Fukushima Nuclear Accident Interim Report:

Effects of the Earthquake and Tsunami on the Fukushima Daiichi and Daini Nuclear Power Stations, especially on electric and I&C systems and equipments

July 27, 2011

@IEEE Nuclear Power Engineering Committee

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What I will present

1 ．What occurred at Fukushima Daiichi (1F) & Daini (2F) in Japan ?

- Earthquake - Tsunami

2 ．What made the difference between 1F and 2F ?

- Electric equipment - Instrumentation & Control
- Transmission lines

3. How we responded ?

- What difficulties existed
- What were effectively utilized

4. Current status and Roadmap

5. Summary

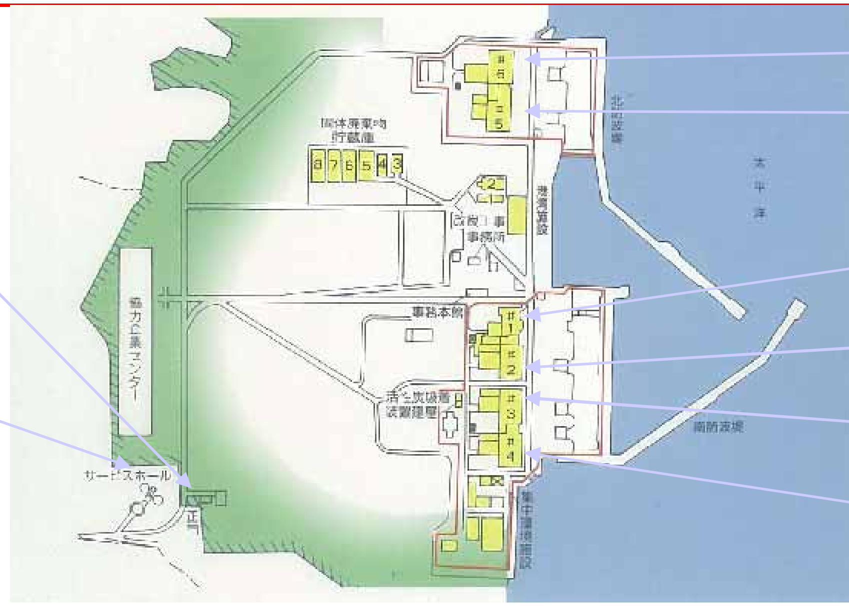
6. References

- Damage status of electric equipments - Restoration process
- Measures to ensure safe shutdown - Chronology

1 . What occurred at Fukushima Daiichi (1F) & Daini (2F) in Japan ?

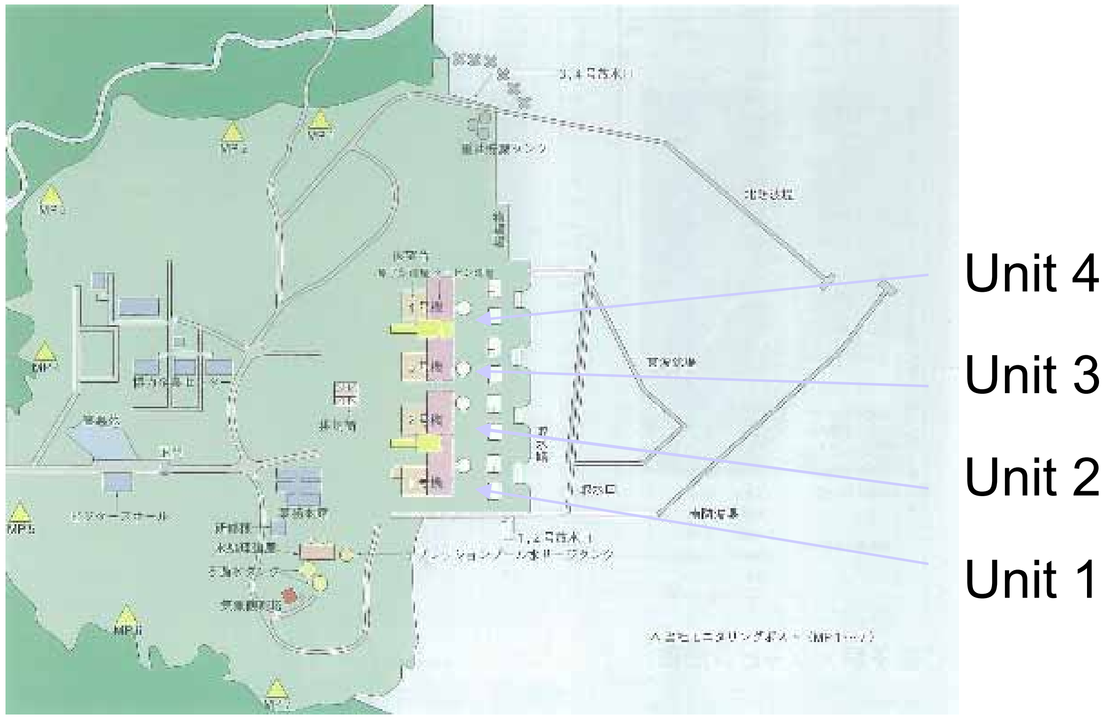
- Earthquake
- Tsunami

Overview of Fukushima Daiichi（ 1 F ）NPS



Location	Unit	In operation since	Plant type	Power Output (MW)	Main Contractor	Pre-earthquake status
Ohkuma	1	1971.3	BWR-3	460	GE	Operating
	2	1974.7	BWR-4	784	GE/Toshiba	Operating
	3	1976.3	BWR-4	784	Toshiba	Operating
	4	1978.10	BWR-4	784	Hitachi	Shutdown for maintenance
Futaba	5	1978.4	BWR-4	784	Toshiba	Shutdown for maintenance
	6	1979.10	BWR-5	1100	GE/Toshiba	Shutdown for maintenance

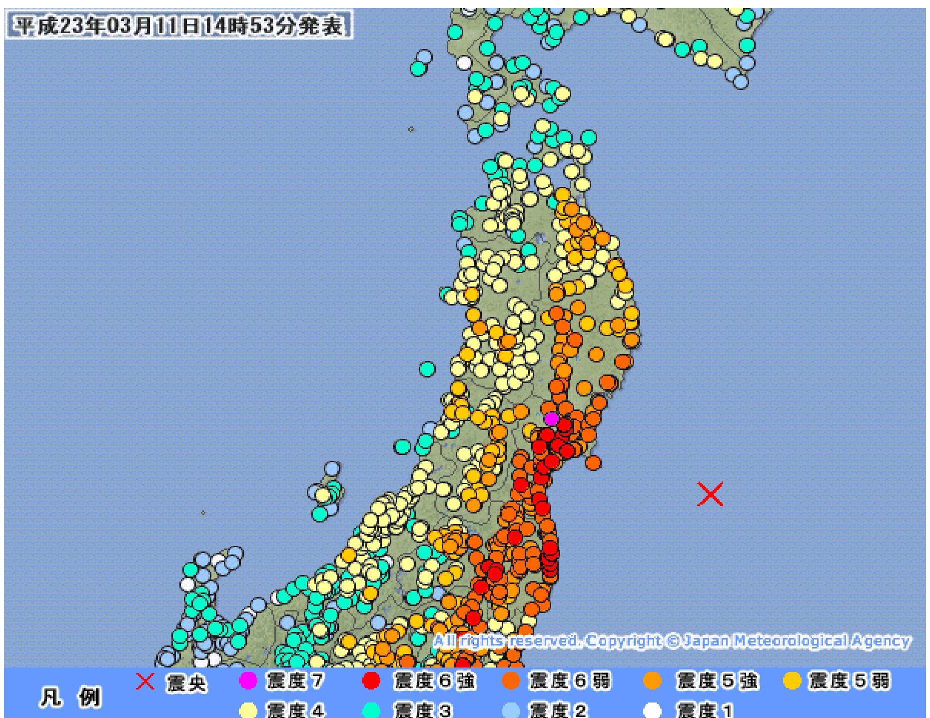
Overview of Fukushima Daini（２Ｆ）NPS



Location	Unit	In operation since	Plant type	Power Output (MW)	Main Contractor	Pre-earthquake status
Naraha	1	1982.4	BWR-5	1100	Toshiba	Operating
	2	1984.2	BWR-5	1100	Hitachi	Operating
Tomioka	3	1985.6	BWR-5	1100	Toshiba	Operating
	4	1987.8	BWR-5	1100	Hitachi	Operating

Tohoku Pacific Ocean Earthquake

- **Time:** 2:46 pm on Fri, March 11, 2011.
- **Place:** Offshore Sanriku coast (northern latitude of 38 degrees, east longitude of 142.9), 24km in depth, Magnitude 9.0
- **Intensity:** **Level 7** at Kurihara in Miyagi Miyagi prefecture
  <u>**Upper 6** at Naraha, Tomioka, Okuma, and Futaba in Fukushima pref.</u>
  Lower 6 at Ishinomaki and Onagawa in Miyagi pref., Tokai in Ibaraki pref.
  Lower 5 at Kariwa in Niigata pref.
  Level 4 at Rokkasho, Higashidori, Mutsu and Ohma in Aomori pref., Kashiwazaki in Niigata pref.



Safe shutdown: Unit 1-3 of 1F and Unit 1-4 of 2F were **successfully shut down by control rods insertion after the earthquake.**

Scram set point by acceleration @ basement of reactor building: Horizontal=135-150 gal, Vertical=100gal

Damages by the earthquake: not fully inspected (Ex.inside PCV) but **safety related systems might not be damaged significantly**.

No functional failure of safety related systems was found through plant walk down @2F, that was also proven by the fact that plant parameters were within ordinary range and the dynamic function of equipments was intact.

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Seismic Observed Data

Comparison between Basic Earthquake Ground Motion and the record of intensity

Observation Point (The lowest basement of reactor buildings)		Observed data (*interim) Maximum Response Acceleration (Gal)			Maximum Response Acceleration against Basic Earthquake Ground Motion (Gal)		
		Horizontal (N-S)	Horizontal (E-W)	Vertical	Horizontal (N-S)	Horizontal (E-W)	Vertical
Fukushima Daiichi	Unit 1	460※2	447※2	258※2	487	489	412
	Unit 2	348※2	550※2	302※2	441	438	420
	Unit 3	322※2	507※2	231※2	449	441	429
	Unit 4	281※2	319※2	200※2	447	445	422
	Unit 5	311※2	548※2	256※2	452	452	427
	Unit 6	298※2	444※2	244	445	448	415
Fukushima Daini	Unit 1	254	230※2	305	434	434	512
	Unit 2	243	196※2	232※2	428	429	504
	Unit 3	277※2	216※2	208※2	428	430	504
	Unit 4	210※2	205※2	288※2	415	415	504

*1: The data above is interim and is subject to change.
*2: The recording time was about 130-150 seconds

