric Power Co., Inc.)

Prepare for Fuel Removal from SFP of Unit 4

- Fuel removal are planned to be initiated in autumn 2013.
- Currently Rubble is being removed to prepare for the relevant works.
- Construction of covering structure will be initiated in spring 2013.



Building image of fuel removal cover



Cross-section diagram

(Source: TEPCO)

Sequence, Causes and Countermeasures of accident at Fukushima Dai-ichi NPS

(Note)

- Slides from the next pages are created based on the Interim Report on Technical Knowledge of the Accident at Fukushima Dai-ichi Nuclear Power Station, TEPCO.
- NISA will further collect technical knowledge on this subject, and improve this Interim Report.
- The Interim Report in English will be published on NISA website (http://www.nisa.meti.go.jp/english/index.html) in the near future.

Ⅰ. Accident Sequence

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Progress of Accident (Outline of Accident Development Common to Units 1-3)

Automatic reactor shutdown due to earthquake, loss of off-site power supply

Dependency on emergency power was inevitable.

- Emergency diesel generator started up and power supply was secured.
- Reactor was cooled by core cooling system.

Start-up / Shutdown operations for IC･RCIC were going on.

Most of electric systems including emergency diesel generators and switchboards were unavailable due to tsunami.

(Only one of emergency air cooling DGs in Unit 6 maintained its function)

Cooling sea water pumps installed along the coast were also unavailable. (Loss of heat sink)

Station Blackout

(On March 13, Unit 5 received power supply from Unit 6 on emergency basis.)

Motor operated pumps etc. were unavailable. (Emergency cooling was carried out by emergency condenser IC in Unit 1, reactor core isolation cooling system [RCIC] in Unit 2, and RCIC and high pressure core injection system HPCI in Unit 3.)

Soaking / dry-up of battery, dry-up of compressed air, etc.

Many on-site works were necessary due to difficulty of measurement / control / communication.

Shutdown of core cooling system

Unit 1 has lost its function at an early phase. Due to this reason, there was only short time to address the situation.

Fuels were exposed and melt down while cooling was not conducted.

Serious degradation of confinement led to the release of radioactive materials into environment.

Water injection from fire protection system (Alternative water injection)

The exposure time of fuels is considered to be prolonged due to insufficient reactor depressurization (reactor depressurization operation for containment, reactor containment depressurization [vent]) to the pressure lower than the fire extinguishing pump head.

Hydrogen generated through zirconium – water reaction. Explosions that seemed to be hydrogen explosion occurred in reactor buildings at Units 1, 3 and 4. (Pressure in the pressure suppression chamber in Unit 2 dropped simultaneously with the Unit 4 explosion.)

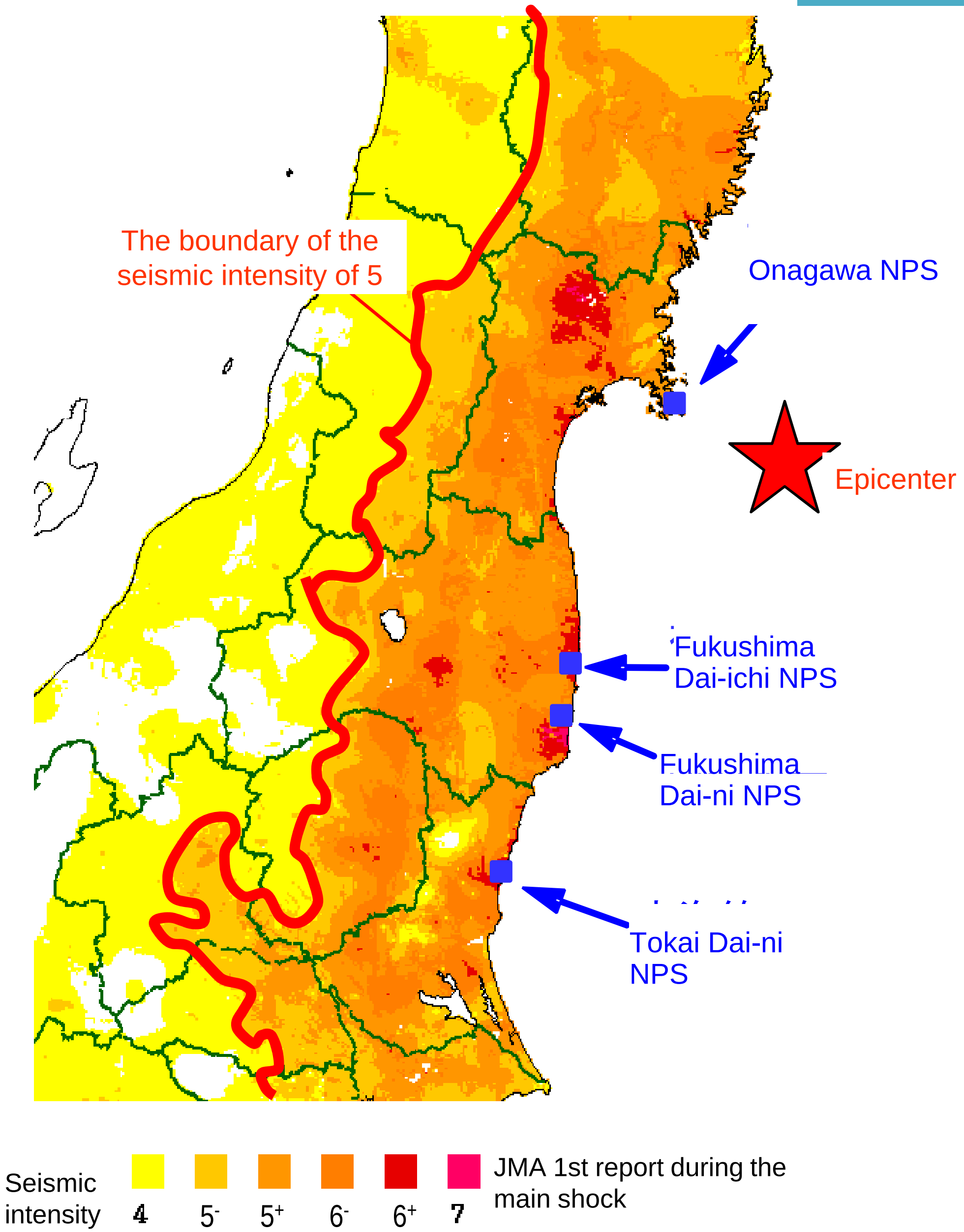
- The explosions deteriorated work performance in the surrounding areas.
- Water leakage from containments / buildings were observed.

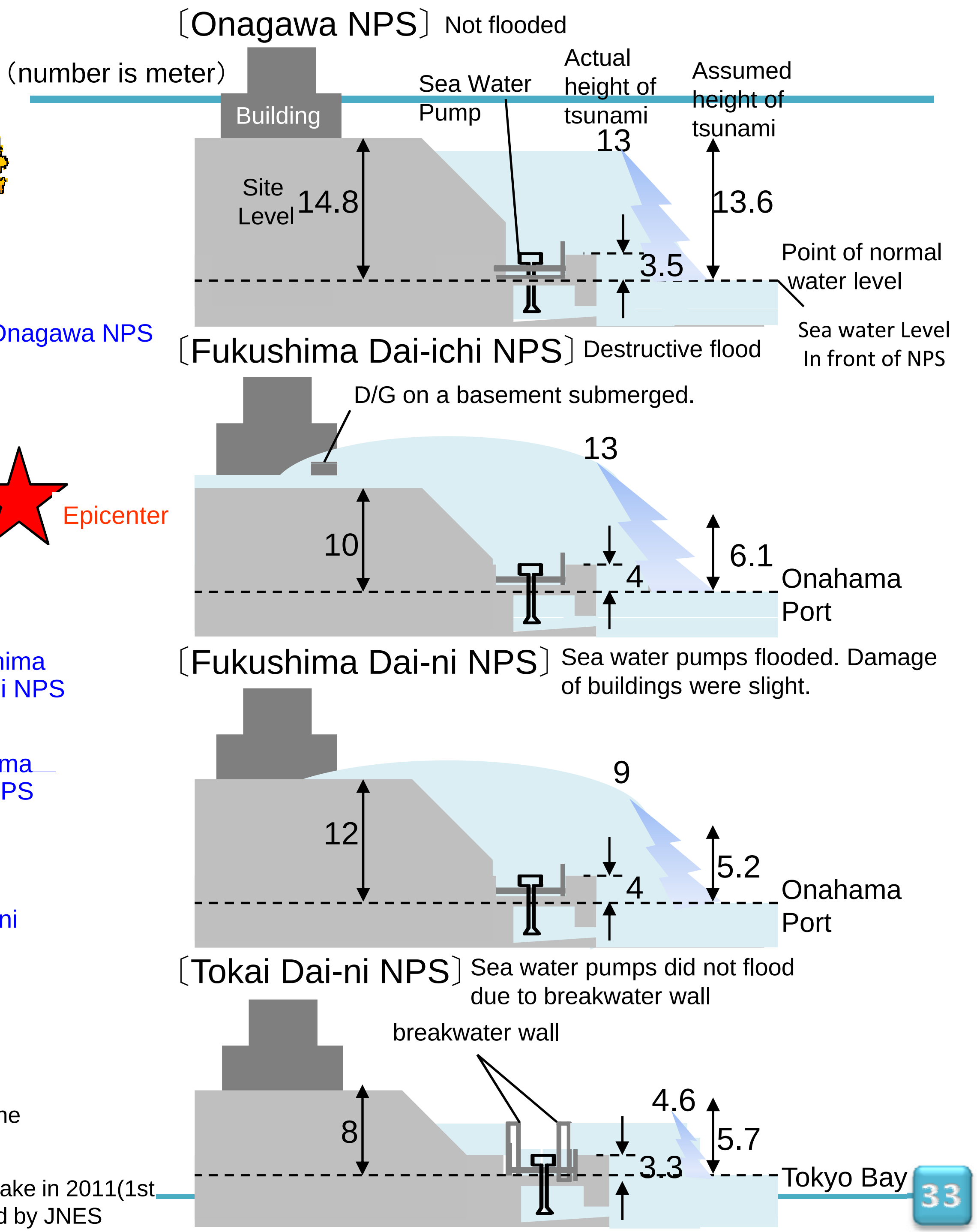
Max. Acceleration Values Observed in Reactor Buildings of each Unit

Loc. of seismometer (bottom floor of reactor bld.)		Record: Max. acceleration (Gal)			Max. response acceleration to the design basis ground motion Ss (Gal)		
		NS	EW	UD	NS	EW	UD
Fukushima Dai-ichi	Unit 1	460※1	447※1	258※1	487	489	412
	Unit 2	348※1	550※1	302※1	441	438	420
	Unit 3	322※1	507※1	231※1	449	441	429
	Unit 4	281※1	319※1	200※1	447	445	422
	Unit 5	311※1	548※1	256※1	452	452	427
	Unit 6	298※1	444※1	244	445	448	415

※1：Each recording was interrupted at around 130-150(s) from recording start time

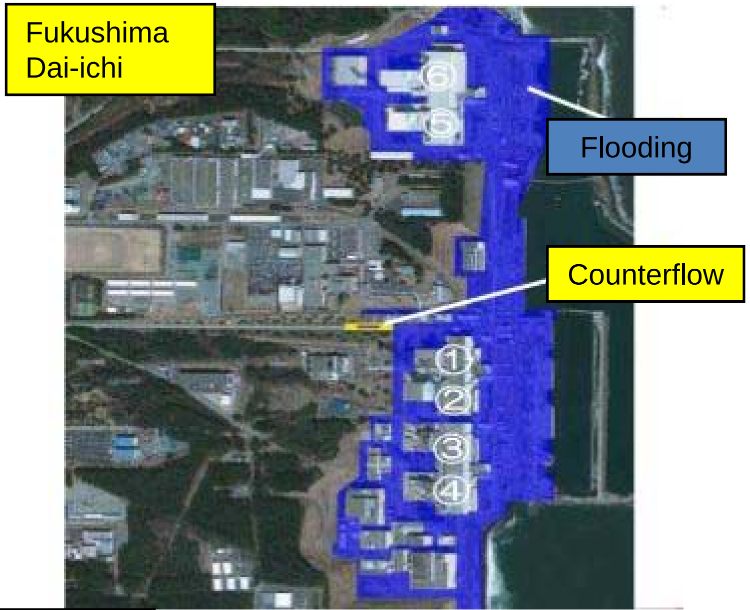
Assumed Height and Actual Height of Tsunami in Each NPS

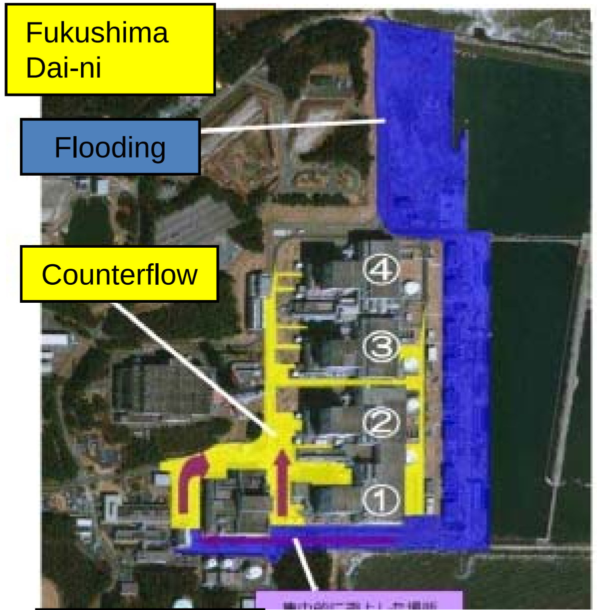


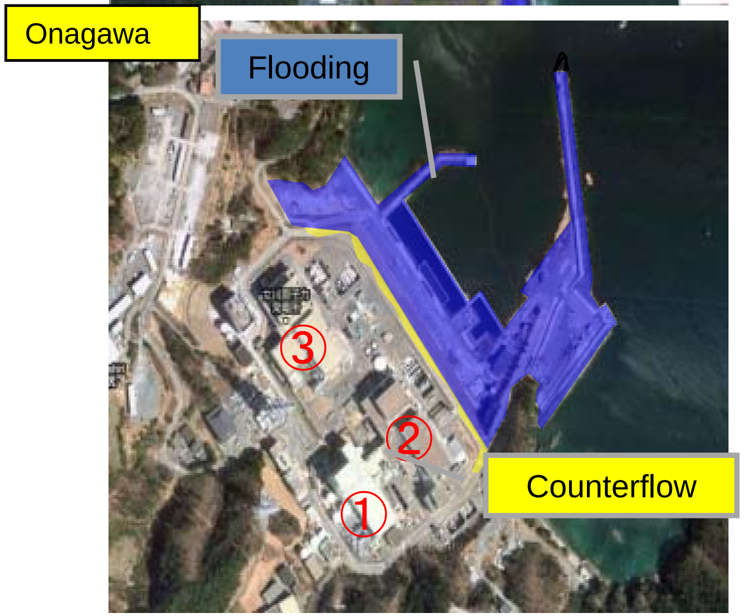


⦿ Reference: JMA "Tohoku District-Off the Pacific Coast Earthquake in 2011(1st Report)," http;//www.jma.go.jp/jma/index.html, partially modified by JNES