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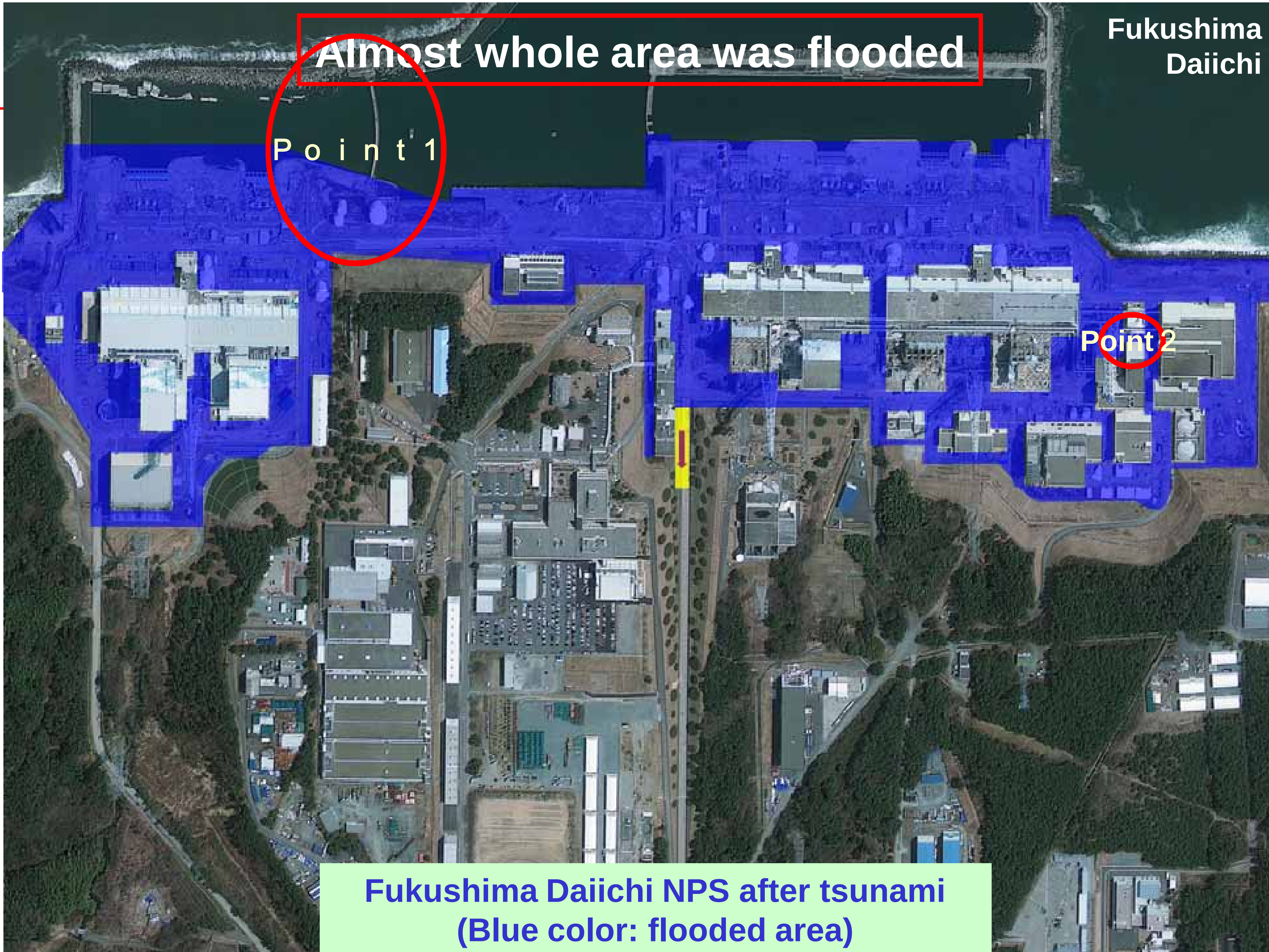
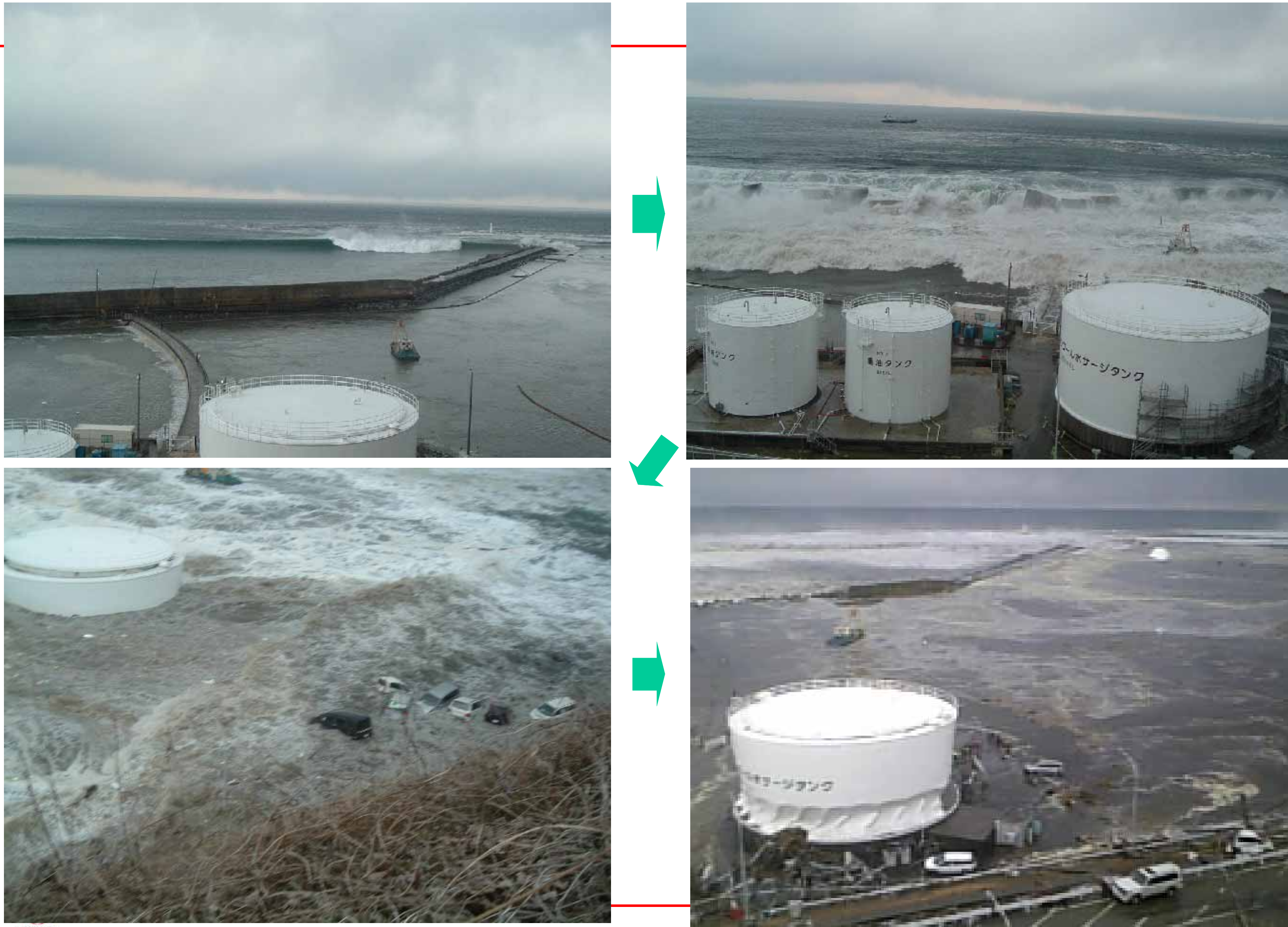

Almost whole area was flooded
Fukushima Daiichi
Point 1
Point 2
Fukushima Daiichi NPS after tsunami
(Blue color: flooded area)

Tsunami Attack to Fukushima Daiichi NPS (Point1)



Tsunami Attack to Fukushima Daiichi NPS (Point2)

Pictures before / after Tsunami @1F

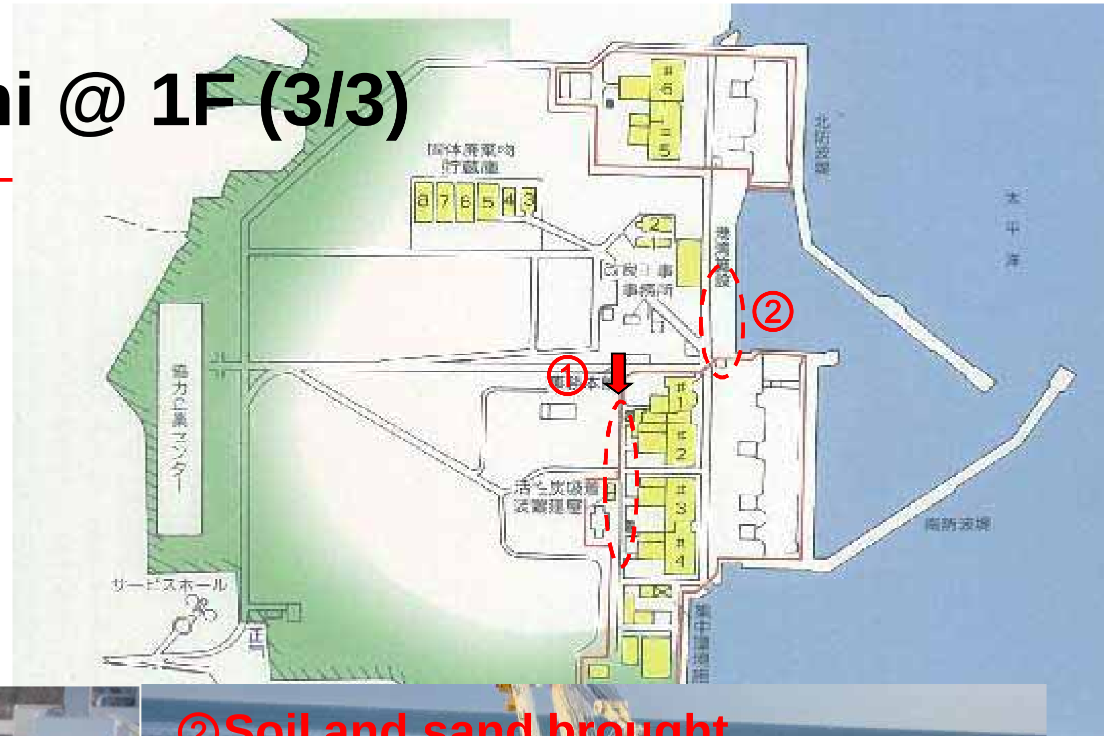
Trees were stripped away

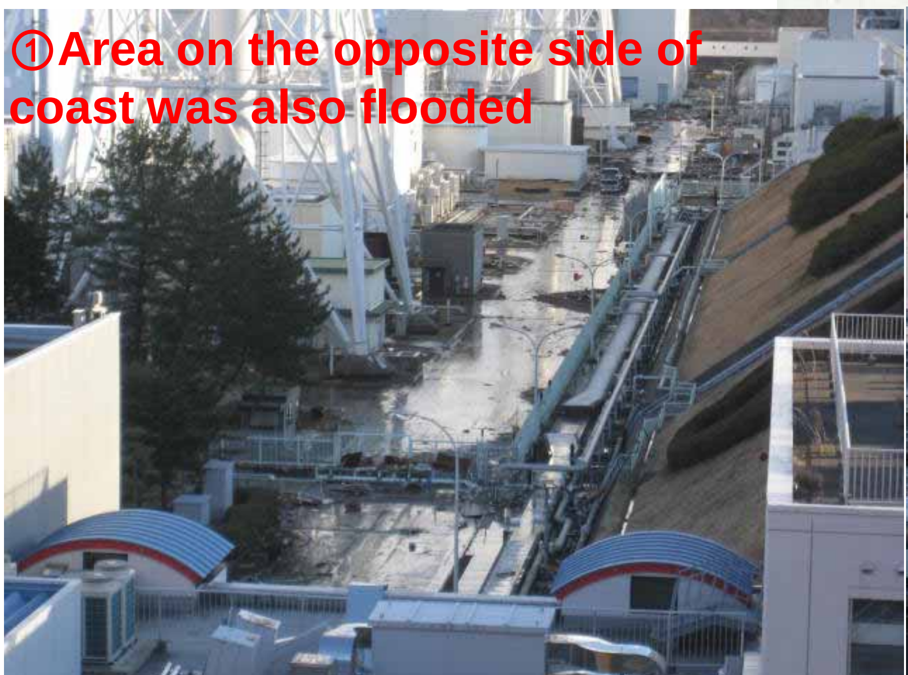
Damages by Tsunami @ 1F (1/3)

Damages by Tsunami @ 1F (2/3)

©GeoEye

Damages by Tsunami @ 1F (3/3)





①Area on the opposite side of coast was also flooded

②Soil and sand brought by tsunami

Damages by earthquake @ Shinfukushima substation

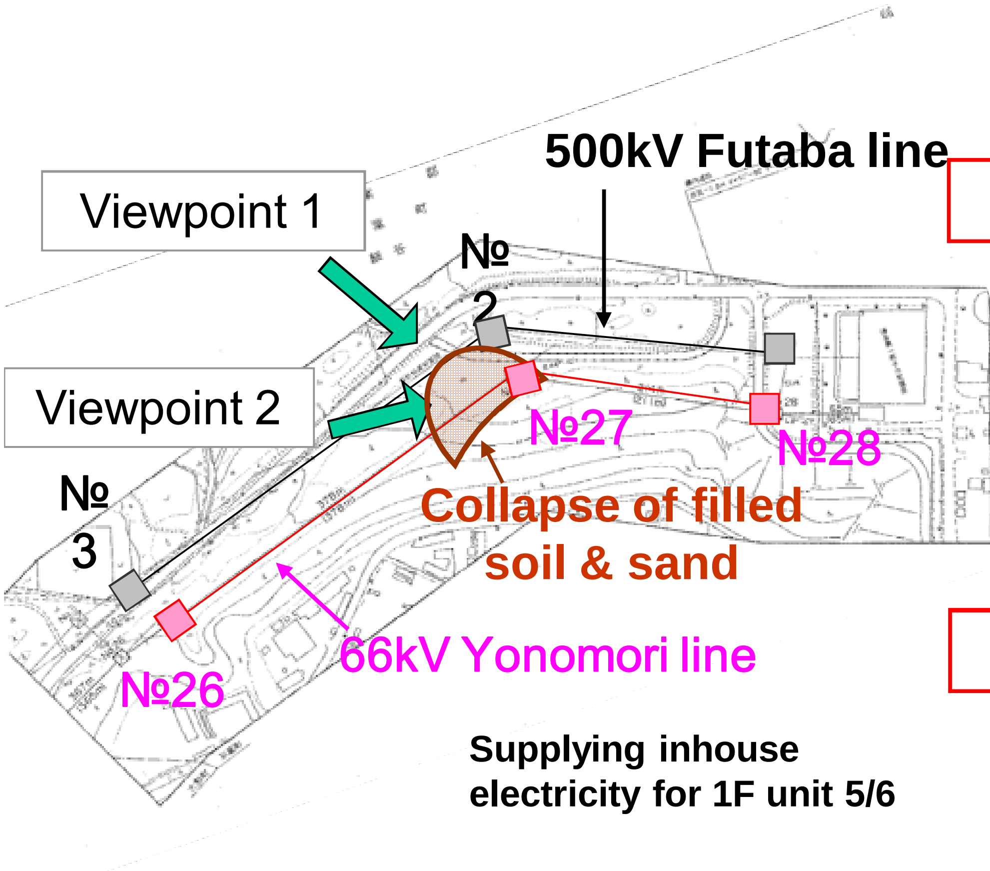
- About 10 km away from both 1F and 2F site
- Important switchgear station from which electricity of 1F & 2F is transmitted to Tokyo area

500kV Disconnector

275kV Circuit Breaker

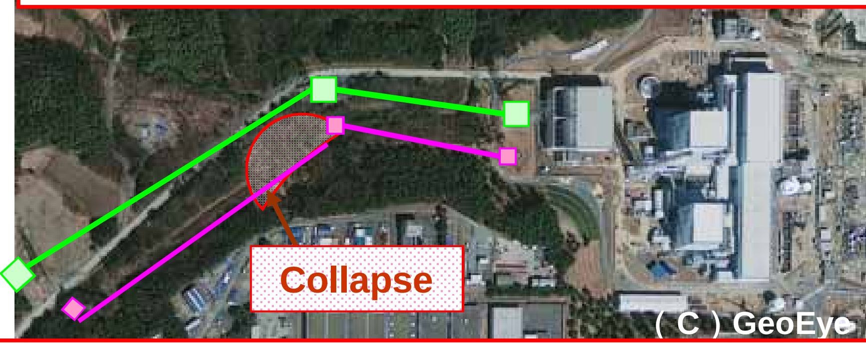
Damage status of transmission line

Yonomori line No.27 Iron tower collapse



Supplying inhouse electricity for 1F unit 5/6

Collapse of filled soil & sand



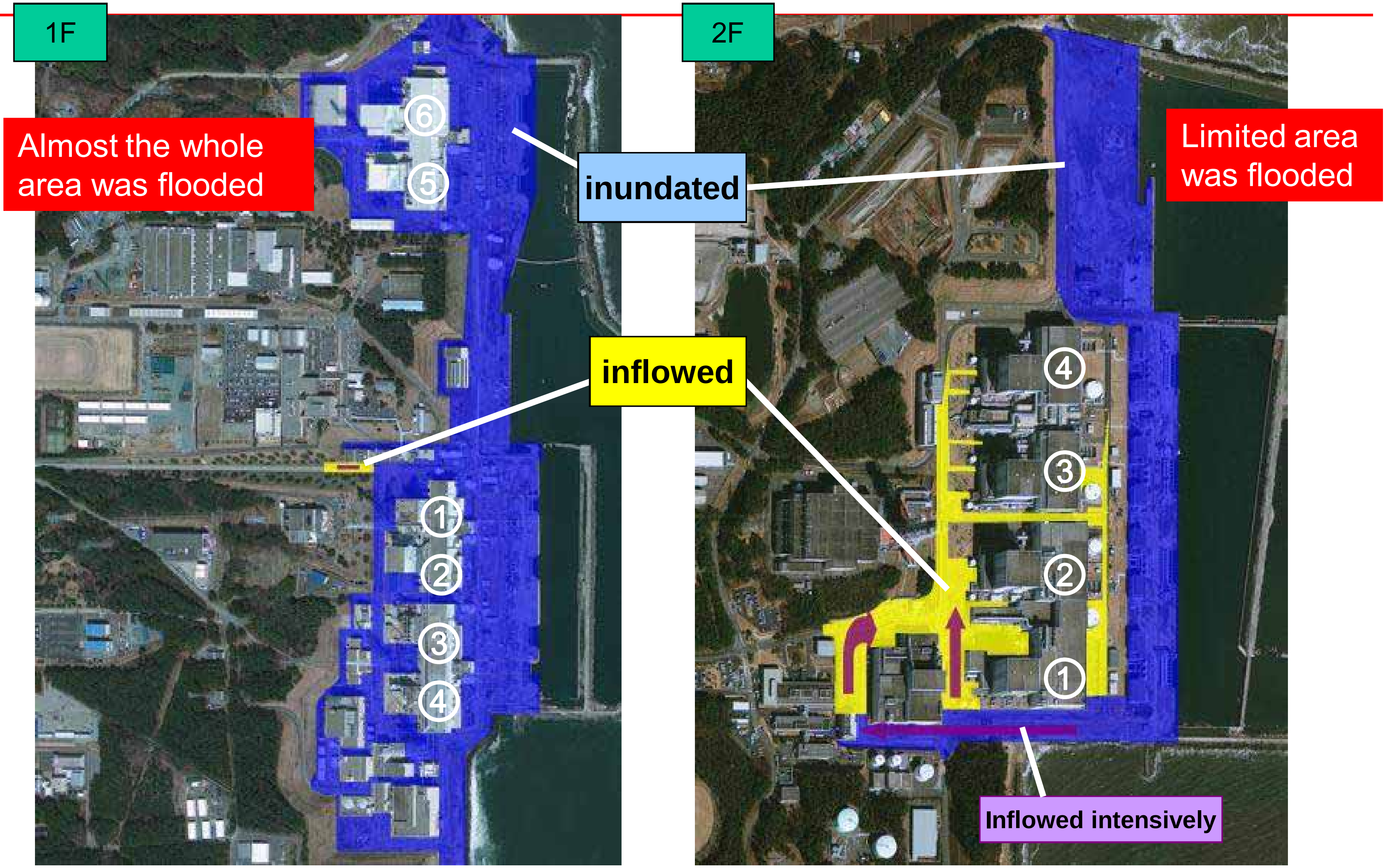
Collapse of filled soil & sand (viewpoint 1)

Transmission tower collapse (viewpoint 2)

2 . What made the difference between 1F and 2F ?

- Electric equipment
- Instrumentation & Control
- Transmission lines

Flooded & Run up Area @ 1F v.s. 2F



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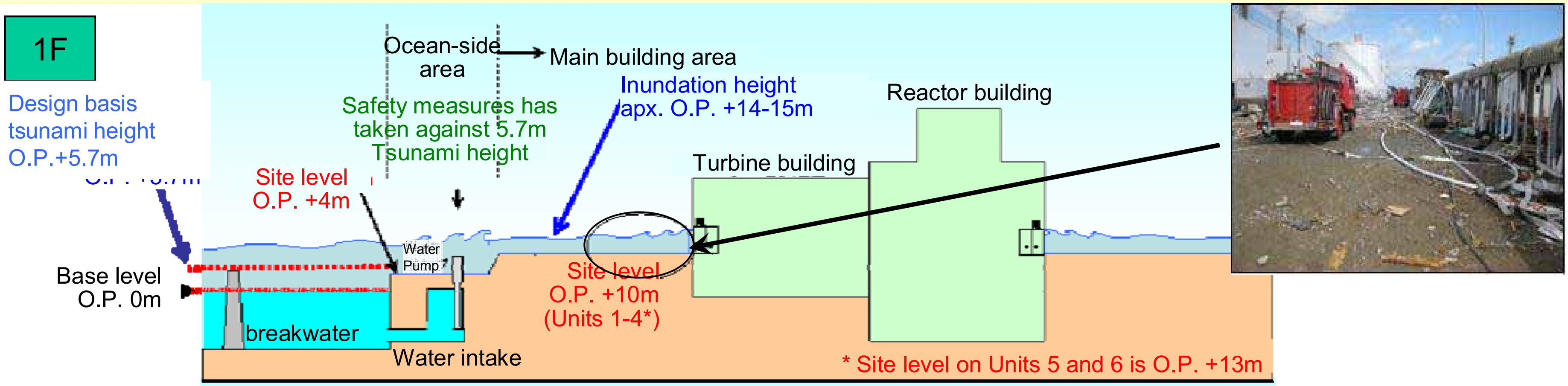
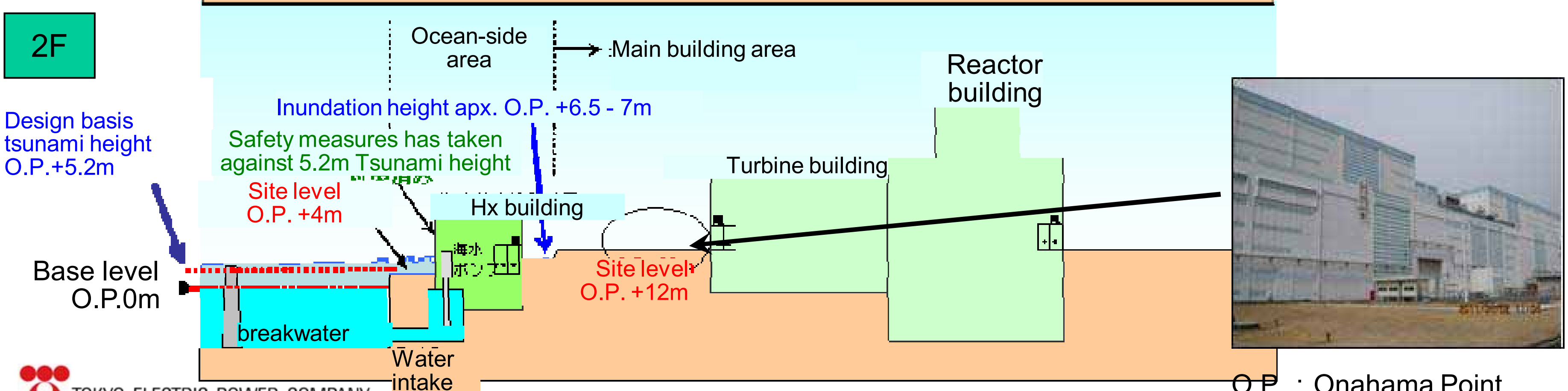
Tsunami Height @1F v.s. 2F

- The new design basis Tsunami height for 1F & 2F were evaluated based on the JSCE Tsunami assessment methodology. (1F: O.P.+5.7m, 2 F: O.P.+5.2m)
- The countermeasures were implemented at both NPSs, such as pump motor elevation raised @1F and openings sealed @2F, that were all equivalent from the viewpoint of resistance against Tsunami hazard.
- The 15m class Tsunami caused by M9.0 class earthquake that accidentally attacked 1F was far beyond design basis and whatever evaluation and whatever countermeasures did not matter at this time.