Areas inundated by Tsunami at Each NPS

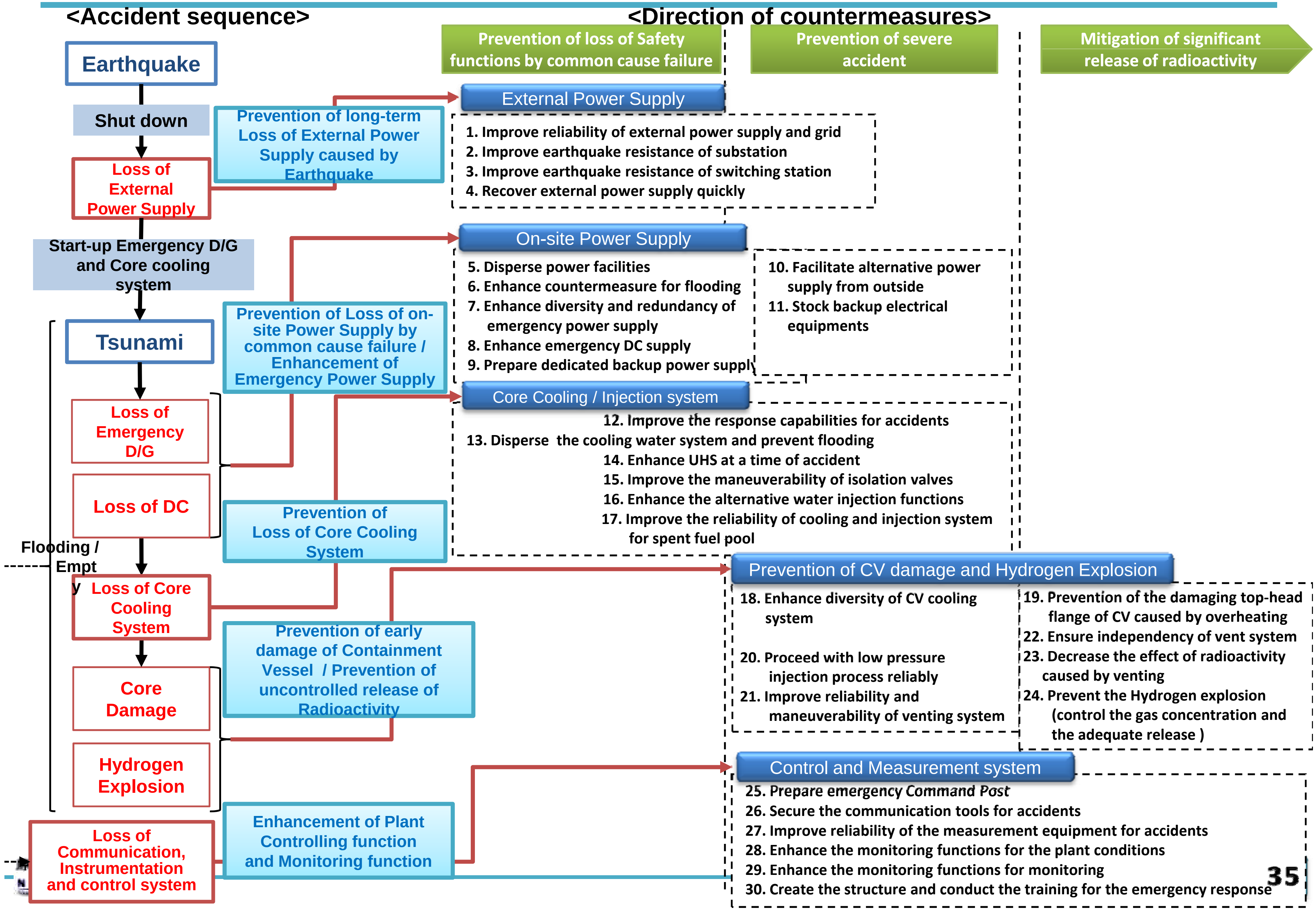






Text added by NISA to published materials from Niigata Prefectural Technology Committee and Google

Technical Knowledge about Accident at Fukushima Dai-ichi Nuclear Power Station, TEPCO
Direction of Countermeasures (Point) - Interim Report -



Ⅱ． External Power Supply Systems

原子力安全・保安院
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Damage of External Power Supply Systems

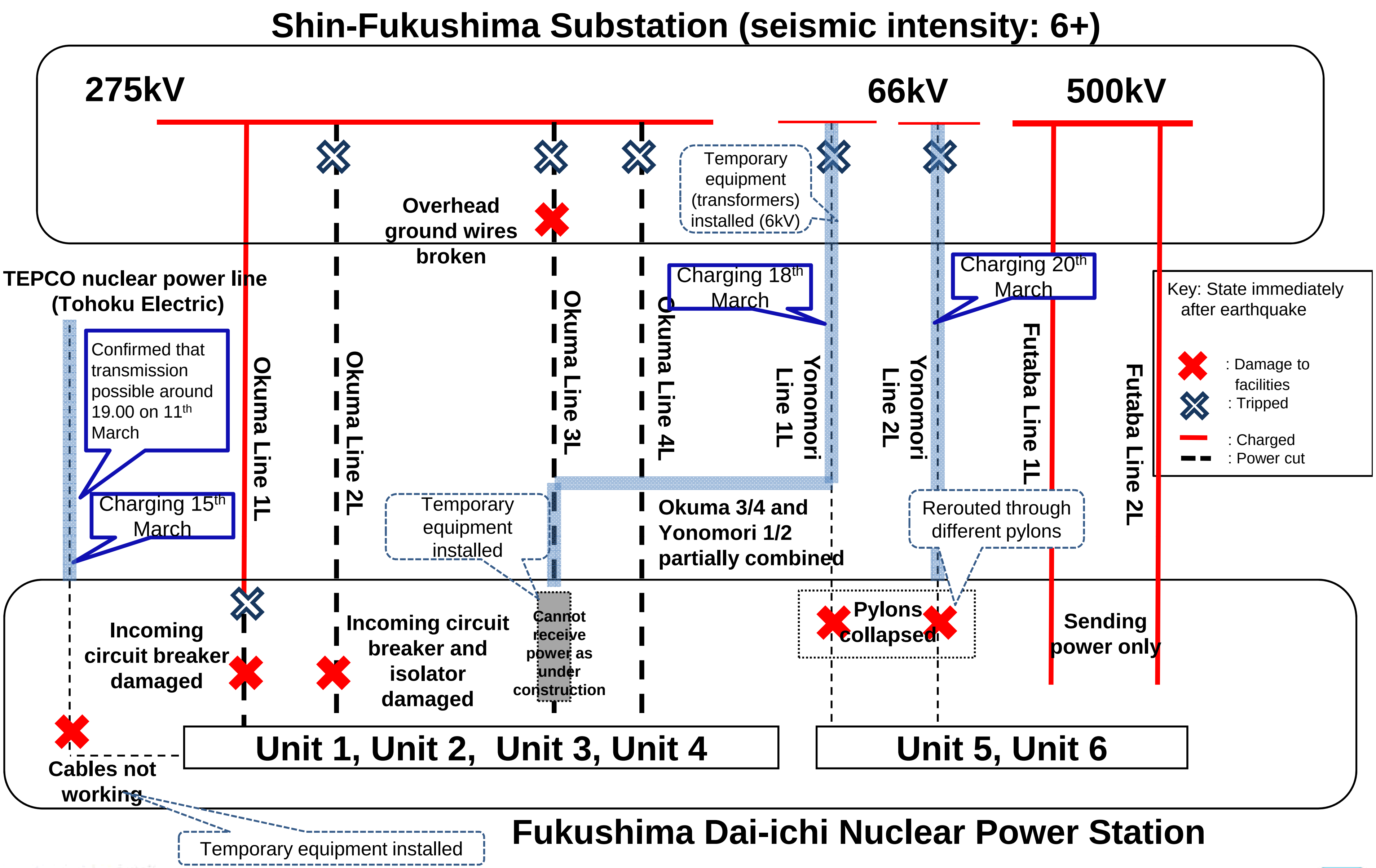
◆ For 5 nuclear power stations (Higashidori, Onagawa, Fukushima Dai-ichi, Fukushima Dai-ni, and Tokai Daini Nuclear Power stations) affected by the earthquake,19 out of 22 external power lines were not available to supply power due to the damage to electric equipments caused by earthquake. (Onagawa and Fukushima Dai-ni NPSs could receive eternal power through surviving 3 lines.)

◆ Situation at Fukushima Dai-ichi NPS

- Damaged circuit breakers and disconnectors in the switchyard (Units 1 and 2)
- Tripped transmission lines (Units 3 and 4)
- A collapse of an nearby embankment which felled electrical towers (Units 5 and 6)

Complete loss of external power

State of External Power Supplies to Fukushima Dai-ichi NPS
(from Immediately after an aftershock to Mar. 20)

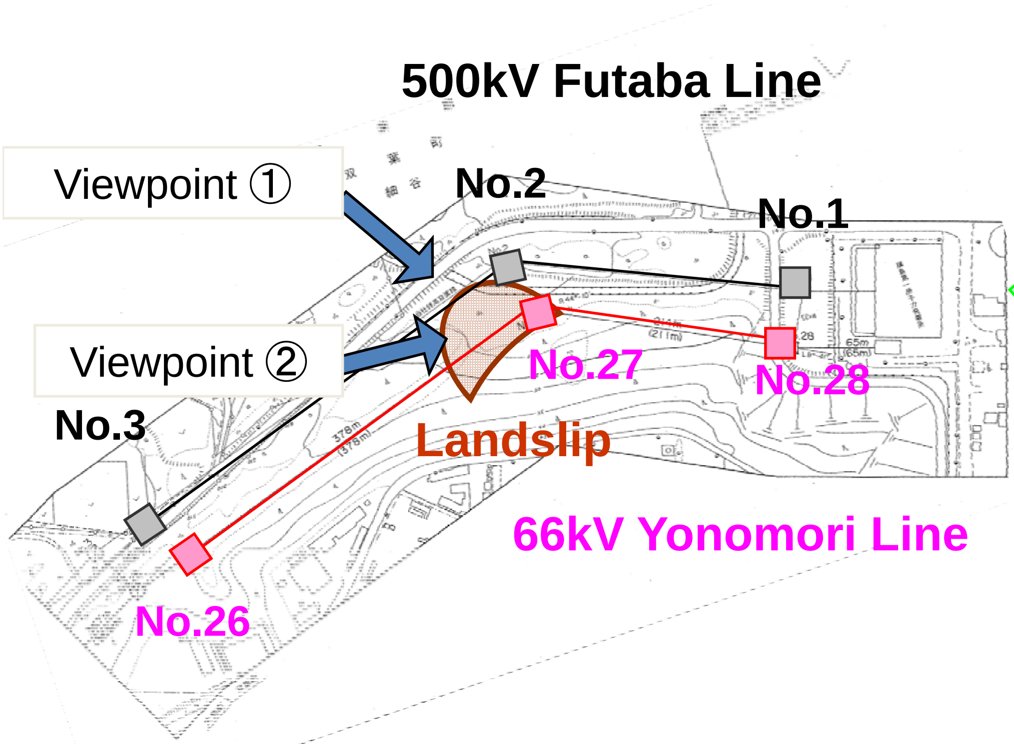


Damage at Switching Stations at Fukushima Dai-ichi NPS

[275kV air blast breaker: completely destroyed]

Damage to Overhead Power Transmission Equipments at Fukushima Dai-ichi NPS

Collapse of pylon due to landslide (Yonomori Line no. 27)



○Status of restoration
- Temporary restoration by circuitous route on Mar. 18 (Reroute to Futaba Line no. 2)
- Futaba line was changed to 66kV (completed in July)

Landslip on slope

(C) GeoEye

Landslip on slope (viewpoint ①)

Collapse of Pylon (viewpoint ②)

Countermeasures for External Power Supply Systems

Countermeasure 1 Improve reliability of external power supply and grid

(Example: Ensuring power supply from various routes (transmission power lines, electrical substations))

Countermeasure 2 Improve earthquake resistance of substation

(Example: Using gas insulated equipments and high-strength isolators)

Countermeasure 3 Improve earthquake resistance of switching station

(Example: Upgrading from air blast breakers (ABB) to gas insulated switchgear (GIS))

Countermeasure 4 Recover external power supply quickly

(Example: Preparing materials and equipments, and manuals
Installing fault locators)

Improve earthquake resistance of substation (on site)

275kV air blast breaker (ABB)
(Source: Electrical Equipment Earthquake Countermeasures WG)

550kV gas insulated switchgear (GIS)
(Source: Japan AE Power Systems Co. website)

Ⅲ. On-site Power Supply Systems

Damage to On-site Power Supply Systems

- Most of the power supply equipment installed on the basement floors of the turbine buildings (T/Bs) and the control buildings (C/Bs) near the ocean were damaged due to flooding or water damage.