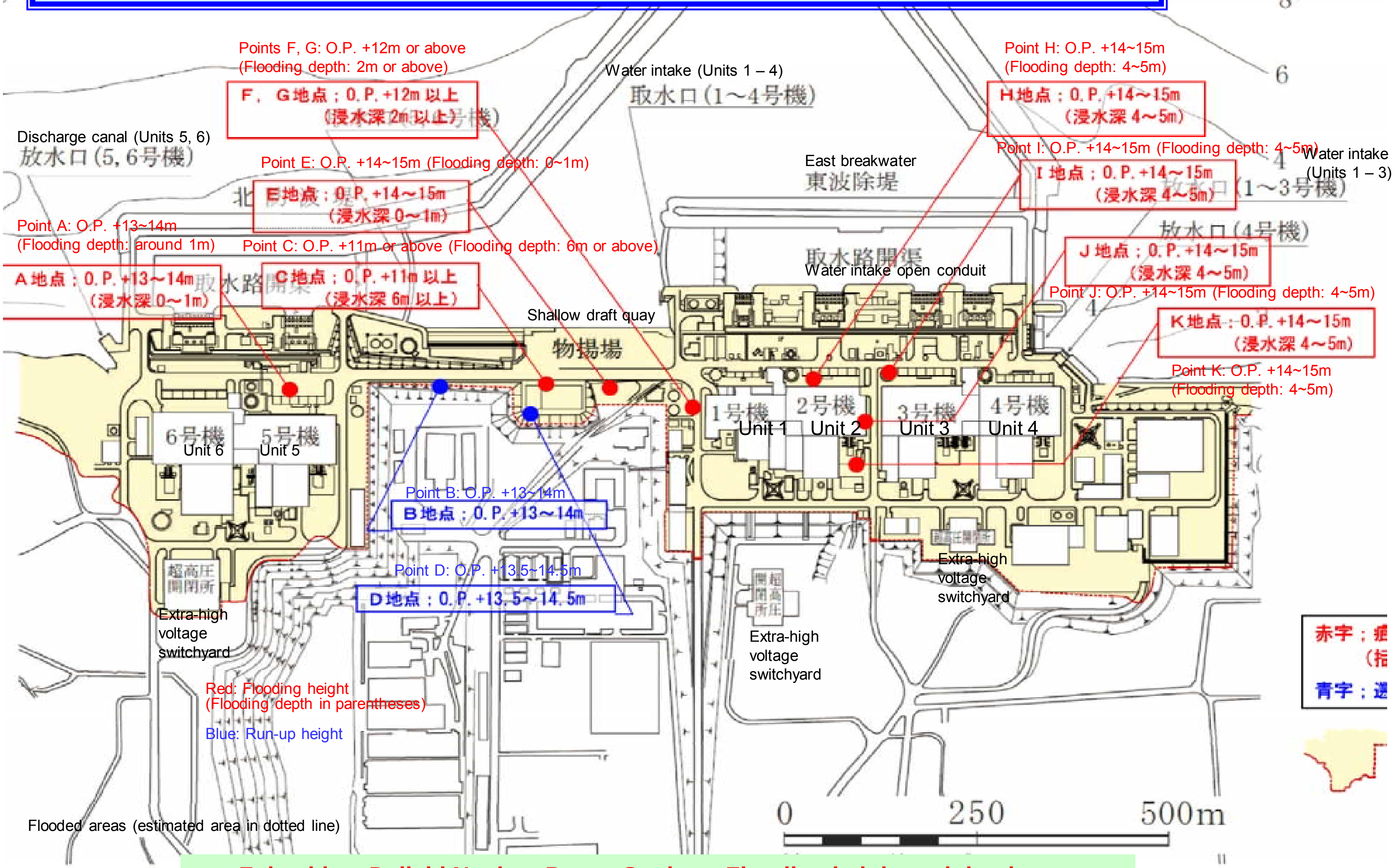




O.P. : Onahama Point

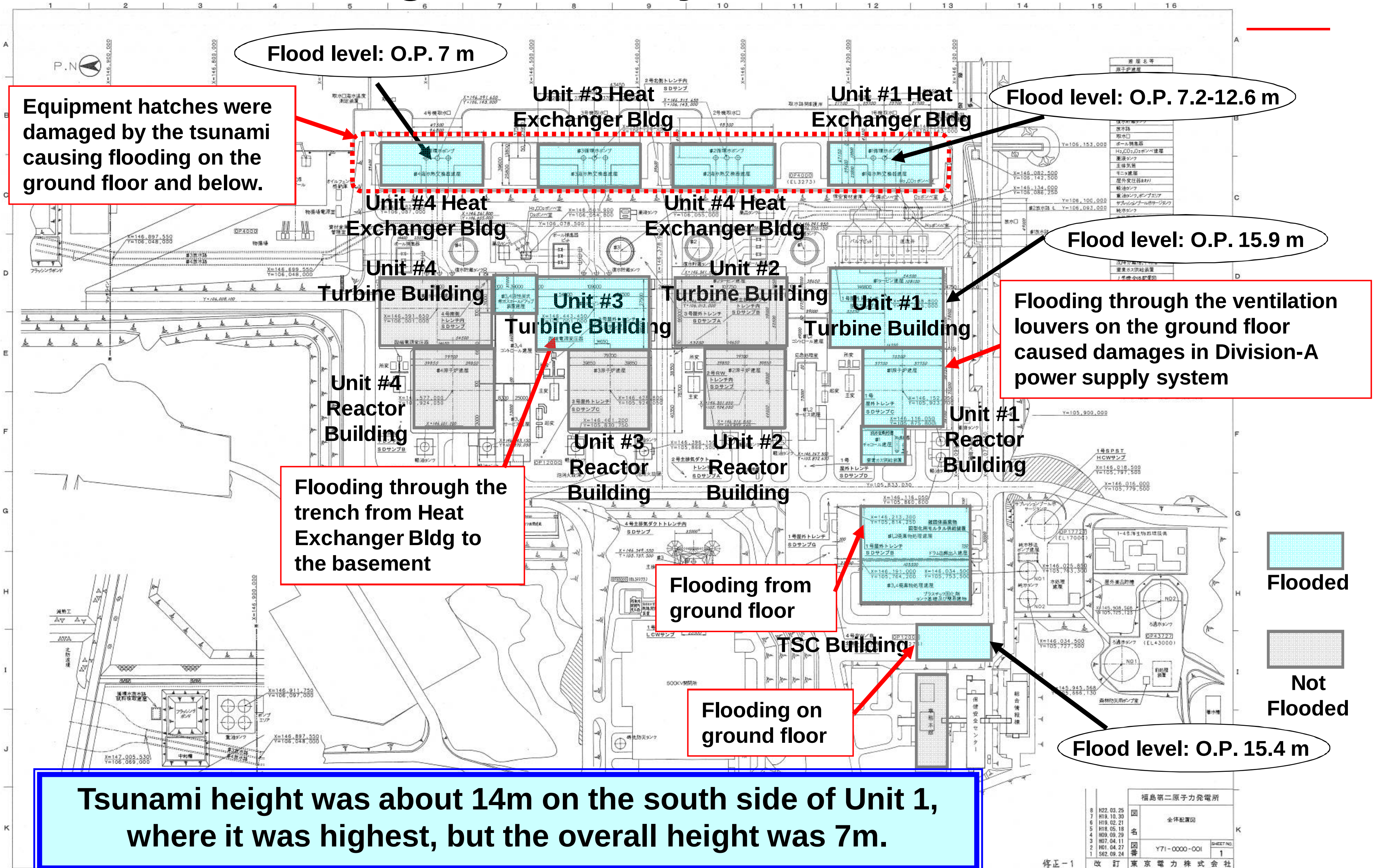
A tsunami about 14m high swept over the entire site of Fukushima Daiichi, with flood waters reaching depths of 4 to 5m

Fukushima Daiichi



Fukushima Daiichi Nuclear Power Station Flooding height and depth, etc.
(Further investigations are currently underway)

Flooding caused by the Tsunami



Tsunami height was about 14m on the south side of Unit 1, where it was highest, but the overall height was 7m.

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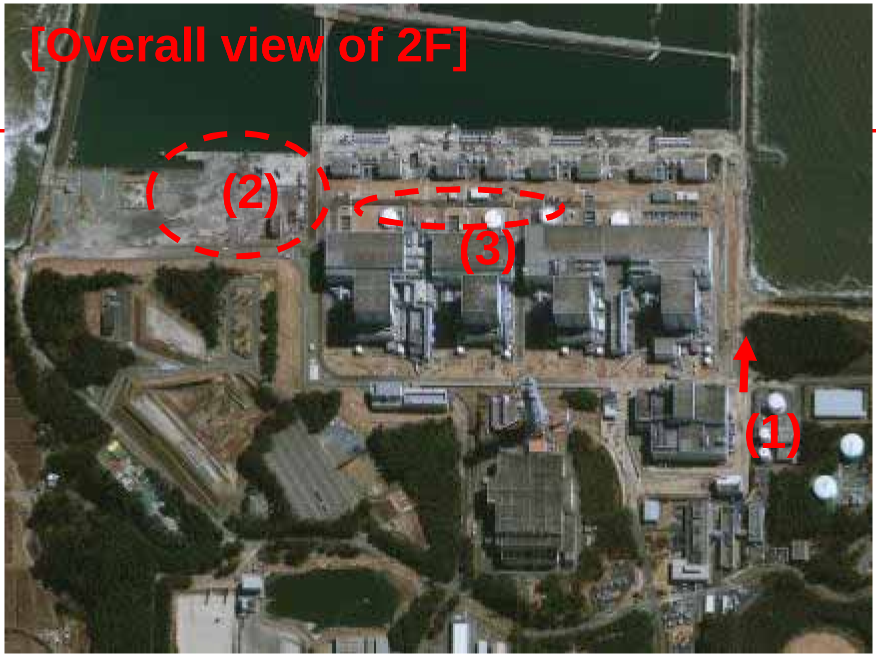
Fukushima Daini



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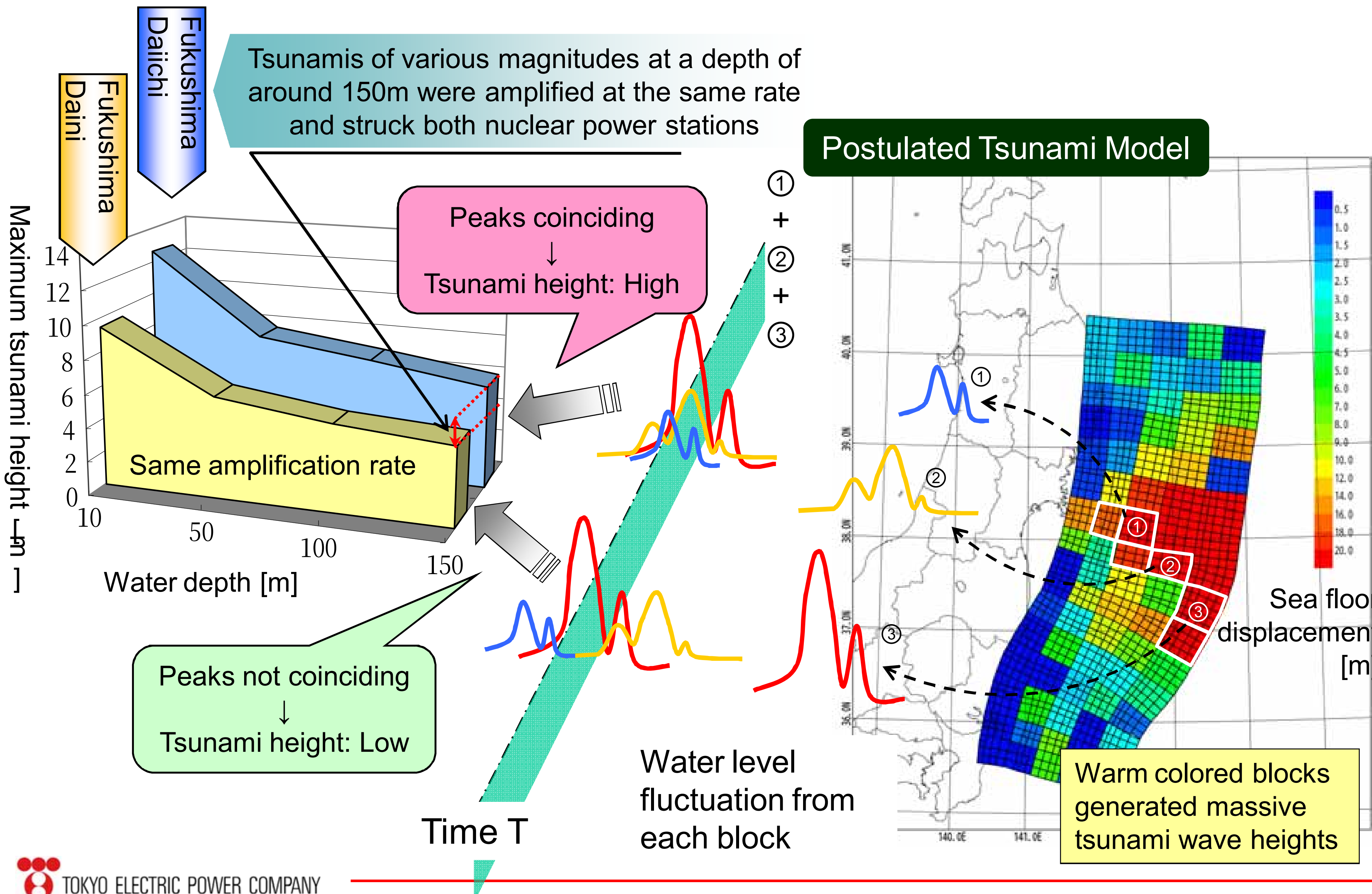
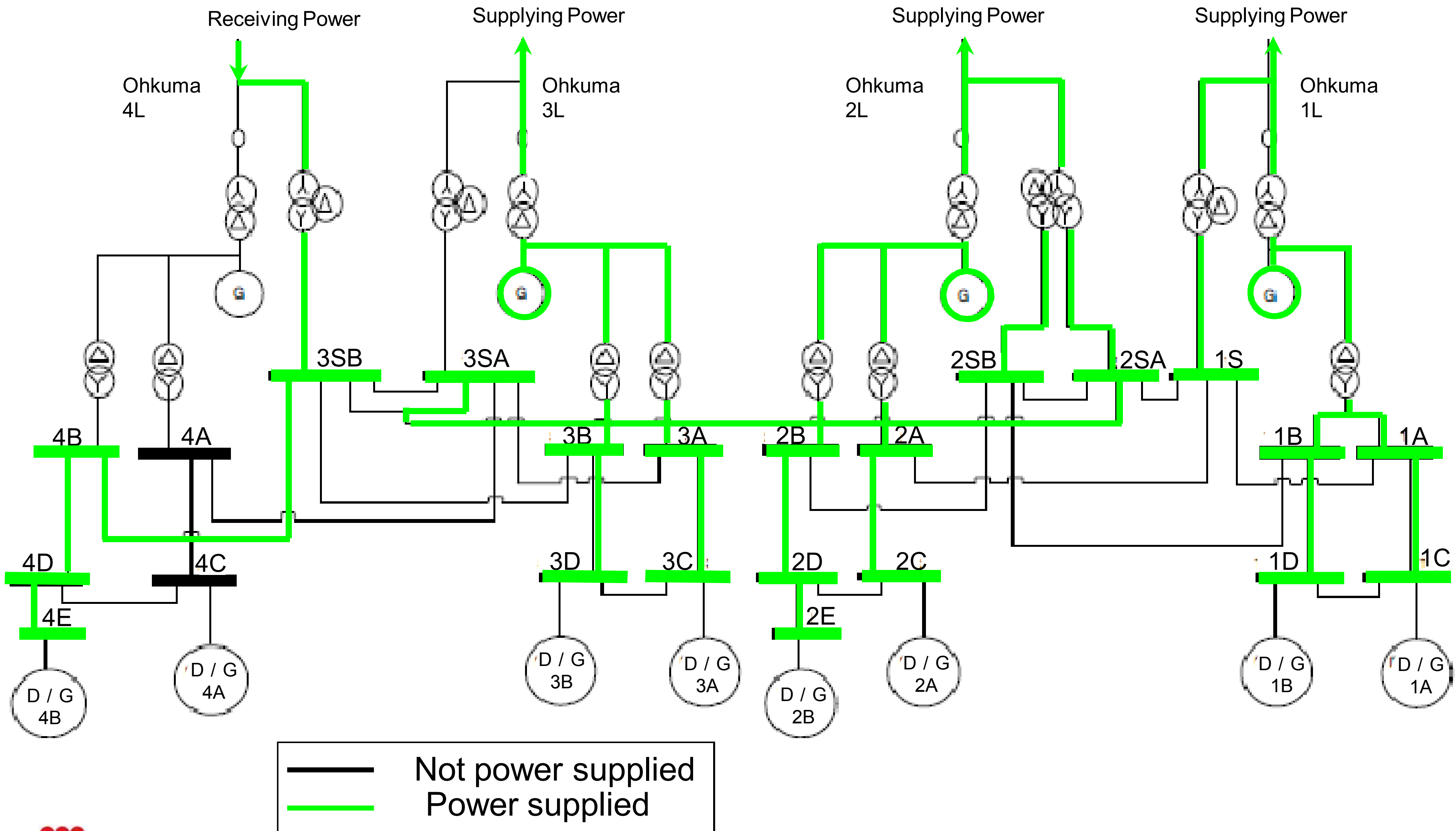
Tsunami damage at Fukushima Daini NPS

Differences in Tsunami that hit 1F and 2F



Power supply of Unit 1-4 @ 1F before earthquake

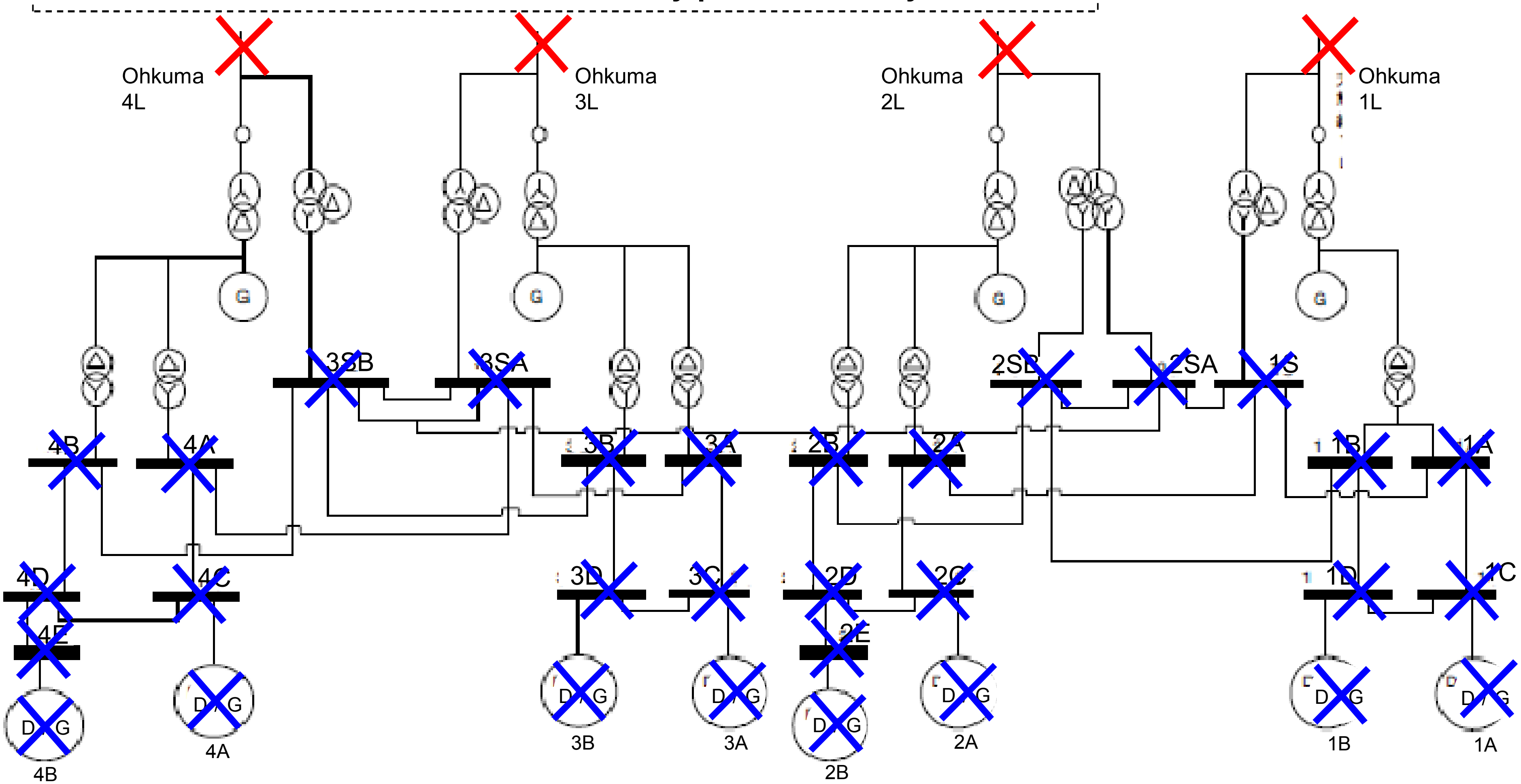
Unit 1-3 in operation, Unit 4 during outage



Power supply of Unit 1-4 @ 1F after Tsunami

Okuma Line 1L, 2L: Receiving circuit breaker damaged in earthquake
Okuma Line 3L: Renovation work in progress
Okuma Line 4L: Circuit breaker shutdown by protection relay activation

Shutdown by earthquake
Shutdown by Tsunami



The DG lost the function due to either "M/C failure," "loss of sea water system," or "DG main unit failure."

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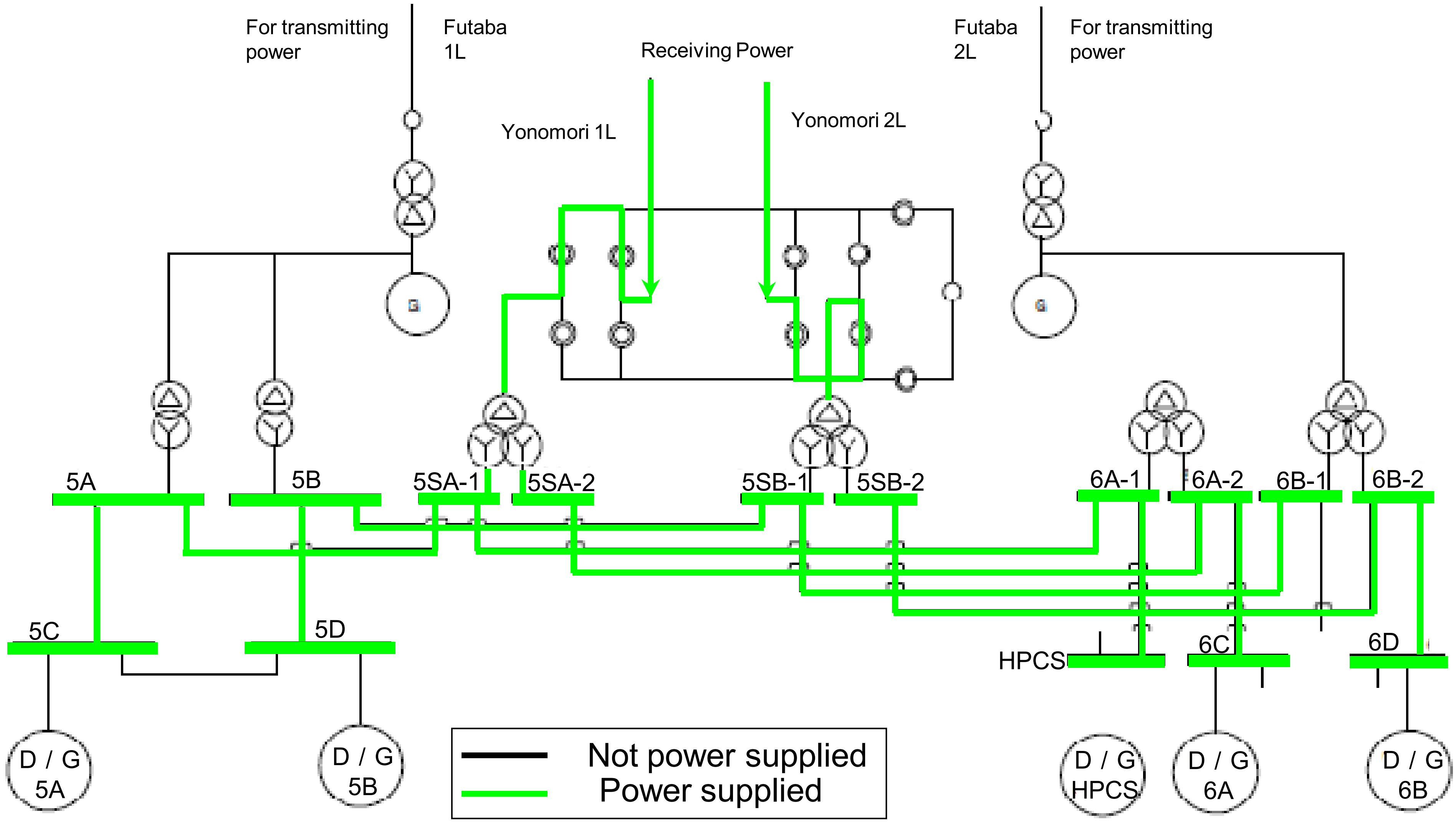
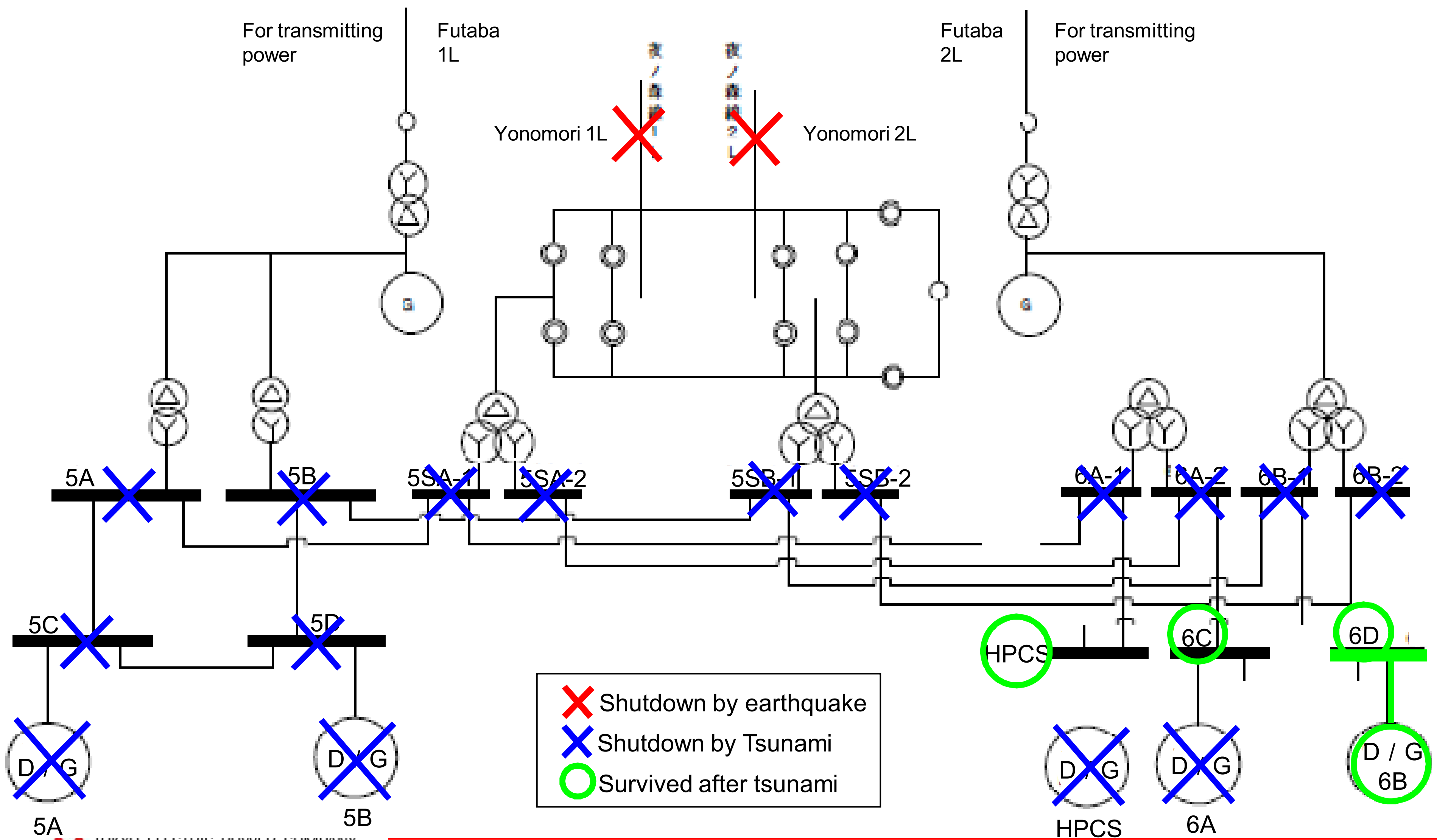
Power supply of Unit 5/6 @ 1F before earthquake