The emergency diesel generators (D/Gs) lost function due to flooding or water damage. Even intact D/Gs could not supply power because supporting equipment such as DC power supply, sea water pumps, high-voltage switch boards (M/Cs), power centers (P/Cs) and etc. lost function due to flooding or water damage.

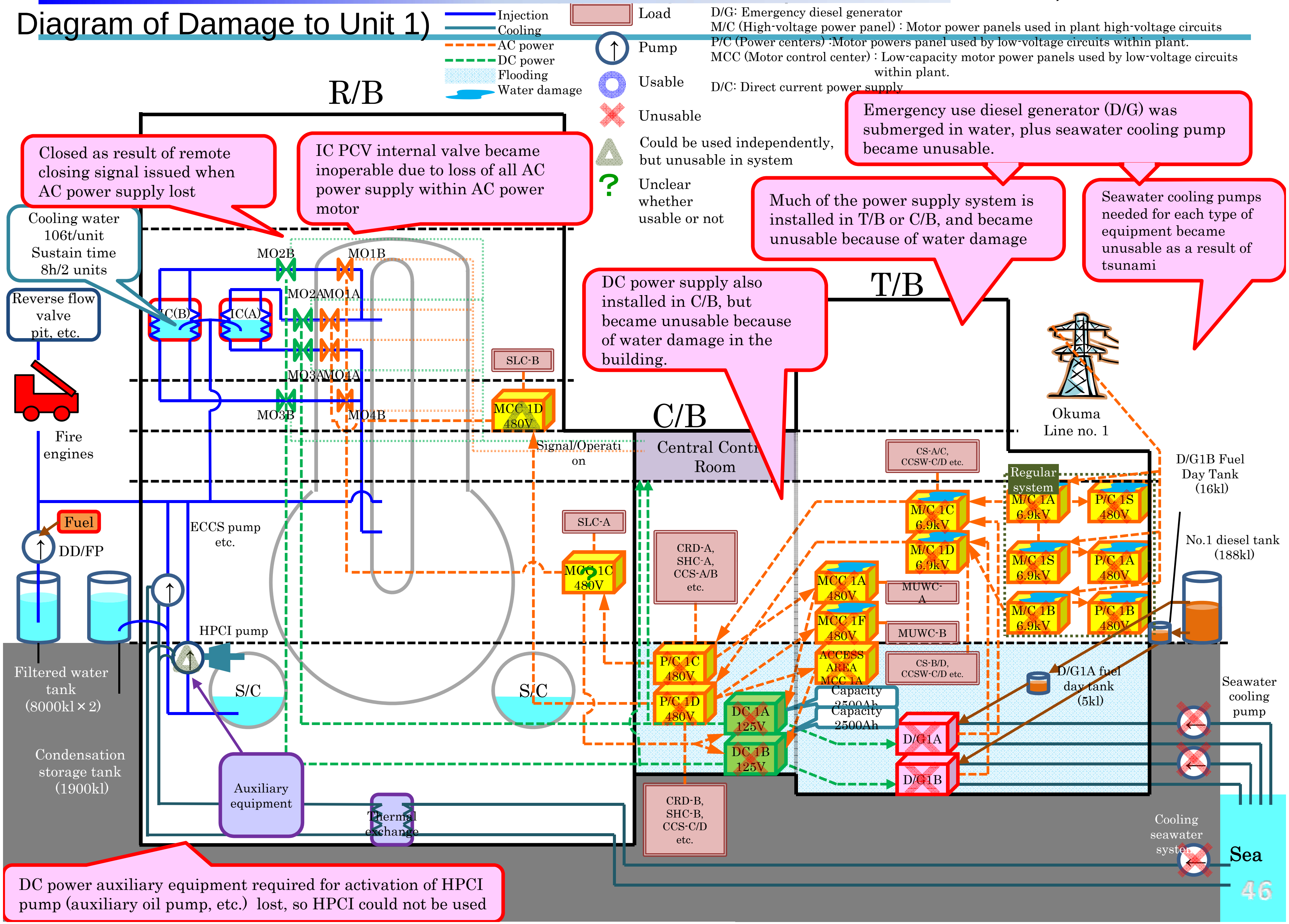
- Unit 1: Complete loss of power supply including D/C power
- Unit 2: Complete loss of power supply as same as Unit 1
- Unit 3: Loss of all AC power supply

Impact of Tsunami on On-site Power Supply and Cooling Systems

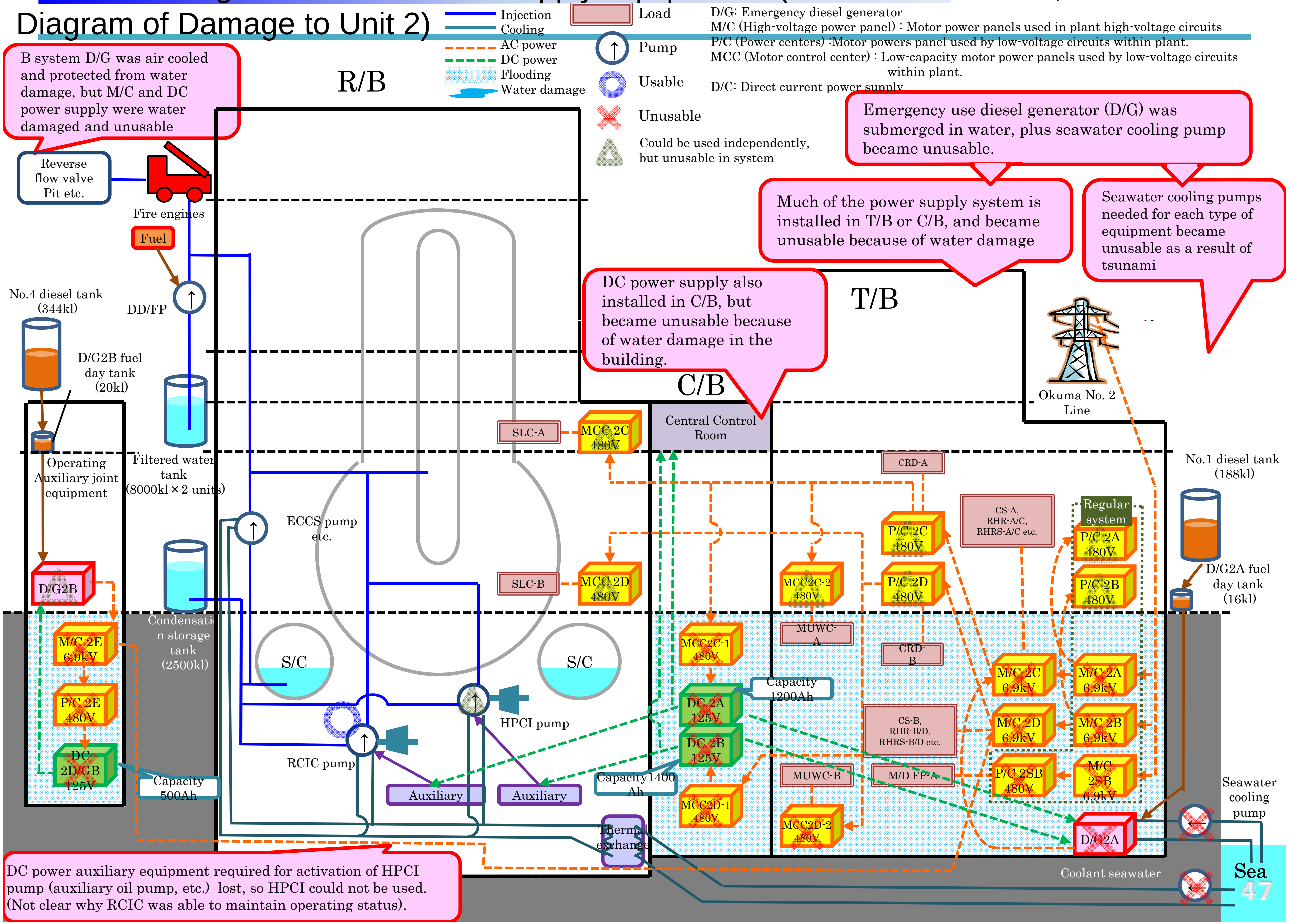
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Emergency Diesel Generator	× 1A, 1B (T/B basement)	× 2A (T/B basement) 2B (Common pool 1F)	× 3A, 3B (T/B basement)	× 4A (T/B basement) 4B (Common pool 1F)	× 5A, 5B (T/B basement)	△ 6A: R/B basement 6B: DG building 1F (Usable) HPCS: R/B basement
high-voltage switch boards	× T/B 1F	× T/B basement, etc.	× T/B basement, etc.	× T/B basement, etc.	× T/B basement, etc.	△ R/B 2F basement
Power center (note)	× T/B 1F etc.	△ T/B 1F etc.	× T/B basement, etc.	△ T/B 1F, etc.	△ T/B 2F, etc.	△ R/B 2F basement, etc.
DC power (battery)	× C/B basement, etc.	× C/B basement, etc.	○ T/B mezzanine basement	× C/B basement, etc.	○ T/B mezzanine basement	○ T/B mezzanine basement
Emergency core cooling equipment	△ However, IC required inspection	△ (RCIC usable)	△ (RCIC and HPC usable)	–	–	–

×: Unusable due to flooding or water damage △: Partially unusable ○: Usable T/B: Turbine building C/B: Control building R/B: Reactor building
(Note) Air circuit breaker (ACB), guard relay and peripheral equipment stored in a compact manner using a motive power panel that uses low-voltage circuits within the plant

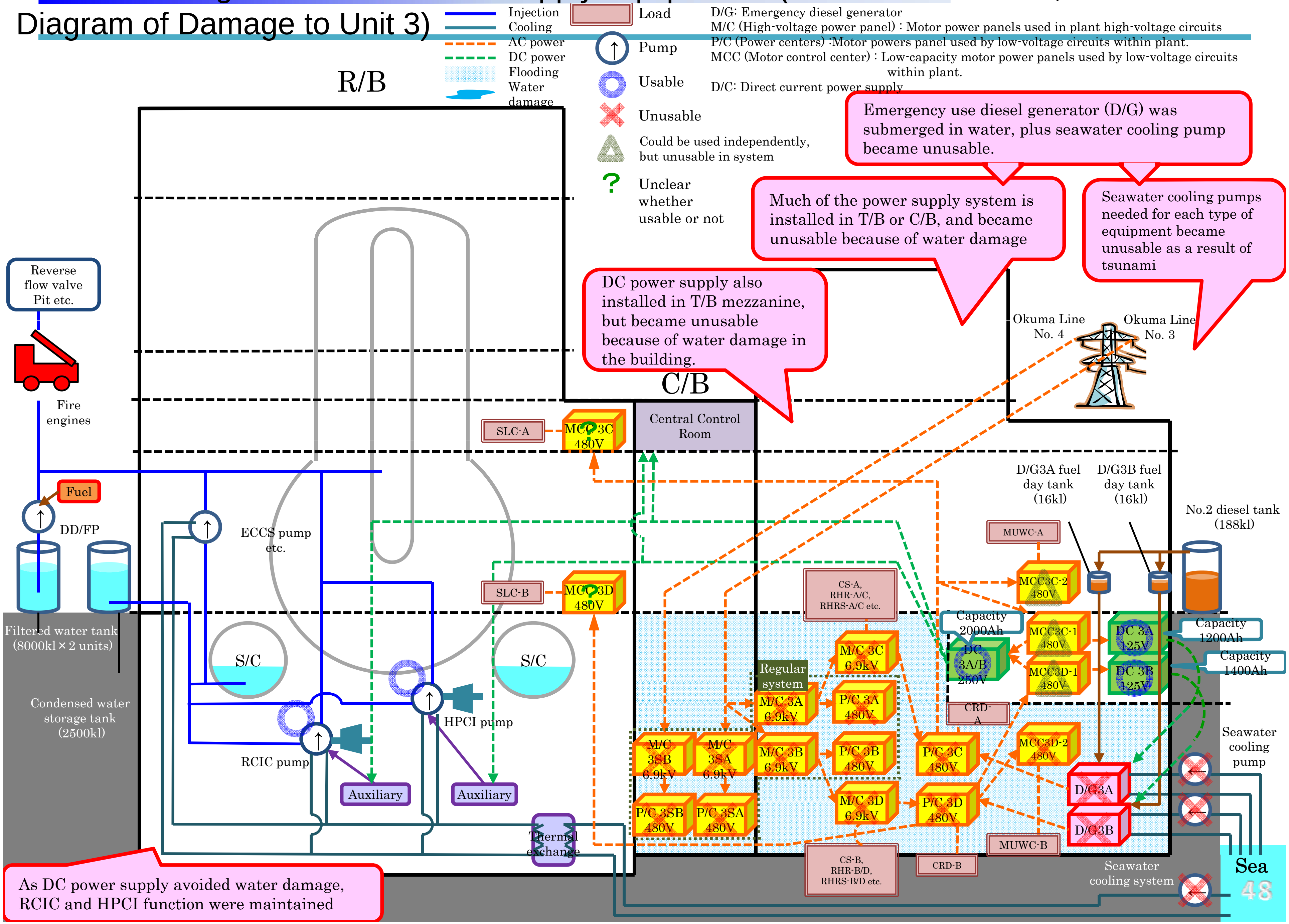
State of Damage to On-site Power Supply Equipments (Fukushima Dai-ichi, Diagram of Damage to Unit 1)



State of Damage to On-site Power Supply Equipments (Fukushima Dai-ichi, Diagram of Damage to Unit 2)



State of Damage to On-site Power Supply Equipments (Fukushima Dai-ichi, Diagram of Damage to Unit 3)



Countermeasures for On-site Power Systems

Countermeasure 5 Disperse On-site power facilities

(Example: Strengthening the redundancy of power supply and switch boards
Ensuring the diversity of installation locations of the buildings and in the buildings)

Countermeasure 6 Enhance countermeasure for flooding

(Example: Adopting watertight buildings/rooms and draining function)

Countermeasure 7 Enhance diversity and redundancy of emergency AC power supply

(Example: Strengthening the diversity of the cooling methods through air cooling, water cooling and etc.)