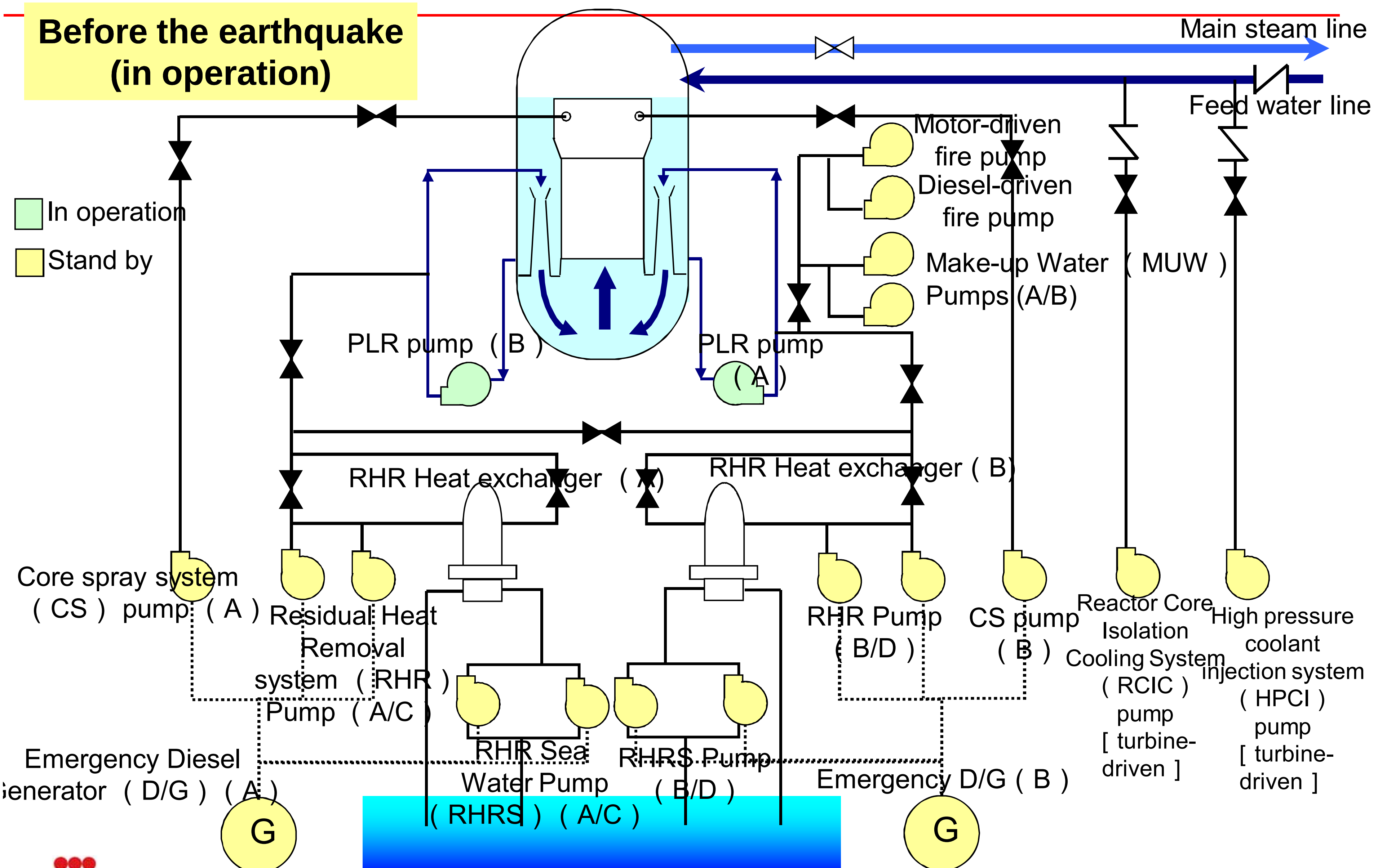
Unit 5/6 during outage



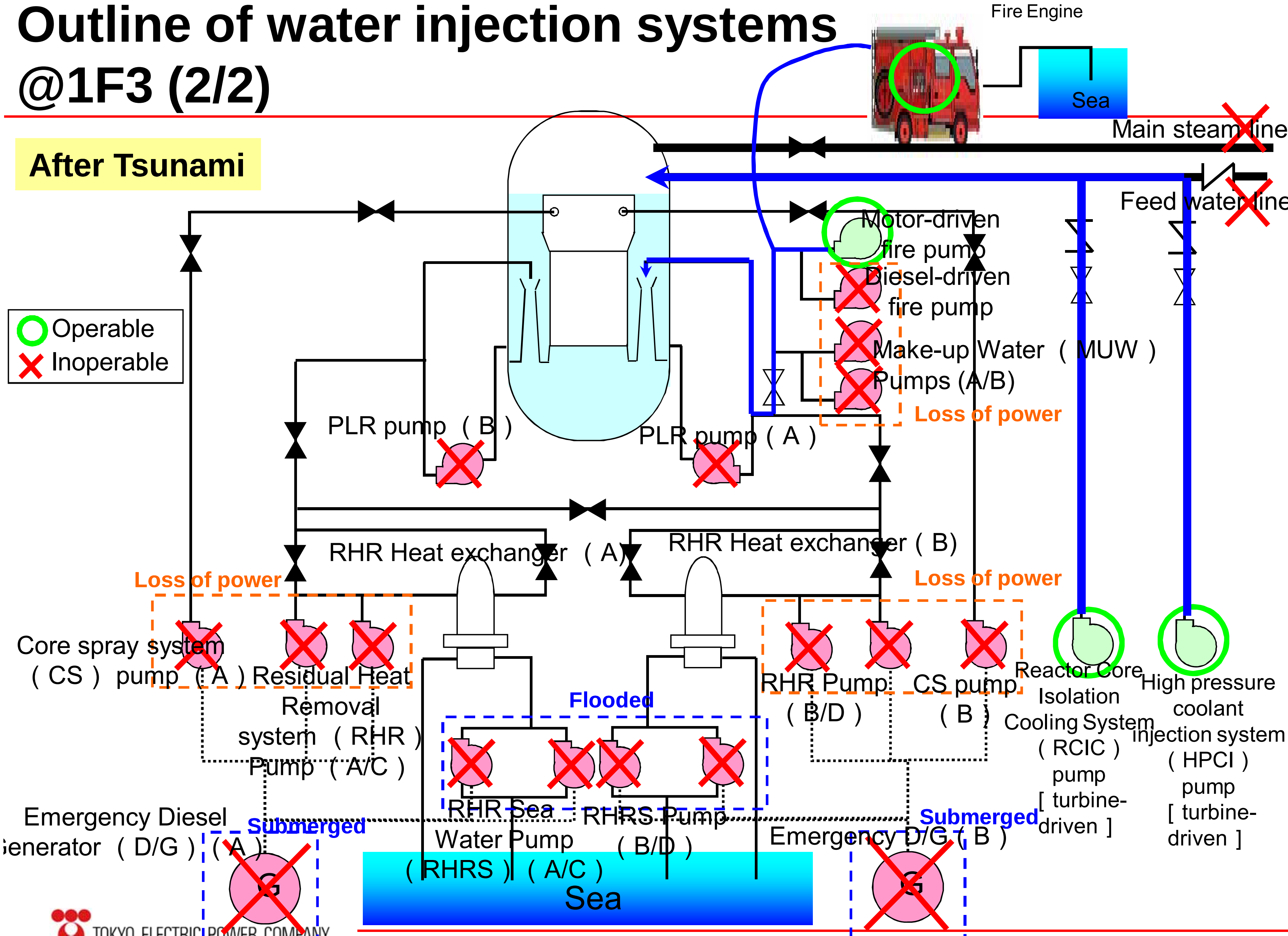
Power supply of Unit 5/6 @ 1F after Tsunami



Outline of water injection systems @1F3 (1/2)



Outline of water injection systems @1F3 (2/2)



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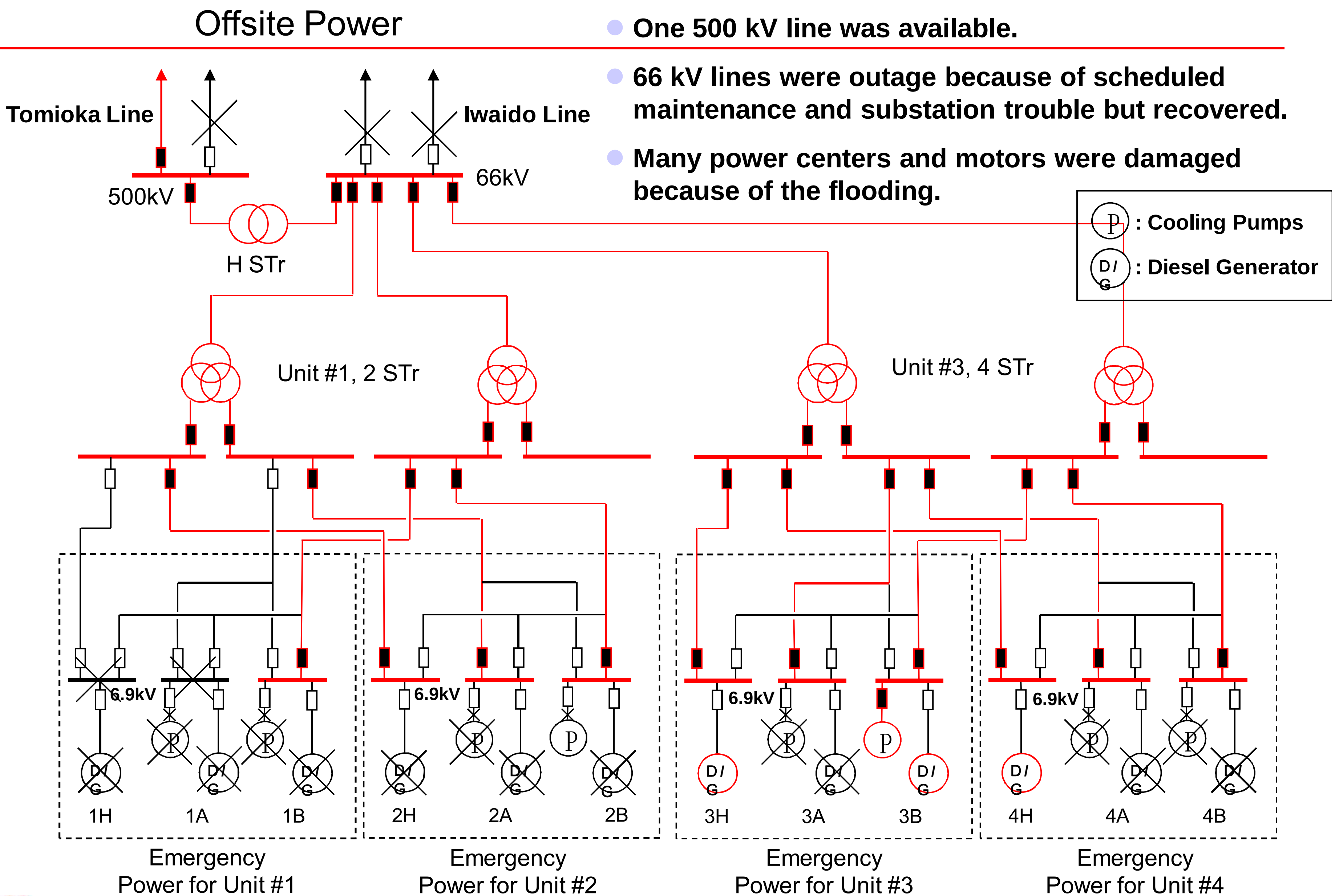
2F Offsite Power was secured after the Tsunami

- One 500 kV line was available.
- 66 kV lines were outage because of scheduled maintenance and substation trouble but recovered.
- Many power centers and motors were damaged because of the flooding.



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What made the difference between 1F and 2F

- **Tsunami height**
  - 1F: **14-15m** in average
  - 2F: **6.5-7m** in average, except on the southern side of unit 1 (run-up height was 14-15m)
- **Offsite Power**
  - 1F: **all lost**
  - 2F: one of the **offsite power lines survived** and the **stepdown transformer** between 500kv/66kv existed
- **Location and elevation of M/C switchgear and D/G**
  - 1F1-5 D/G & M/C: **T/B B1F flooded**
  - 1F6 D/G & M/C**: R/B B1F &1F survived but sea water pump-motor flooded** (loss of cooling function)
  - 1F2-4 air-cooled D/G: **Shared pool 1F,** M/C: **B1F flooded**
  - 1F6 **air-cooled D/G: independent building 1F survived, M/C: R/B B1F survived**
  - 2F D/G & M/C: **R/B B1F & B2F**
  - D/G & M/C of Unit 1: damaged by flooding
  - D/G 3B, 3H and 4H: in stand-by condition
  - the other D/Gs: out of function because of loss of cooling function (pump-motor flooding)

3. How we responded ?

- What difficulties existed
- What were effectively utilized

Progress made by each plant towards cold shutdown (outline)

Fukushima Daiichi Units 1 - 4

Units 1-3 in operation
Unit 4: outage in progress

↓

[Power supply] Total loss of off-site power supply and DG
[Sea water system] Total loss

↓

Water injection using IC, RCIC, HPCI

↓

PCV Venting, SRV operation & Sea water injection

↓

Switch to freshwater

↓

- **Heat removal route has been continuously improved**
- **Currently the closed cycle cooling is in function**

Sea water was initially injected into the spent fuel pool; currently injecting freshwater

Fukushima Daiichi Units 5 & 6

Outage in progress

↓

[Power supply] Emergency DG 6B start up
[Sea water system] Total loss

↓

Increase in spent fuel pool temperature to near 70°C

↓

Installation of temporary RHRS
Installation of temporary power supply

↓

3/19
Alternative RHRS was started and the spent fuel pool and reactor were cooled

3/20
Units 5, 6 cold shutdown

Fukushima Daini Units 1 - 4

In operation

↓

[Power supply] One off-site power supply system secured
[Sea water system] Total loss apart from Unit 3

↓

Water injection using RCIC

↓

3/12
Unit 3 cold shutdown

Units 1, 2, 4
Water injection using MUWC

↓

RHRC motor was replaced
Installation of temporary power supply

↓

3/14
RHR startup

↓

3/14 Units 1, 2 cold shutdown

3/15 Unit 4 cold shutdown

Status of 1F 1-3 immediately after the tsunami (1)

- Fallen into the Station Black Out (SBO):
  - All safety and non-safety systems driven by electricity were unavailable.
  - No lights in the control rooms, R/Bs, T/Bs, etc.
  - No important instrumentations for Unit 1 &2 due to loss of AC power sources and DC 125V batteries; the reactor water level/ pressure, drywell pressure, wet-well (S/C) pressure, etc. ; Operators were totally blind!
    - The instrumentation of Unit 3 was available immediately after the tsunami but only lasted for about 30hours because the DC 125V battery charger was flooded.
- No communication media between the Emergency Response Room and workers at the field: only one wired telephone was available between the ERR and each control room.

Status of 1F 1-3 immediately after the tsunami (2)

- The sea water systems were totally destroyed: no ultimate heat sink
- Status of cooling and flooding of the reactors were as follows:
  - Operation of the isolation condenser of Unit 1 was unclear.
  - The RCIC system of Unit 3 tripped after about 21hours since the tsunami. Then the HPCI system was activated but worked only for about 14 hours.
  - The RCIC system of Unit 2 worked for about three days after the tsunami but the actual status could not be confirmed at the control room.

What 1F site focused on during March 11-15

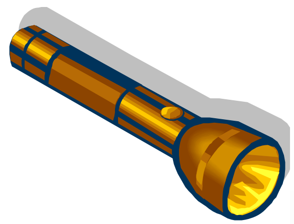
- Establishing an alternative method to inject water into the reactor pressure vessel (RPV)
- Venting of the primary containment vessel (PCV)
- Recovery of the most important instrumentations:
  - reactor water level
  - reactor pressure
  - drywell pressure
  - wet-well (suppression chamber: S/C) pressure
- Recovery of the lights in the control rooms and other power supply sources

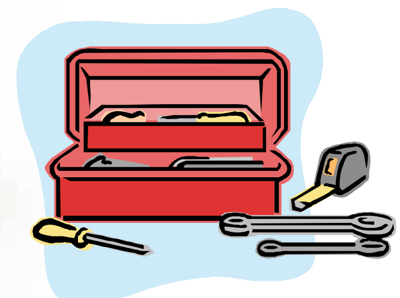
What were available for the recovery work after the tsunami?

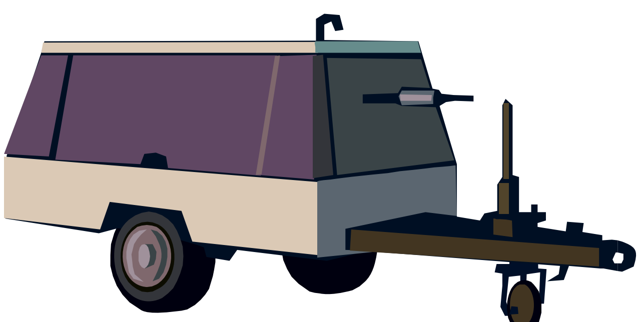
There were only the following limited number of devices and tools available !

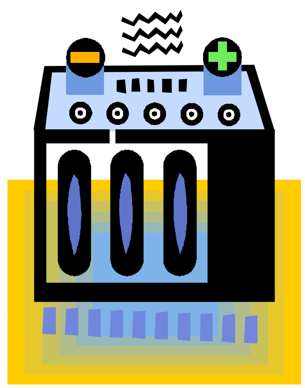
- Fire Engines: only a few people knew how to operate them.
- Flashlights
- Cable
- Tools (screwdrivers, etc.)
- Batteries taken from cars
- Engine driven Generators*
- Engine driven Air Compressors*

*They were in the warehouses of the affiliated companies and difficult to find.









Human Resource Issues after the Tsunami @1F

- After the tsunami, approximately 400 people (about 130 for operation, about 270 for maintenance) were available for the recovery process.
- The number of the operations personnel was totally insufficient for the recovery operation of six units.
- About 70 TEPCO employees (maintenance) and about 40 people from affiliated companies were engaged in the initial field work to recover Unit 1-3; most of the work was recovery of instrumentations and power supply.
- Number of electric and I&C maintenance personnel was also insufficient.
- High radiation dose made the above human resource problem more serious.

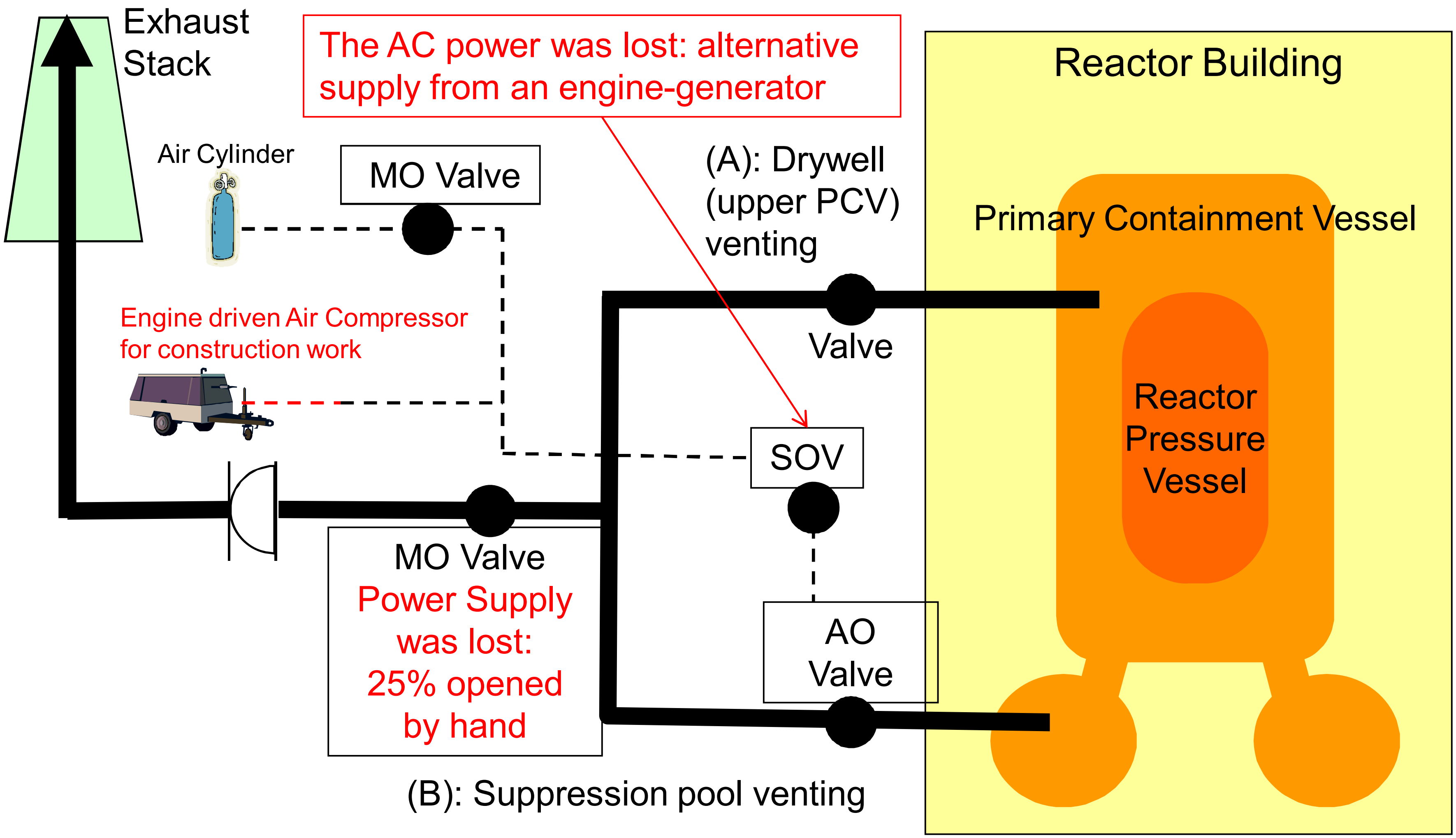
Alternative water injection into the reactors @1F

1. Tried to inject fresh water using the diesel driven fire protection pump (DDFP): failed.
   - Unit 1: mechanical problem of the DDFP
   - Unit 2: the DDFP was flooded
   - Unit 3: the RPV pressure was too high
2. Injection of fresh water from underground water tank (16units/site×40m3/site) using the fire engine pumps : succeeded but did not last for long time due to insufficient water supply.
3. Injection of sea water using the fire engine pump.

- Hurdles for the work:
  - Suspensions due to aftershocks and tsunami alarms
  - Damages of the fresh water lines due to the earthquake
  - Debris and damages of the gates caused by the tsunami
  - Hydrogen explosions (rubble, damage of fire engines and other devices, injury of field workers and fear of another explosion)
  - No lights. Problem with the PHS telephone and radio communication

Venting of the PCV @1F

It was extremely difficult to achieve the venting line without supply of the electricity and instrumentation air. High radiation dose in R/B also impeded the work.



Initial recovery of instrumentations and power supply @1F

- Used batteries taken from cars for recovery of important instrumentations.
- Put Engine-Generators to provide power for the control room lightings.
- Tried to connect a power supply cart to P/C 2C with temporary cable. The hydrogen explosion of Unit 1 caused damage of the temporary cable.
- Hurdles for the work:
  - Darkness and suspensions due to aftershocks, tsunami alarms,
  - Puddles, openings of manholes, debris and other obstacles caused by the tsunami,
  - Influence of the hydrogen explosions

Batteries brought into the control room

Image of a power supply cart

Factors disturbing the recovery work (outside the buildings) @1F

- The initial recovery work after the tsunami was dangerous due to aftershocks , openings of manholes, cracks and holes on the roads. Especially work during night was in complete darkness and very dangerous.
- Many obstacles such as rubble and damaged cars disturbed the access to equip. & comp..

<u>Cracks and holes on the roads</u>: dangerous even for walking, especially during night.

<u>Obstacles on access routes:</u> needed not to pass on the fire protection hose. After the explosions, damaged fire engines, rubble disturbed the access.

<u>Setting up a temporary power source (1):</u>

Destroy the shutter of the delivery entrance by a construction machine.

<u>Setting up a temporary power source (2):</u>

Laying of cable was done by man power

Factors disturbing the recovery work (inside the buildings) @1F

- Activities were done in complete darkness due to lack of power sources.
- In some places, radiation dose level was very high.

Work in complete darkness

In the service building. Many scattered objects were also on the floor.

Temporary power supply

Connect temporary batteries to recover instrumentations.

Supervising (1)

Check indicated values only with a flashlight in complete darkness

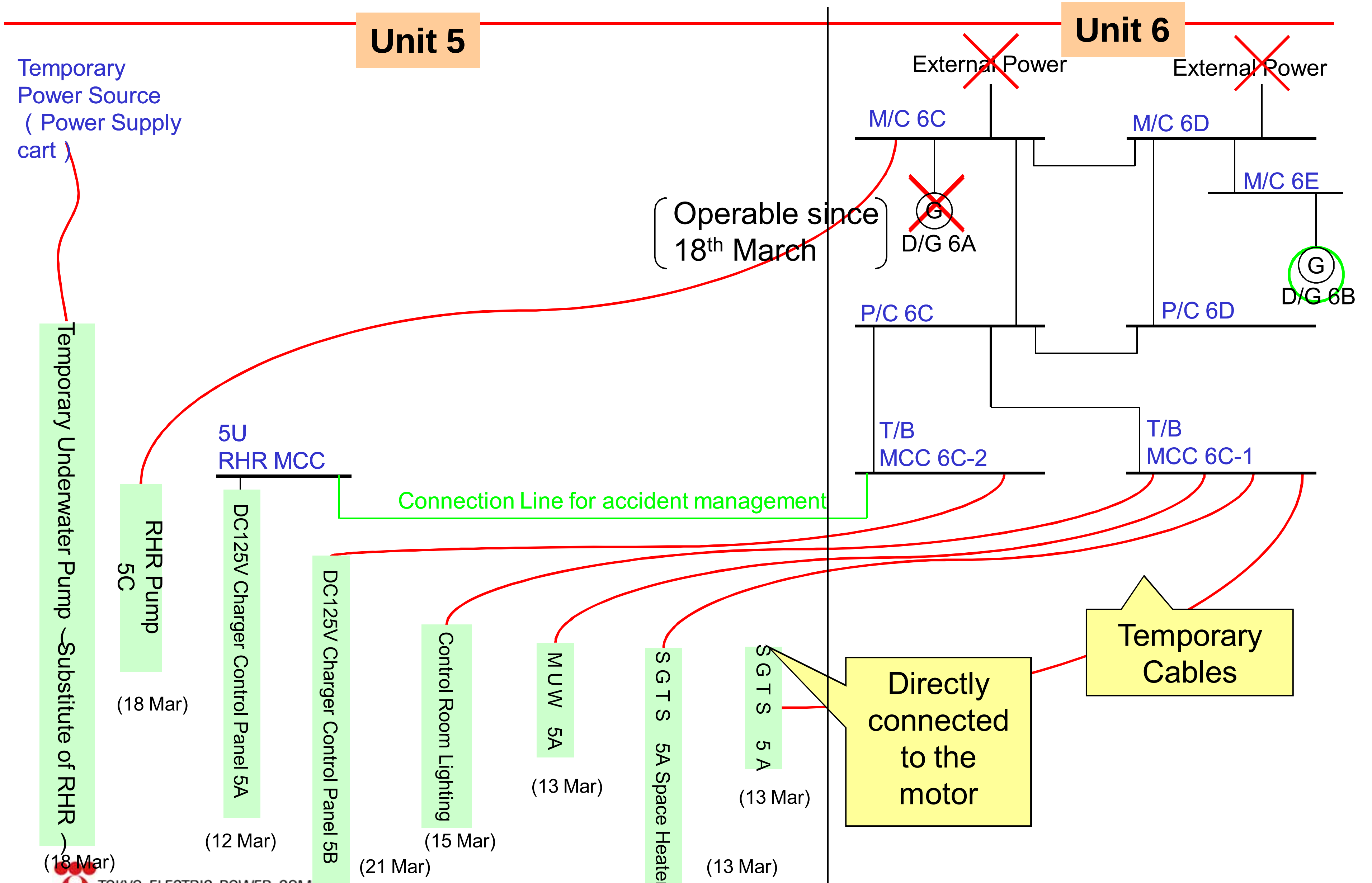
Supervising (2)