Countermeasures for On-site Power Systems (cont.)

Countermeasure 8 Enhance emergency DC power supply

Example: Securing the storage capacity of batteries according to the characteristics of the plant (it is necessary to secure a storage capacity of at least 8 hours with the storage capacity of the batteries of one system without isolating the load/ and at least 24 hours after the unnecessary loads are isolated.)

Countermeasure 9 Prepare dedicated backup power supply

Example: Securing a power supply dedicated to particularly important management system, by separately preparing a charging system and batteries in addition to the existing and alternative power supplies

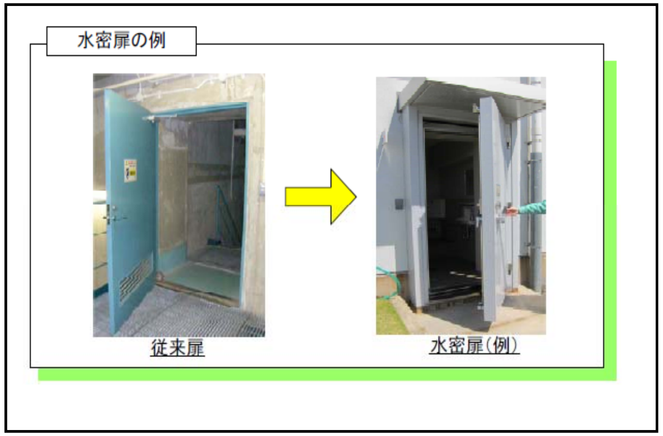
Countermeasure 10 Facilitate alternative power supply from outside

Example: Standardization of the power supply inlets outside of the buildings from power supply car
Splitting them into two locations or more (including measures against salt water)

Countermeasure 11 Stock backup electrical equipments

Example: Securing spare parts of M/Cs, P/Cs and cables
Installing backup equipments
Preparing portable lights

Related Facilities for Countermeasures



Watertight door (Source: The Shikoku Electric Power Co.,Inc.)

Gas turbine generator (Source: The Chugoku Electric Power Co.,Inc.)

Emergency generator of cooling methods through air cooling (Source:The Chugoku Electric Power Co.,Inc.)

125V battery charger room

250V battery charger room

Power supply inlets outside of the buildings (Source: The Shikoku Electric Power Co.,Inc.)

spare parts (electric motor)

Replacement (pumps)

Spare parts of electric motors and replacement of pumps (Source: The Chugoku Electric Power Co.,Inc.)

Ⅳ. Cooling Systems

Relation between of Power Supply and Cooling Systems

- Unit 1: Cooling systems became uncontrollable due to loss of all power supply in the early stage.
- Unit 2: All power supply was lost. RCIC continued cooling.
- Unit 3: RCIC and HPCI continued cooling until D/C power supply ran out.

The reactors shut down automatically due to earthquake, loss of external power supply.

↓

Power supply equipment such as D/Gs was not unavailable due to tsunami, loss of all AC power supply

Unit 1 & 2

Loss of function of DC power supply due to tsunami

Unit 1

IC was unavailable to check status and operate. HPCI was unavailable to start up.

Developing into accident at early time

Unit 2

RCIC continued cooling.

RCIC continued to operate until 13:25 on Mar.14.

Unit 3

Function of DC power supply maintained

Unit 3

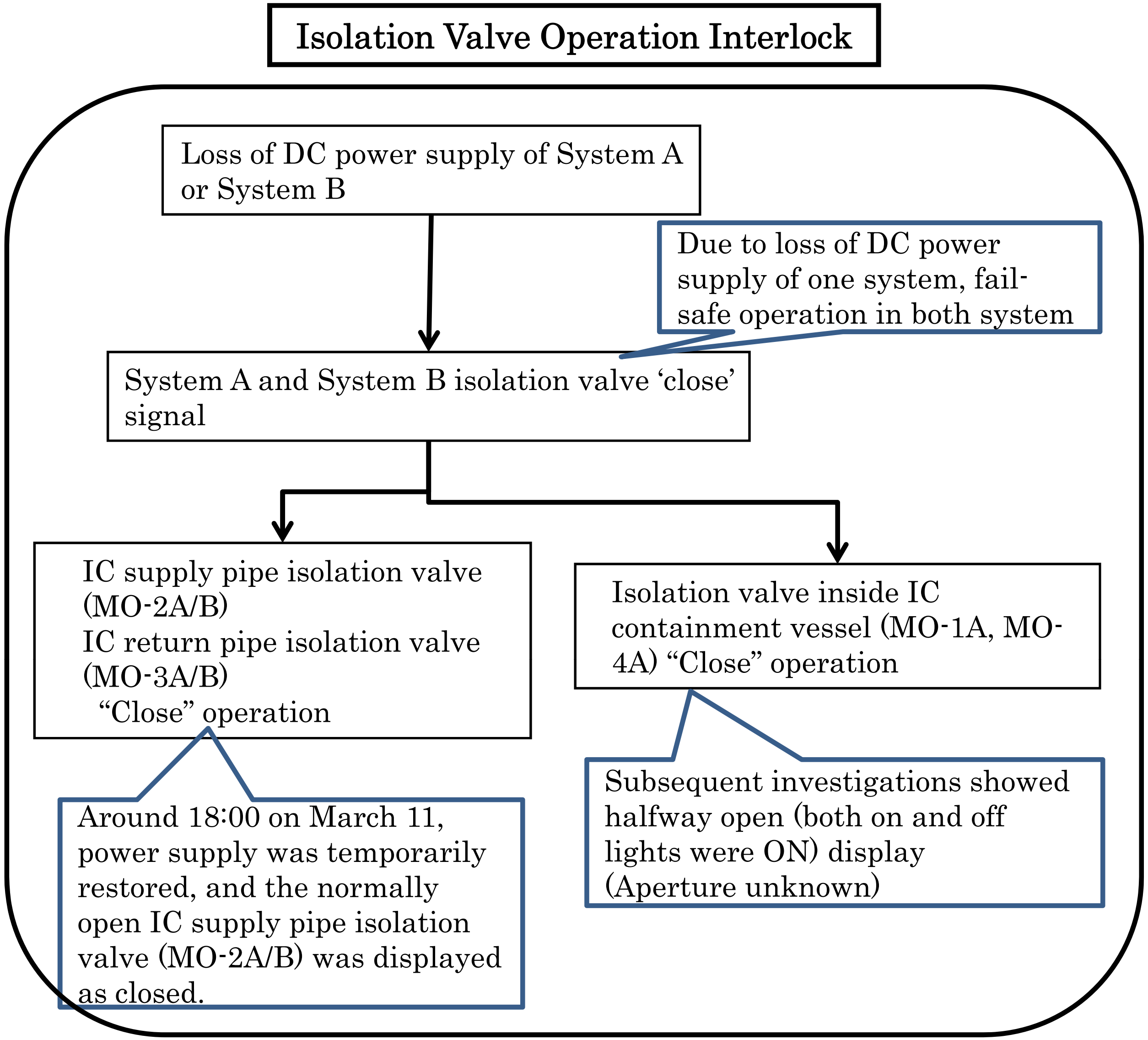
RCIC or HPCI continued cooling until battery ran out.

After RCIC stopped at 11:36 on Mar.12, HPCI started up automatically due to low level of water in reactor.

Operating Conditions of Isolation Condenser (IC) of Unit 1

- Due to loss of DC power supply after tsunami, the indication of the valve status (open or close) went off, and the IC became uncontrollable.

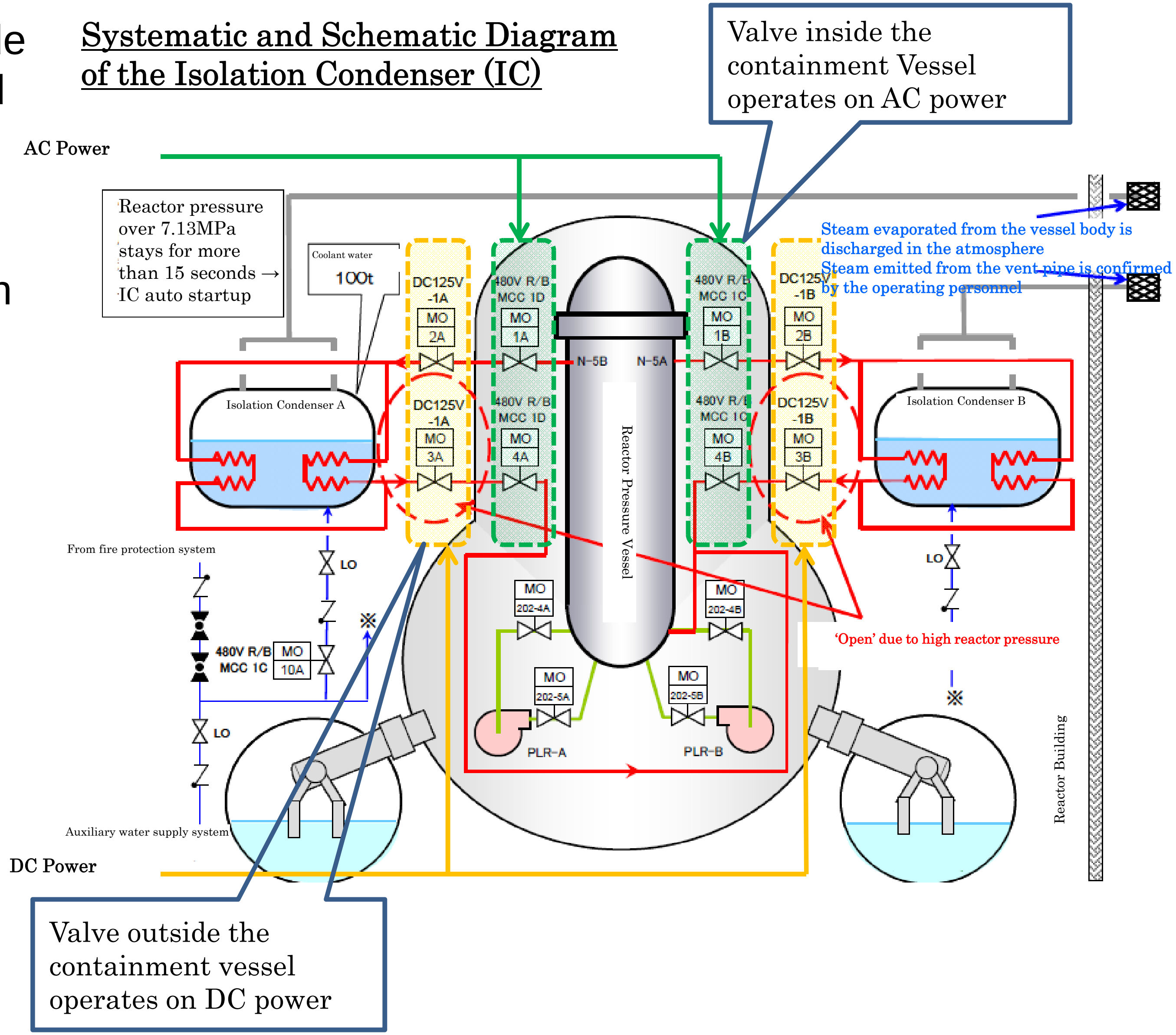
- Due to loss of DC power supply, the interlock of the isolation valve in fail-safe mode closed the IC valves.



Operating Conditions of the Isolation Condenser (IC) of Unit 1 (cont.)

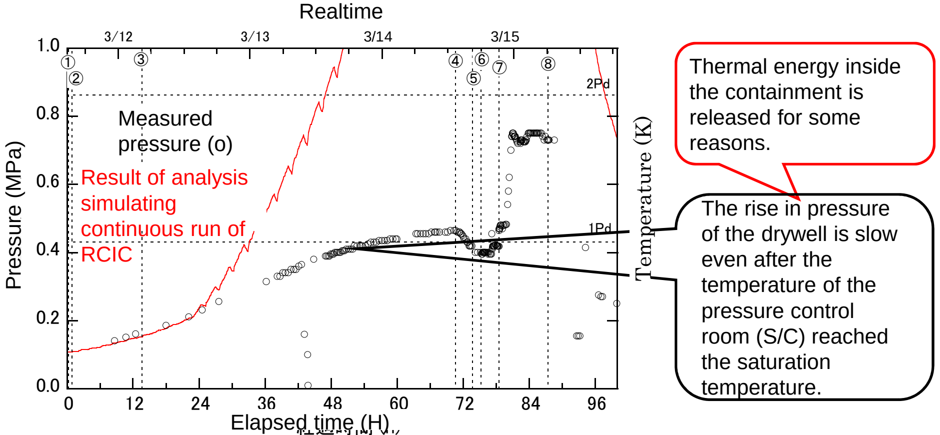
- Since the valves inside the PCV are operated with AC power, both status-check and operation were impossible even when the DC power supply was temporarily restored.

- The status of the IC was misunderstood.

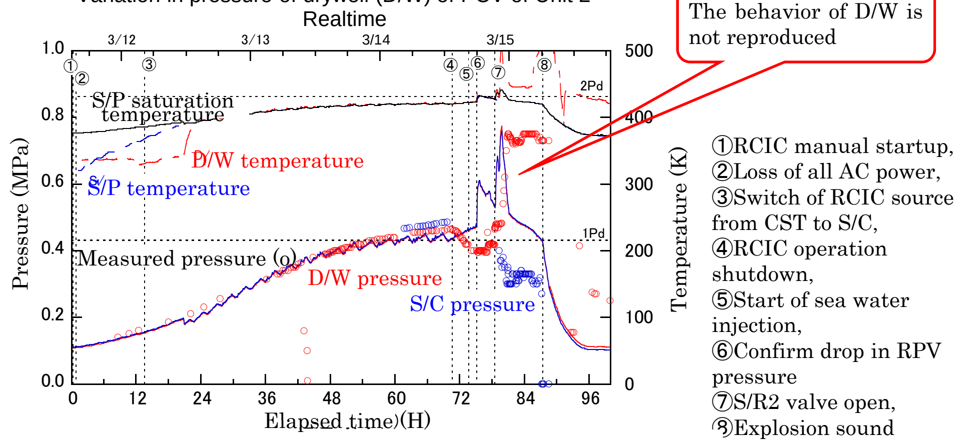


Analysis of Condition of PCV of Unit 2

- In the analysis in June, 2011, PCV leakage was assumed in order to explain slow rise of PCV pressure until Mar. 14.
- It is newly assumed that sea water intruded into the S/C room and contributed to the slow rise of PCV pressure.



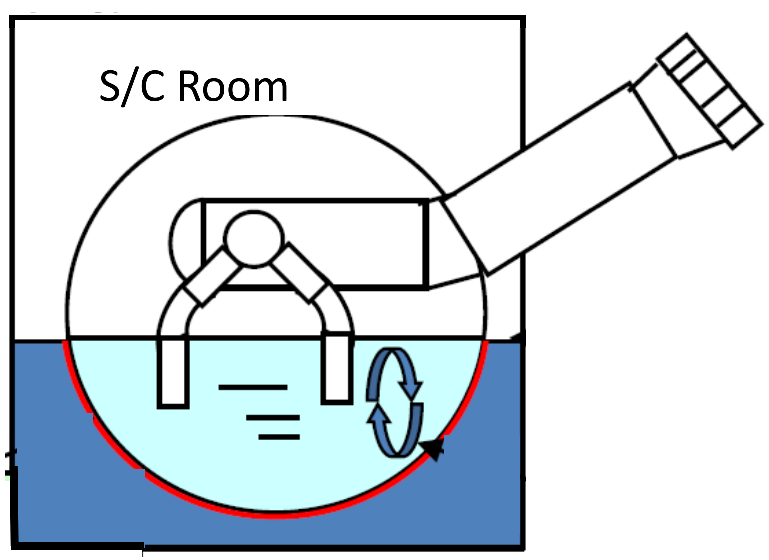
Variation in pressure of drywell (D/W) of PCV of Unit 2



①RCIC manual startup,
②Loss of all AC power,
③Switch of RCIC source from CST to S/C,
④RCIC operation shutdown,
⑤Start of sea water injection,
⑥Confirm drop in RPV pressure
⑦S/R2 valve open,
⑧Explosion sound

Variation in temperature and pressure of PCV of Unit 2
(solid line indicates the result of analysis assuming the leakage of PCV)

Newly assumed condition



Source: Added to "About evaluation on the situation of the reactor core of Unit 1, Unit 2, and Unit 3 of Tokyo Electric Power Co., Inc. Fukushima Daiichi Nuclear Power Station concerning the accident" (Jun. 6, 2011, revised Oct. 20, 2011, Nuclear and Industrial Safety Agency)

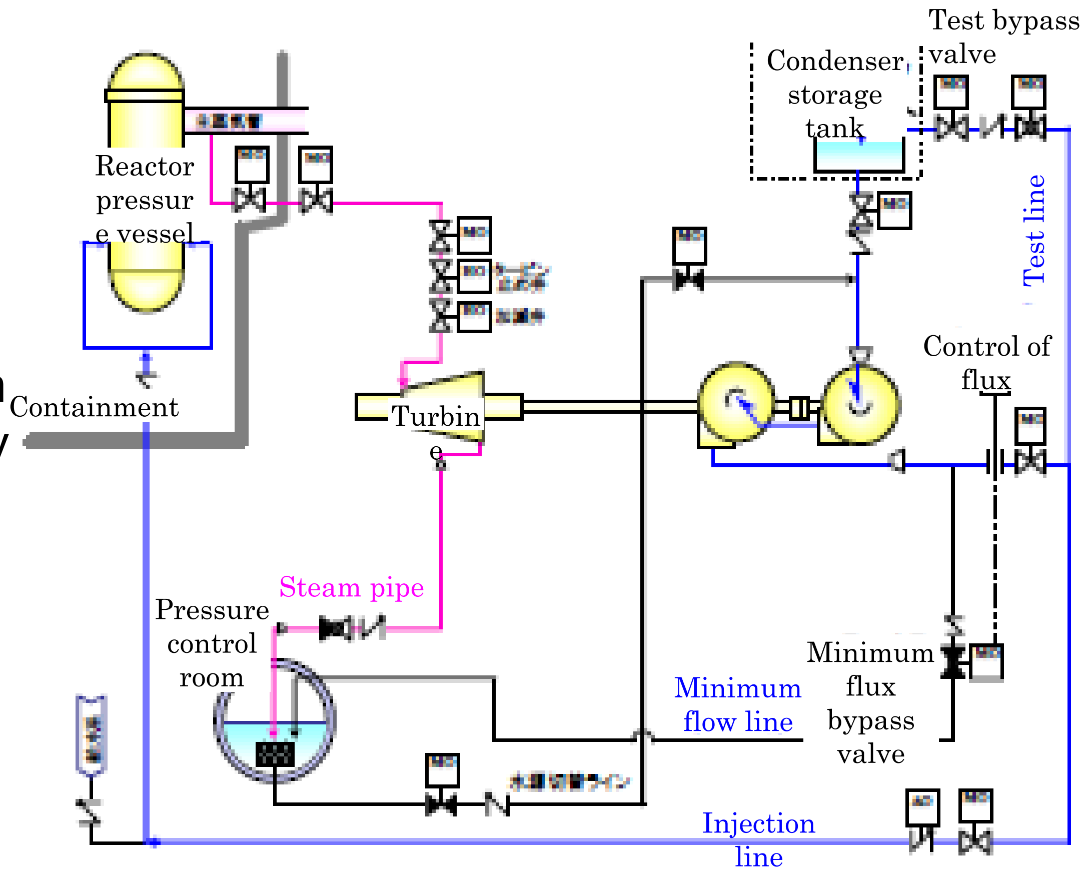
Operating Conditions and Causes of shot down of High Pressure Coolant Injection (HPCI) System of Unit 3

- Situation of HPCI of Unit 3,

(1) The amount of flow was adjusted using test lines.
(2) Minimum flow line was closed.
(3) The HPCI was manually shut down when the reactor pressure dropped below1MPa.

- This decision on manual shut down was made only by a worker on duty and some other staffs without consulting senior managers.

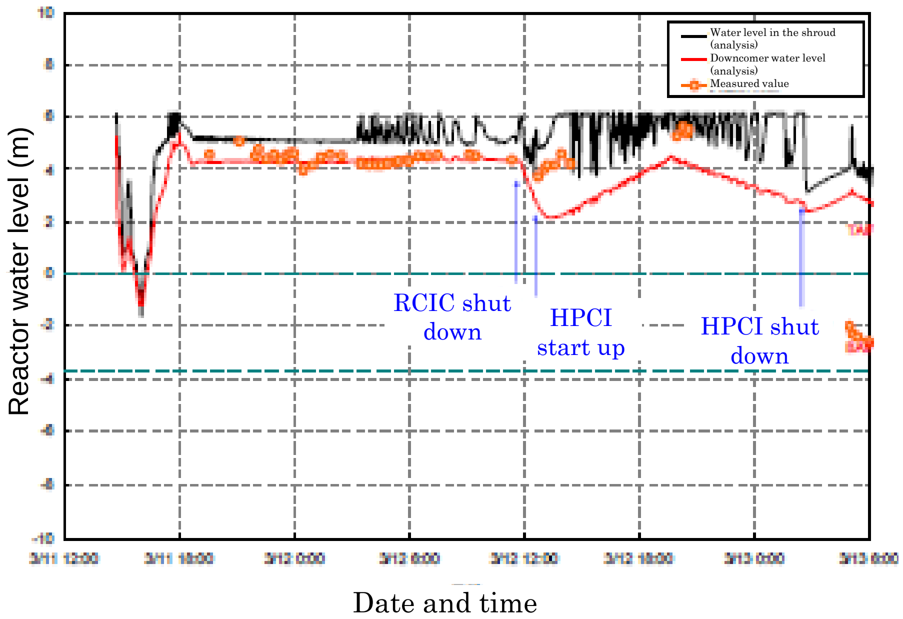
- Because the SRV could not be opened due to battery depreciation after the HPCI shut down, RPV pressure rose. And alternative low pressure coolant injection by fire truck did not work either.



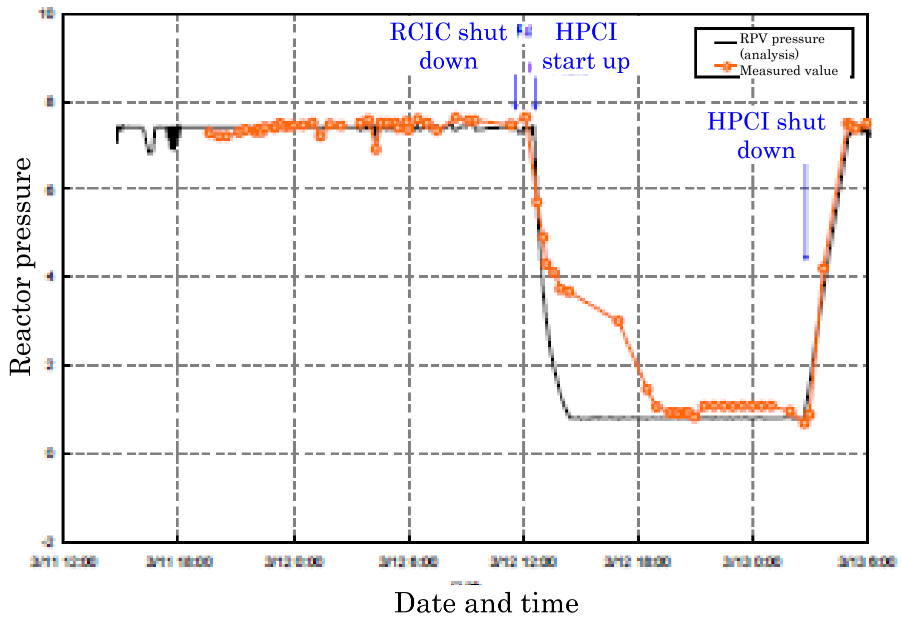
HPCI system diagram

Water level went down, and the core was exposed

Operating Conditions and Causes of shot down of HPCI System of Unit 3 (cont.)



Time variation of reactor water level of Unit 3



Time variation of reactor pressure of Unit 3

Source: Response by Tokyo Electric Power Co. Inc, for “on submission of materials on facts on the results of investigation of the accident and its progress of Tokyo Electric Power Co. Inc Fukushima Daiichi Nuclear Power Station (instruction) issued on Dec. 16, 2011” (Dec.22, 2011)

Countermeasures for Cooling Systems

Countermeasure 12 Improve the response capabilities for accidents

Example: Establishing procedure manual
Securing both hardware (dosimeters and masks) and software (operation manuals and blueprints)
R&D of tsunami prediction systems

Countermeasure 13 Disperse the cooling water system and prevent flooding

Example: Adopting watertight buildings and pumping rooms, and draining function

Countermeasure 14 Enhance UHS at a time of accident

Example: Installing portable alternative RHRSs and/or air-cooling equipments

Countermeasure 15 Improve the maneuverability of isolation valves

Example: Ensuring portable air compressors and DC sources
Measures to manually operating

Countermeasures for Cooling Systems (cont.)

Countermeasure 16 Enhance the alternative water injection functions

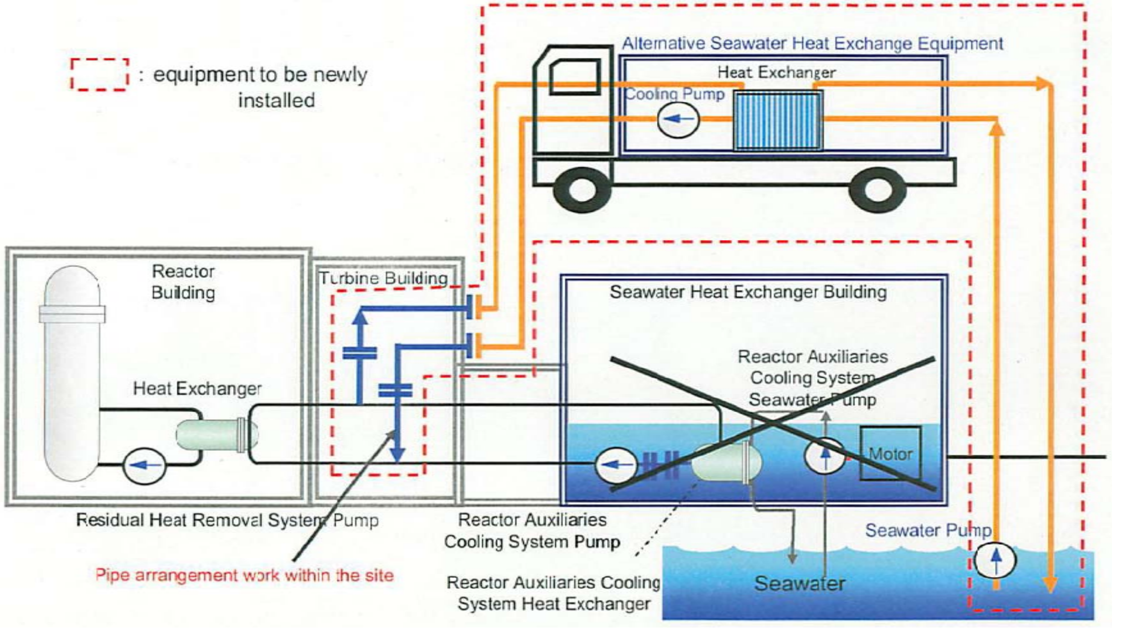
(Example: Ensuring pumps with high discharge pressures
Installing injection ports outside of the pump building)

Countermeasure 17 Improve the reliability of cooling and injection system for spent fuel pool

(Example: Ensuring diversity and redundancy of cooling and injection function (Moreover, studying to ensure a sufficient quantity of cooling water, a decentralized storage configuration, air-cooled facilities and the use of dry storage))

Countermeasures for Cooling Systems (cont.)

Watertight door (Source: The Chugoku Electric Power Co.,Inc.)



Portable alternative RHRSs (Source: TEPCO)

Ⅴ. Confinement Systems

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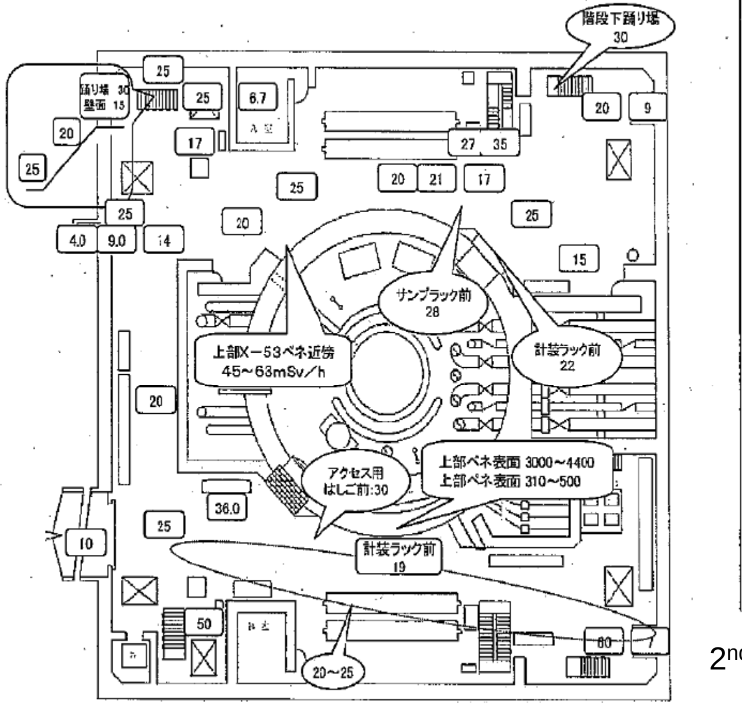
Impact on Loss of Function of Confinement Systems

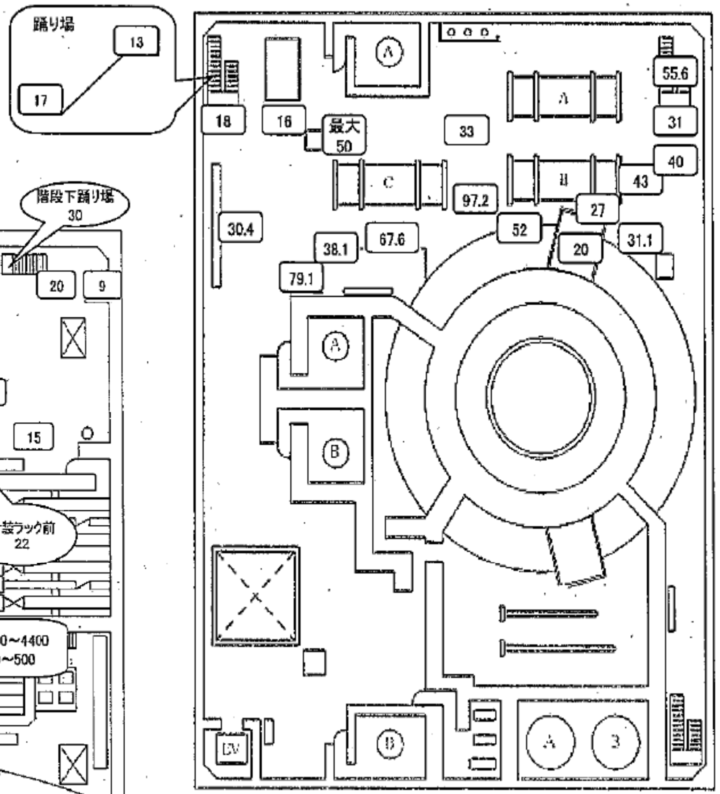
- Radioactive material leakage presumably occurred when the pressure of the PCV was increased after the venting because the radioactive dose had increased after increasing of the pressure of the PCV of the Unit 1. Possible location of leakage was top flange, penetration of the containment vessel and/or equipment hatches.
- It is highly possible that the leakages were caused by deterioration of the organic sealing as a result of high temperatures by thermal radiation directly from the pressure vessel.
- When venting was conducted, the standby gas treatment systems (SGTS) was not properly isolated, thus hydrogen gas back flew into the reactor building. (in paticular, Unit 4)

Results of Dose Measurement (Each Floor (Unit 2 Reactor Building))

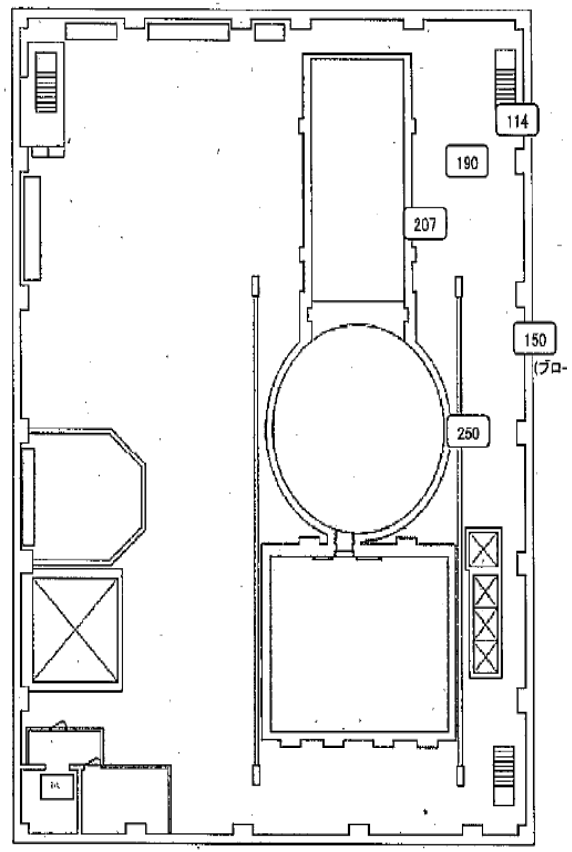
- Amount of leakage from upper part of the PCV must be relatively dominant because the dose of 5th floor is a few hundred mSv/h while the other floors are some dozen mSv/h.



1st floor of the Unit 2 reactor building



2nd floor of the Unit 2 reactor building



5th floor of the Unit 2 reactor building

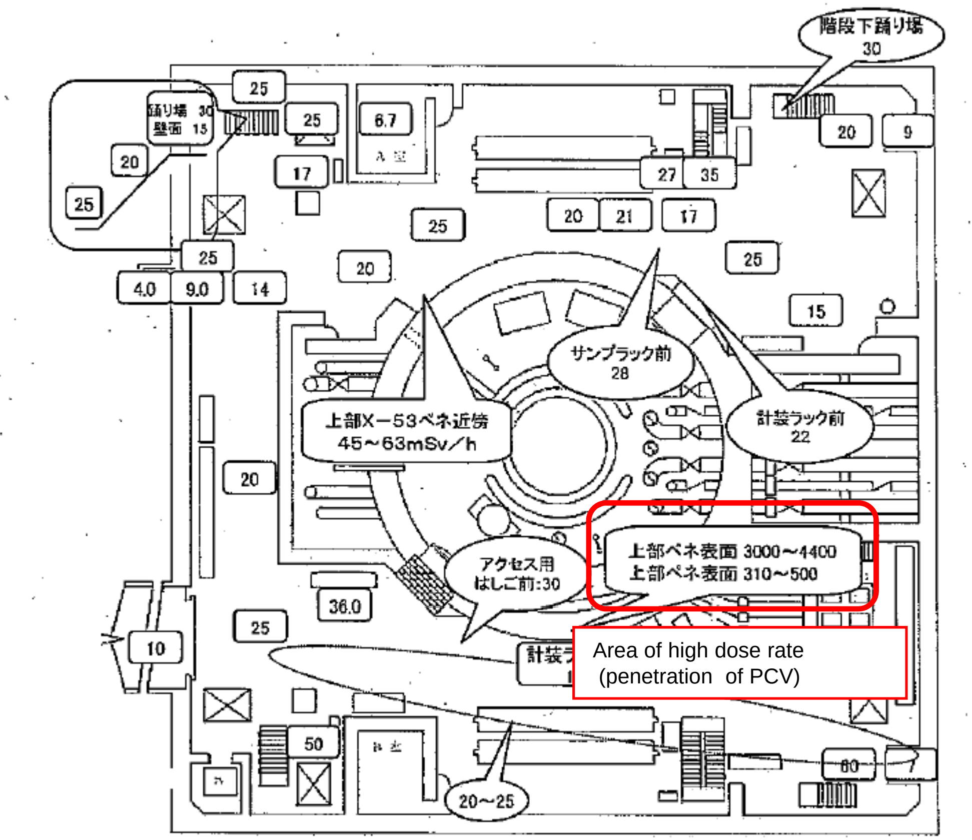
unit: mSv/h

(Source) Materials published by Tokyo Electric Power Co., Inc.

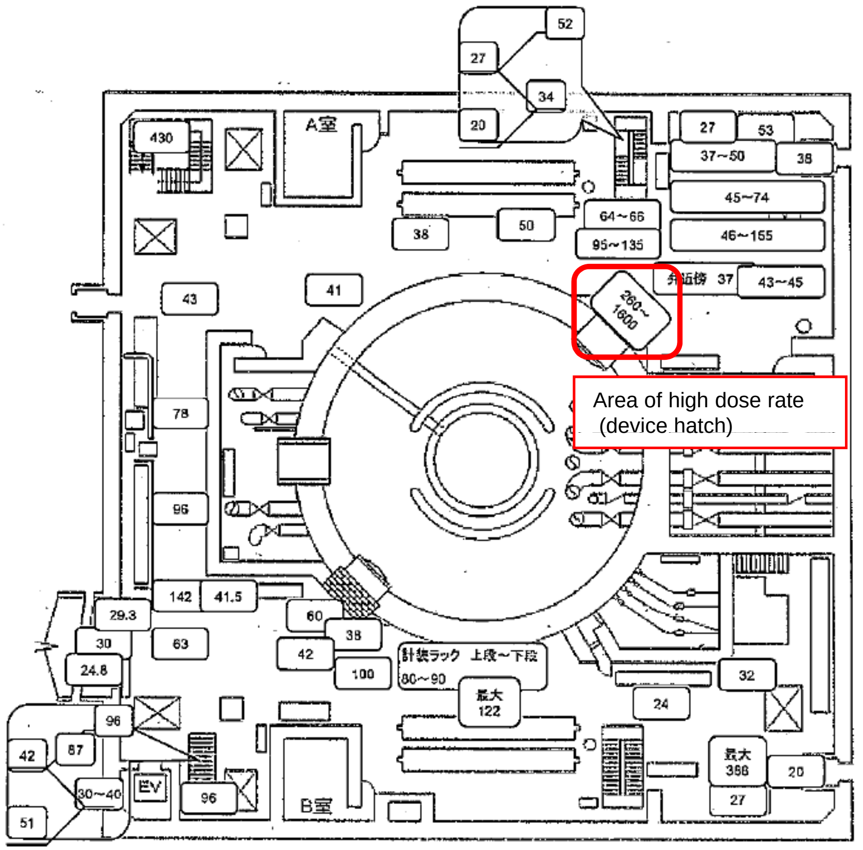
(Note) As for the results of measurement, internal contamination of pipes etc, and surface contamination of walls are not distinguished.

Results of Dose Measurement (Spot: Penetration of PCV, Device Hatch)

- There are several places where a locally high dose rate is detected.

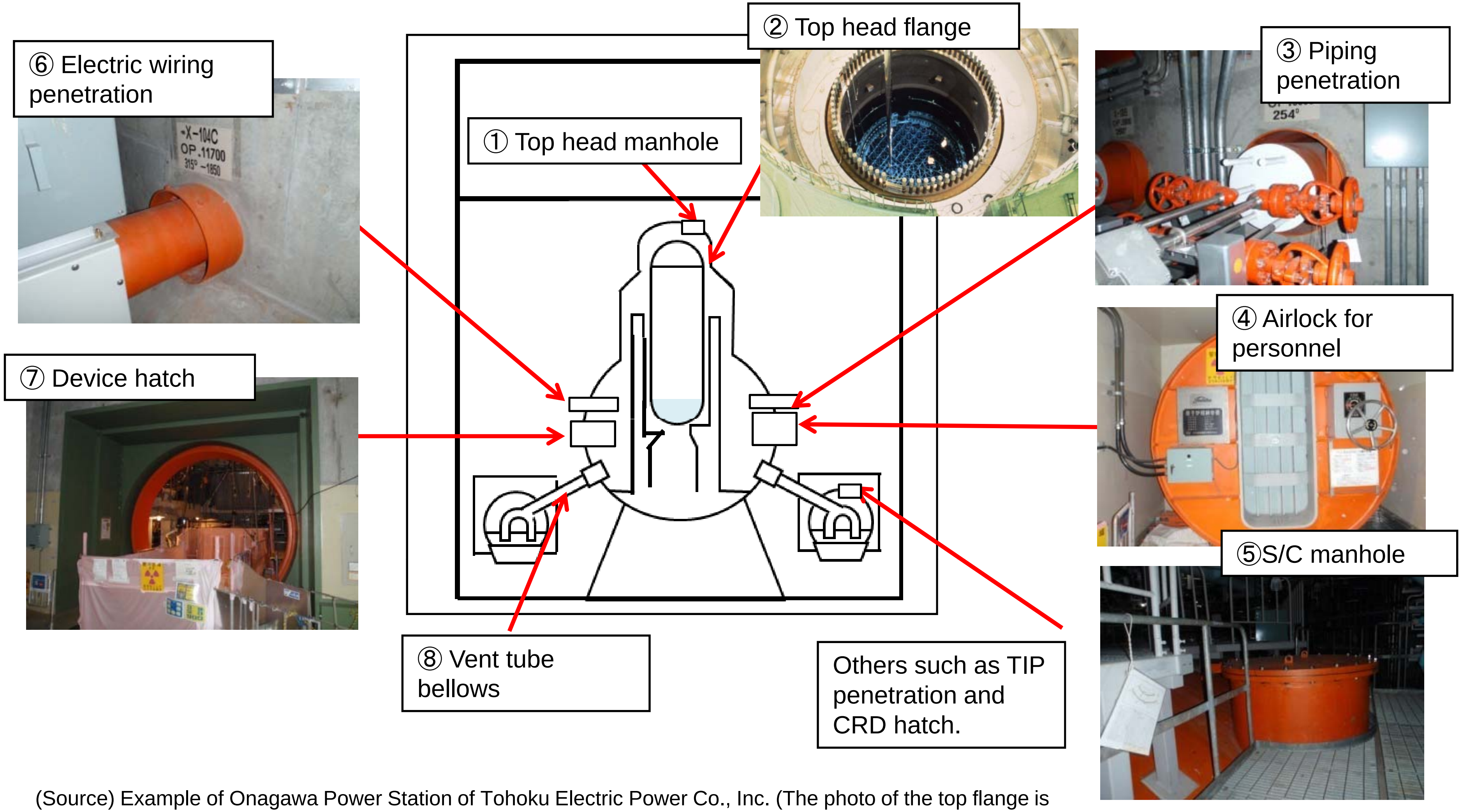


1st floor of the Unit 2 reactor building



1st floor of the Unit 3 reactor building

Places of Possible Release (Example of Mark-I type Reactor)



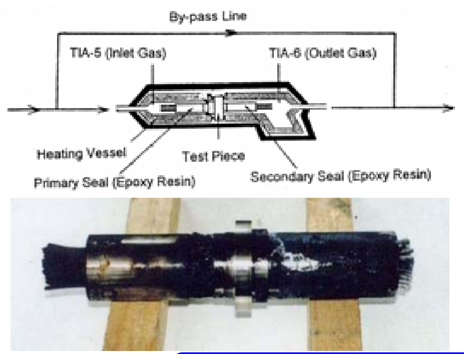
(Source) Example of Onagawa Power Station of Tohoku Electric Power Co., Inc. (The photo of the top flange is courtesy of Tokyo Electric Power Co., Inc.)

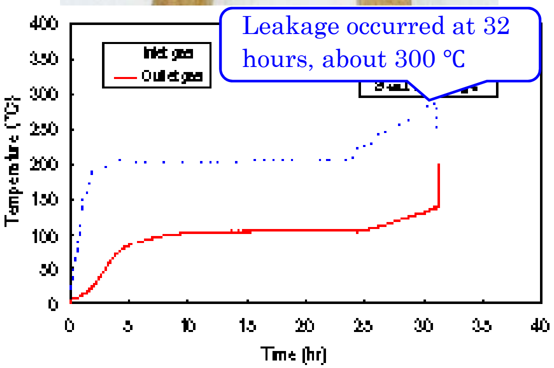
Possibility of Containment Damage due to Over-pressurization and/or Over-heating (over-Heating Damage)

- Experiments show leakage can occur from the seal materials of wiring penetration and flange gaskets even under pressure of 0.4～1MPa if heated over 250℃.
- PCVs' temperature were estimated over 500℃ for Unit 1, about 280℃ for Unit 2, and over 400℃ for Unit 3 by MELCOR analysis.
- According to JNES experiments, the leak rate can reach 100%/day at a containment pressure of 0.2MPa, taking only the deterioration of the top flange gasket into account, which is consistent with the situation of large-scale vapor release at the accident.

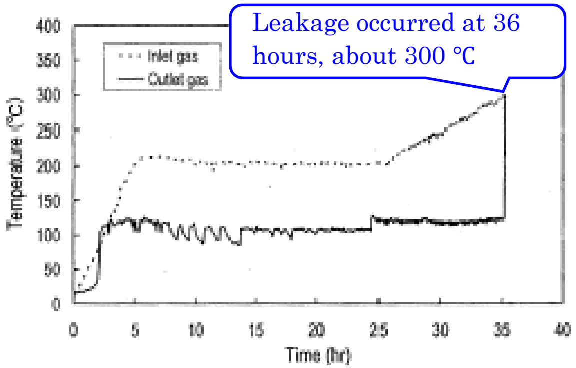
Example of test results (low-voltage module)

< wiring penetration >

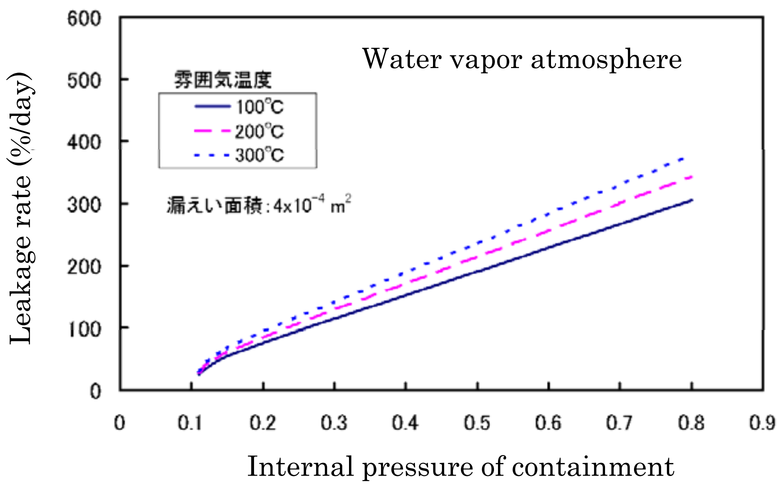




< flange gaskets>



Estimation of leakage rate at the top flange gasket of deterioration due to over-heating

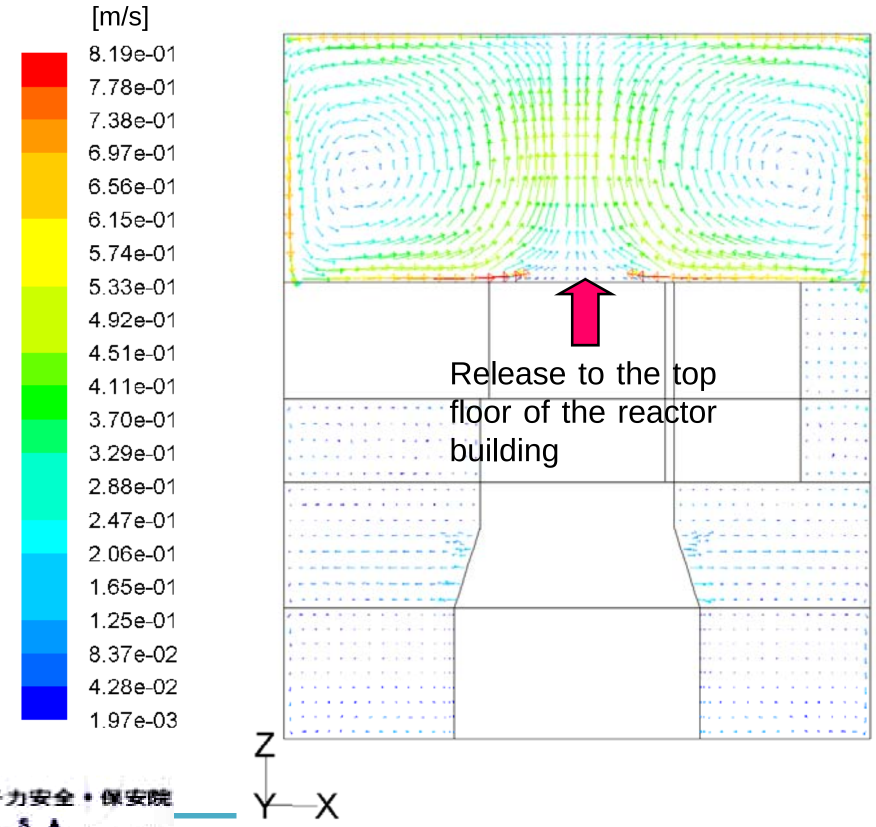


(Source) JNES materials

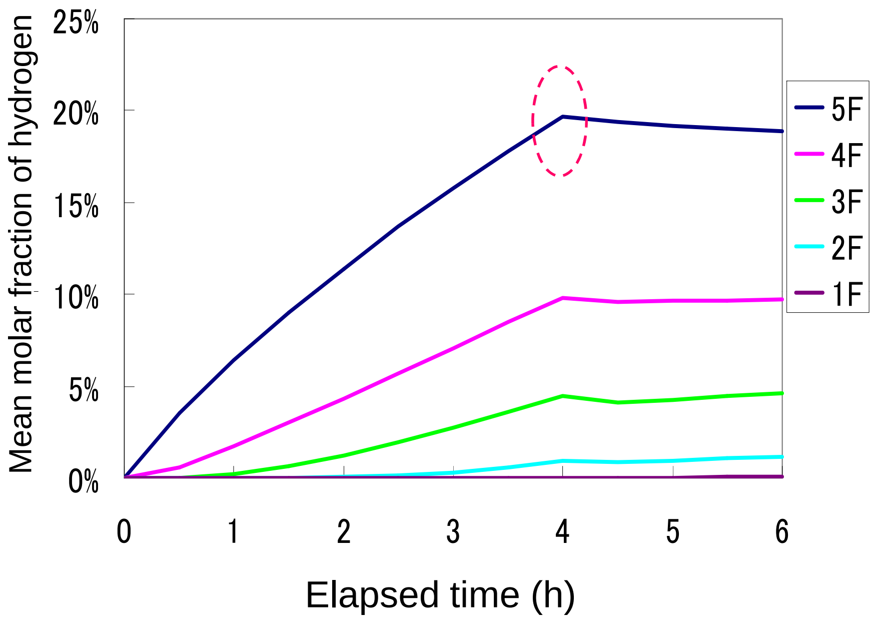
Examination of Leakage Path Using Hydrogen Behavior Analysis

- It is highly possible that the leakage occurred at the top flange because the explosion occurred on the top floor (5F) in Unit 1.
- The released hydrogen into 5F of the reactor building accumulated mainly in 5F. (The hydrogen density is about 20% in the case of 400kg hydrogen release.)

Behaviors of hydrogen gas assuming the release of hydrogen of 400kg from the floor surface of the top floor of the reactor building. (flow field)



Time variation in hydrogen density in the reactor building assuming the release of hydrogen of 100kg/h for 4 hours.

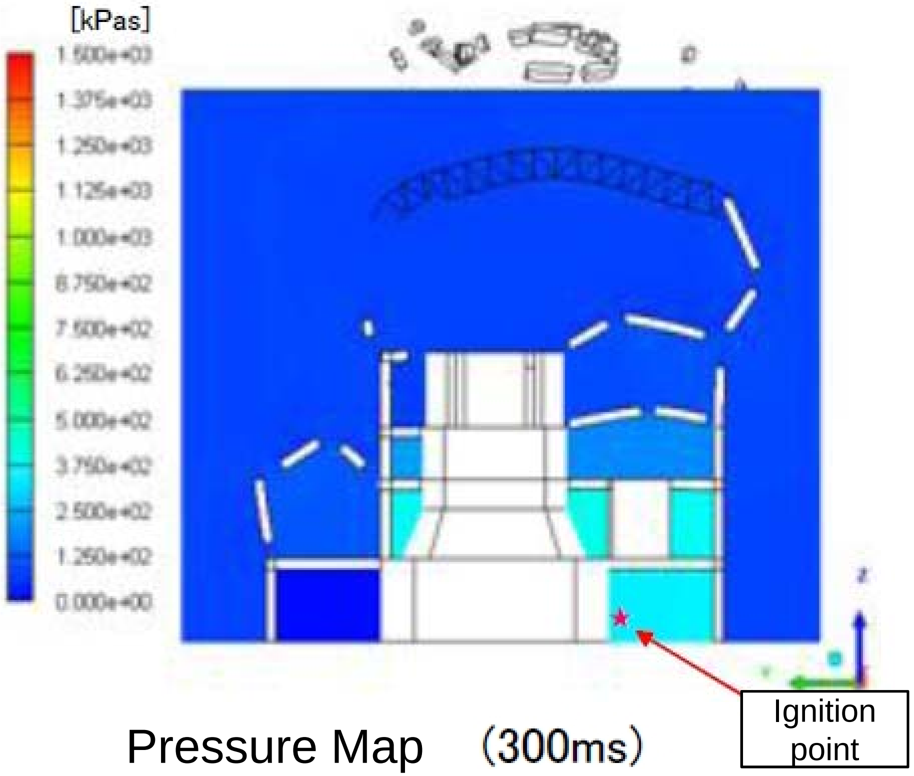


(Source) JNES materials

Examination of Leakage Path Using Hydrogen Behavior Analysis (Cont'd)

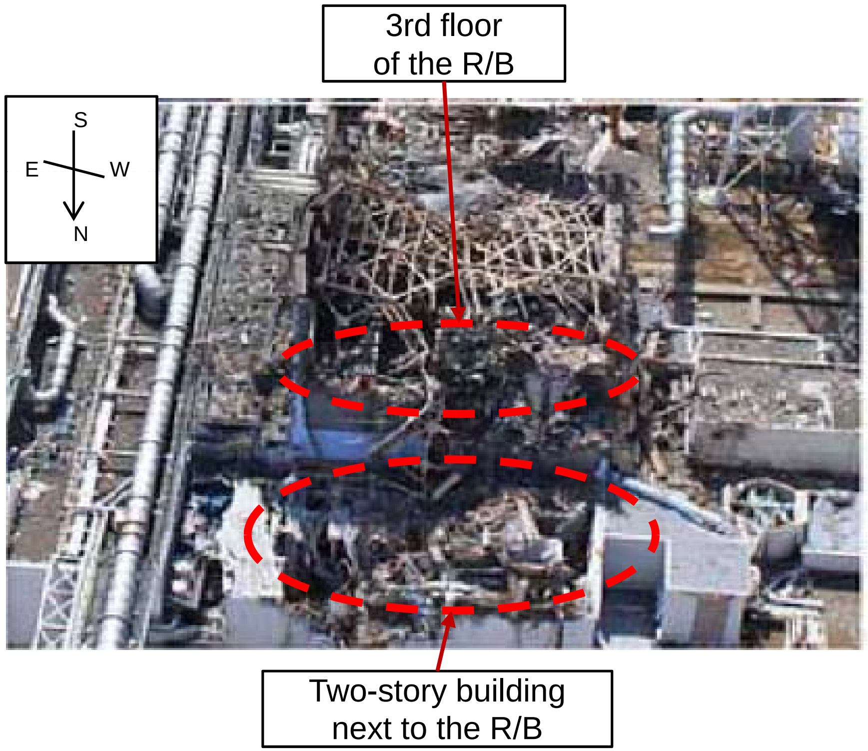
- For Unit 3, an analysis result of the explosion and the actual damage state show probability of hydrogen leakage through hatches and/or penetrations to 1st floor of the reactor building.

Assuming 1,000kg H_2 leakage from PCV to 1st floor of R/B, an analysis (using AUTODIN) results in damages not only on the upper part of R/B but also other parts including surrounding buildings



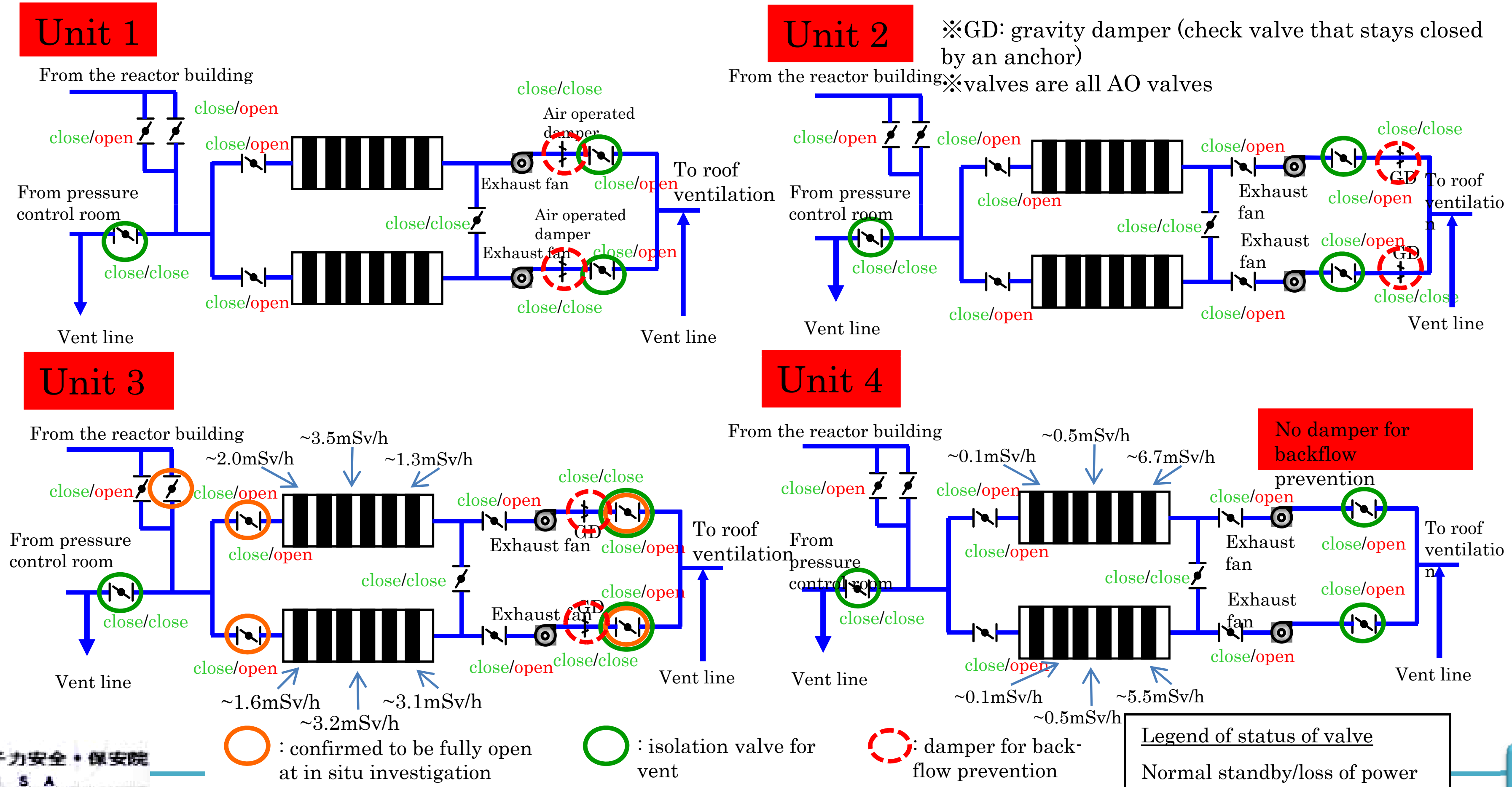
Pressure Map (300ms)

The 3rd floor of Unit 3 R/B and the top of a two-story building next to the R/B have also been damaged.



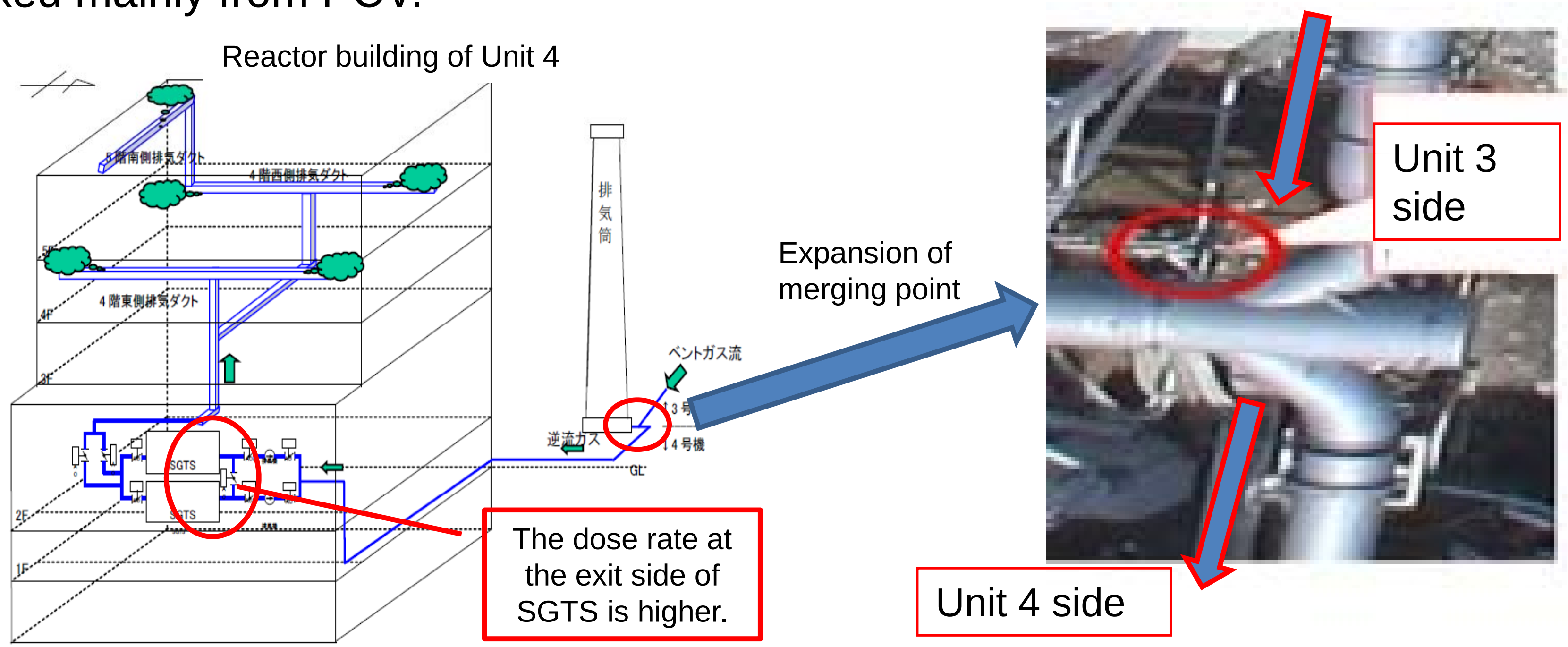
Possibility of Back-flow to Building by PCV Vents (Units 1-4)

- To isolate SGTS at the time of PCV vents, the outlet valves of SGTS must be closed according to the operational procedure. But the outlet valves of SGTS of Unit 3 were not isolated. Those of Unit 4 were thought not to be isolated as well.
- Because of the damper at the outlet for Units 1-3 which closes during loss of power, the flow into the building was supposed to be more prevented than Unit 4. Regarding Unit 3, there are no significant backflow in one direction into the building but it is difficult to deny the occurrence of backflow itself.



Possibility of Back-flow to Building by PCV Vents (Unit 3⇒Unit 4)

- When hydrogen gas generated in Unit 3 backflows in SGTS of Unit 4, it will be released into the Unit 4 building via the building ventilation system.
- The floor and ceiling of the 4th floor of Unit 4 were deformed in the direction of expansion. As the contamination in the building of Unit 4 is lower than that in Units 1-3, it is supposed that it exploded due to hydrogen that flew into the building through filter, while explosions of Units 1 and 3 were caused by hydrogen leaked mainly from PCV.



Path of inflow of vent of containment from Unit 3 to Unit 4

: flow of hydrogen gas

Source: Added to “The impact of Tohoku-Chihou Taiheiyo-Oki Earthquake to Nuclear Reactor Facilities at Fukushima Daiichi Nuclear Power Station” (Sep. 9, 2011, revised Sept. 28, 2011, Tokyo Electric Power Co., Inc.)

Countermeasures for Confinement Systems

Countermeasure 18 Enhance diversity of PCV cooling system

(Example: Ensuring additional heat removal function by using a PCV spray (which can also remove radioactive substances in the CV) or RHR without using the AC power supply, and diversity of CV cooling function)

Countermeasure 19 Prevention of the damaging of PCV top-head flange caused by overheating

(Example: Examining cooling from outside of top head)

Countermeasure 20 Proceed with low pressure injection process reliably

(Example: Securing response manual for complete loss of power supply)

Countermeasure 21 Improve maneuverability of venting system

(Example: Installing a compressor battery and/or equipment to manually open the valve
Examining the bypass pipe line with a valve of the rapture disk)

Countermeasures for Confinement Systems (cont.)

Countermeasure 22 Decrease the effect of radioactivity caused by venting

(Example: Installing radioactive substance removal (filtering) facilities to the vent system)

Countermeasure 23 Ensure independency of vent system

(Example: Isolating the vent pipes from the SGTS
Prohibiting connection of the vent's pipe systems between the Units)

Countermeasure 24 Prevent the Hydrogen explosion (control the gas concentration and the adequate release)

(Example: Installing the large opening with filters and the hydrogen concentration detector)

Ⅵ. Communication, Instrumentation and Control Systems, and Emergency Response Arrangements

原子力安全・保安院
N I S A
Nuclear and Industrial Safety Agency

Damages of Communication, Control and Instrumentation System

- Most of the communication facilities were unavailable due to the power loss or other causes.
- The use of instrumentation devices was severely limited after tsunami-caused power loss because connection to outside batteries was needed.
- The monitoring post were also unavailable due to the tsunami-caused power loss.

Countermeasures for Communication, Instrumentation and Control System, and Emergency Response Arrangement

Countermeasure 25 Prepare emergency Command Center

Example: Securing power source
Preventing the influx of radioactive material
Ensuring communications
Monitoring functions of the nearby situation

Countermeasure 26 Secure the communication tools for accidents

Example: Securing power source
Installing equipments with earthquake resistance
Taking measures to protect the primary communication base from water
Establishing an emergency response information system and televised conference system including a transmission system

Countermeasure 27 Improve reliability of the measurement equipment for accidents

Example: Securing power source
Providing storage batteries dedicated to instruments, and spare instrumentations & parts

Emergency Response Center in Fukushima Dai-ichi NPS

(Source: TEPCO)

Countermeasures for Communication, Instrumentation and Control System, and Emergency Response Arrangement (cont.)

Countermeasure 28 Enhance the monitoring functions for the plant conditions

(Example: Utilizing surveillance cameras including inside the PCV
Promoting research and development to expand the range of instrumentation specifications)

Countermeasure 29 Enhance Emergency functions

(Example: Supplying power from emergency power sources and installation of dedicated power sources for monitoring posts)

Countermeasure 30 Create the structure and conduct the training for the emergency response

(Example: Ensuring spare parts
Installing lighting equipments
Establishing a system of securing the manpower and calling out)

Conclusion

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- To avoid repeating accidents like TEPCO's Fukushima Dai-ichi, bills to reform regulatory organizations and systems were submitted to the Diet. We expect this will contribute also to increased regulatory competence.
- Some technical knowledge has been extracted through investigations from engineering point of view so far, and will be utilized to make the new regulatory framework able to function practically and effectively, being shared with international community.
- On the way toward safe decommissioning of the accident site several decades after, we have a lot of issues still uncertain or necessary to be investigated further.
  Japan will share the latest information and lessons learned continually, and tackle every issue in cooperation with international colleagues.

To date, Japan has received a wide array of support from the world.

Japan expresses its deepest gratitude, and would sincerely ask for your continued support.

Thank you for your attention !