Supervising at a deputy supervisor's desk wearing a full face mask in complete darkness

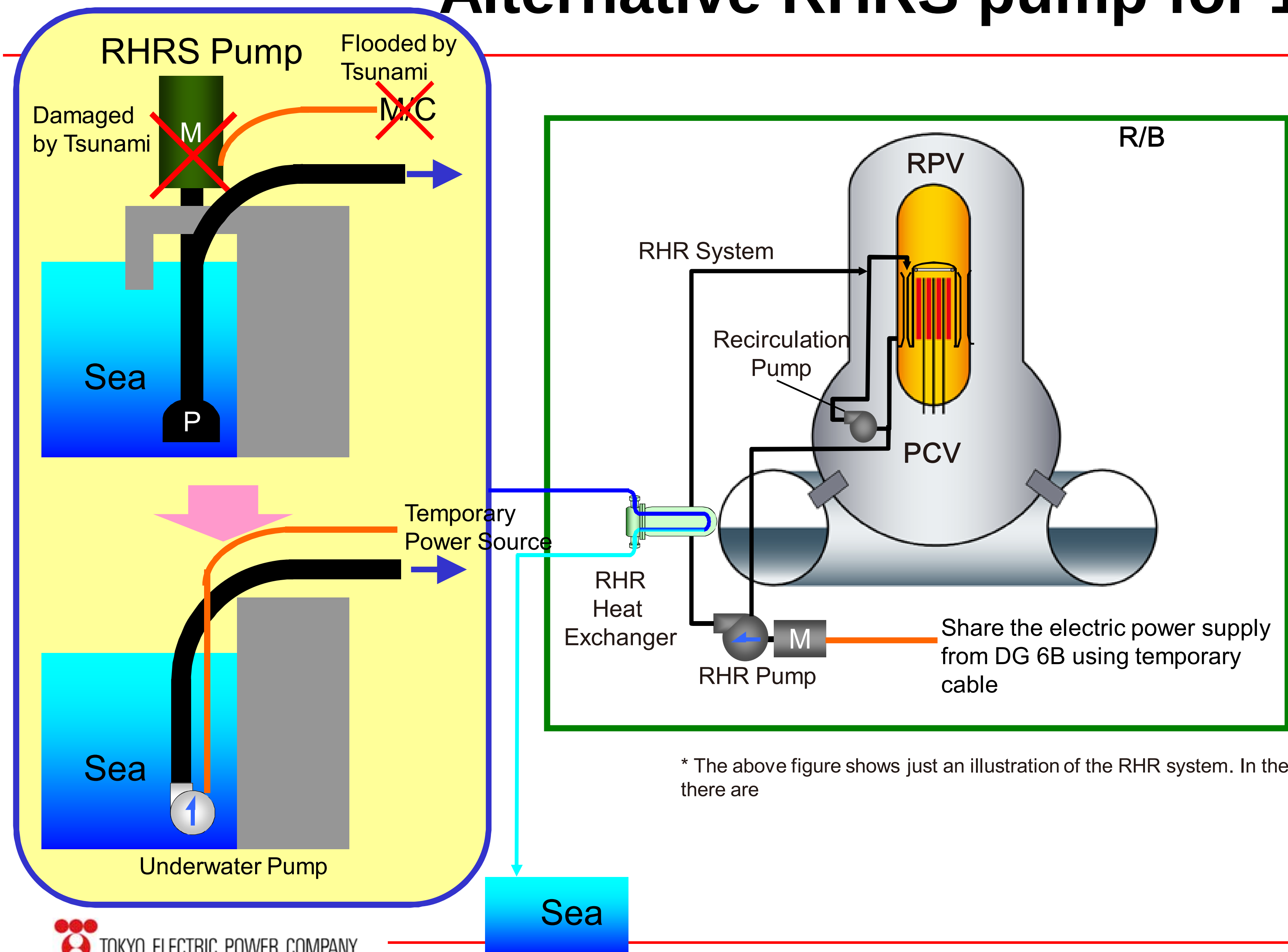
Efforts to recover the status of 1F5

- Unit 5 also lost the all AC power supply (Only one train of the DC125V battery was available: Temporary AC power had been supplied to the charger before the battery was exhausted).
- Status of Unit 5 was just after the RPV leak test: the reactor pressure and temperature were certainly high.
- The reactor temperature of Unit 5&6 once exceeded 100ºC.
- Key success stories:
  - Prompt supply of power from DG 6B to selected components of Unit 5 by directly connecting with temporary cables,
  - Prompt acquisition and utilization of general industrial grade underwater pumps as an alternative of the RHRS pumps.
- Information exchange with Fukushima Daini NPS and supports from Kashiwazaki Kariwa NPS were very useful and helpful during the recovery process.

Power Supply from 1F6 to 1F5



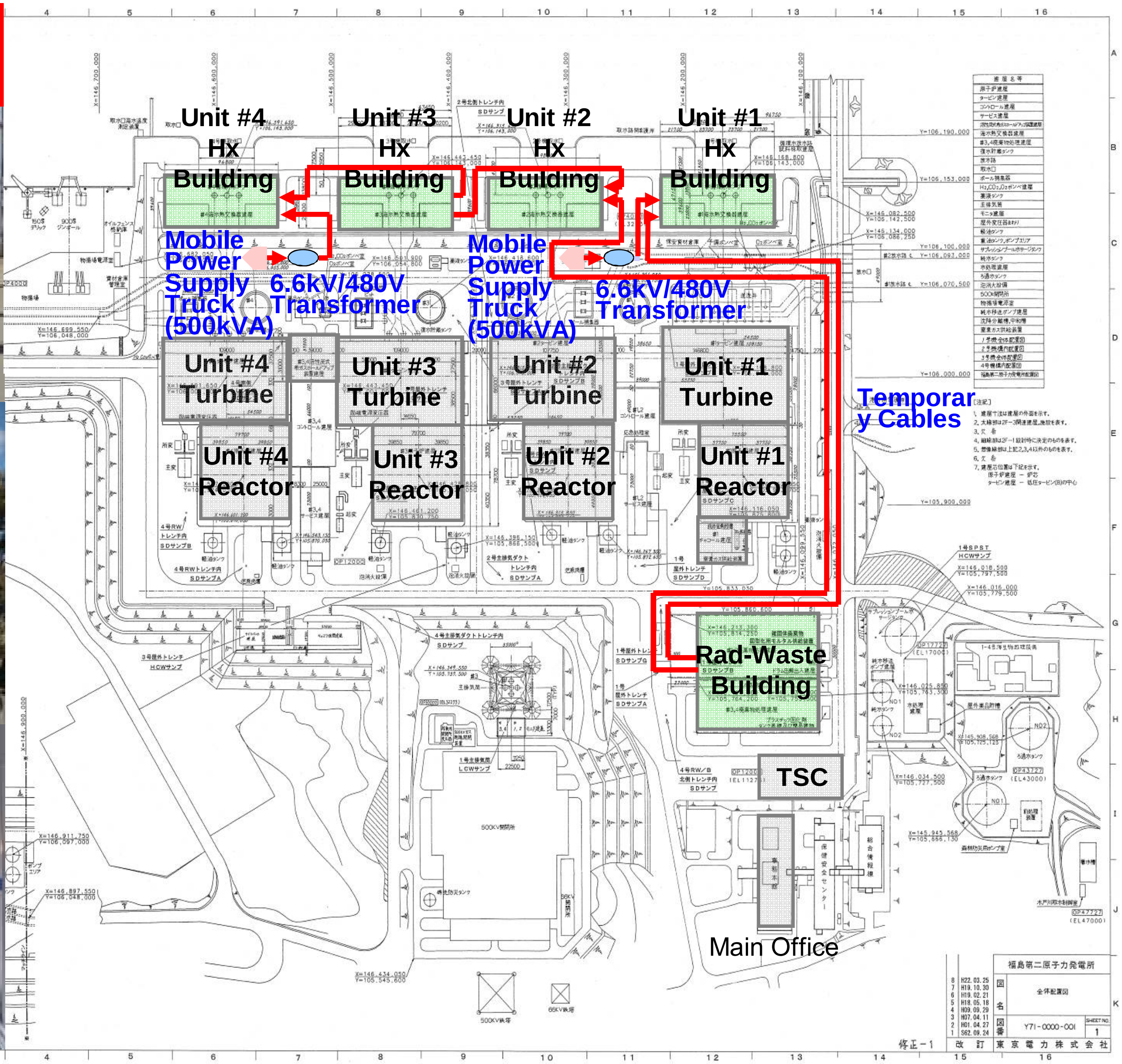
Alternative RHRS pump for 1F5



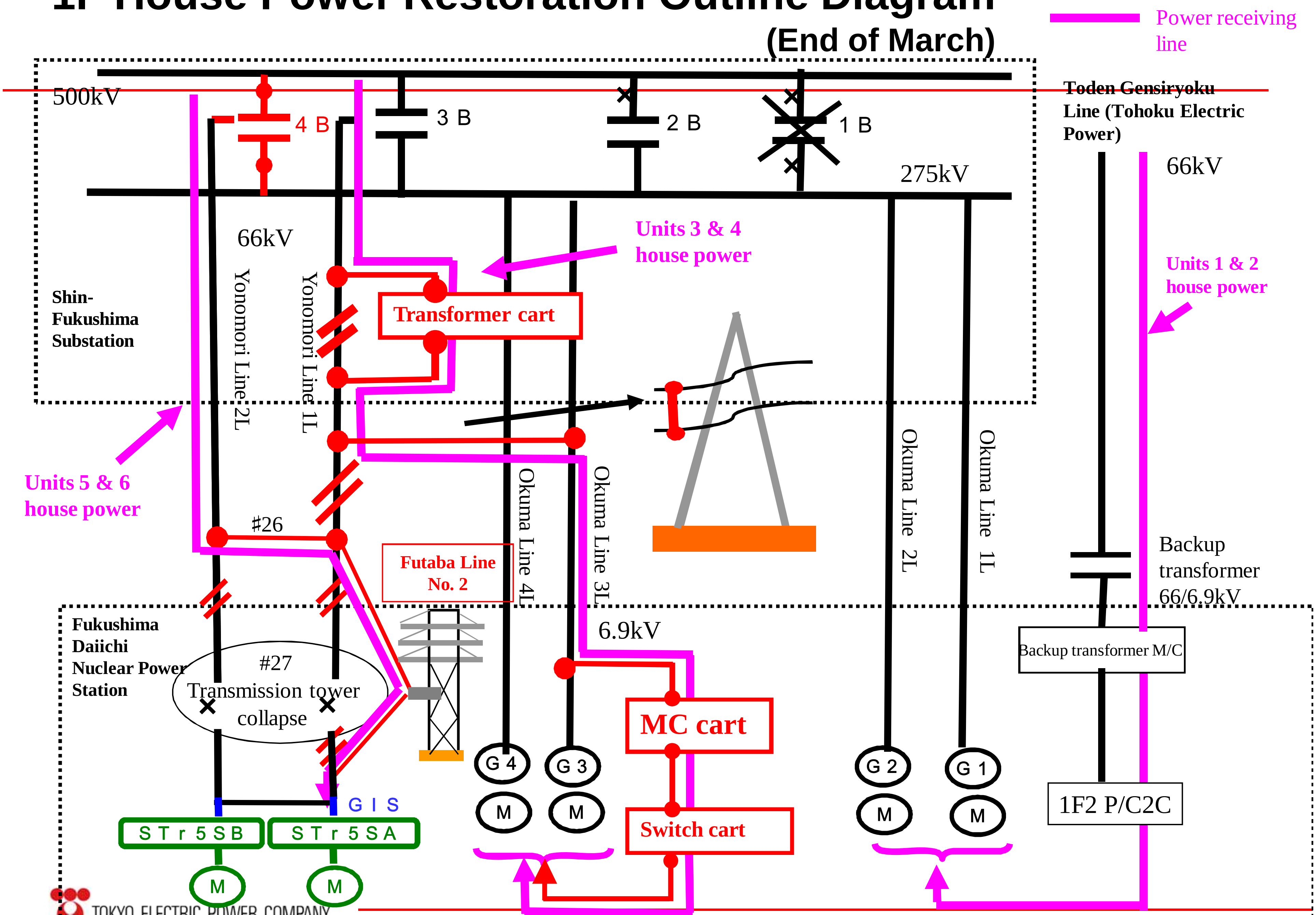
* The above figure shows just an illustration of the RHR system. In the actual unit, there are

Temporary Power Supply and Motor Replacement @2F

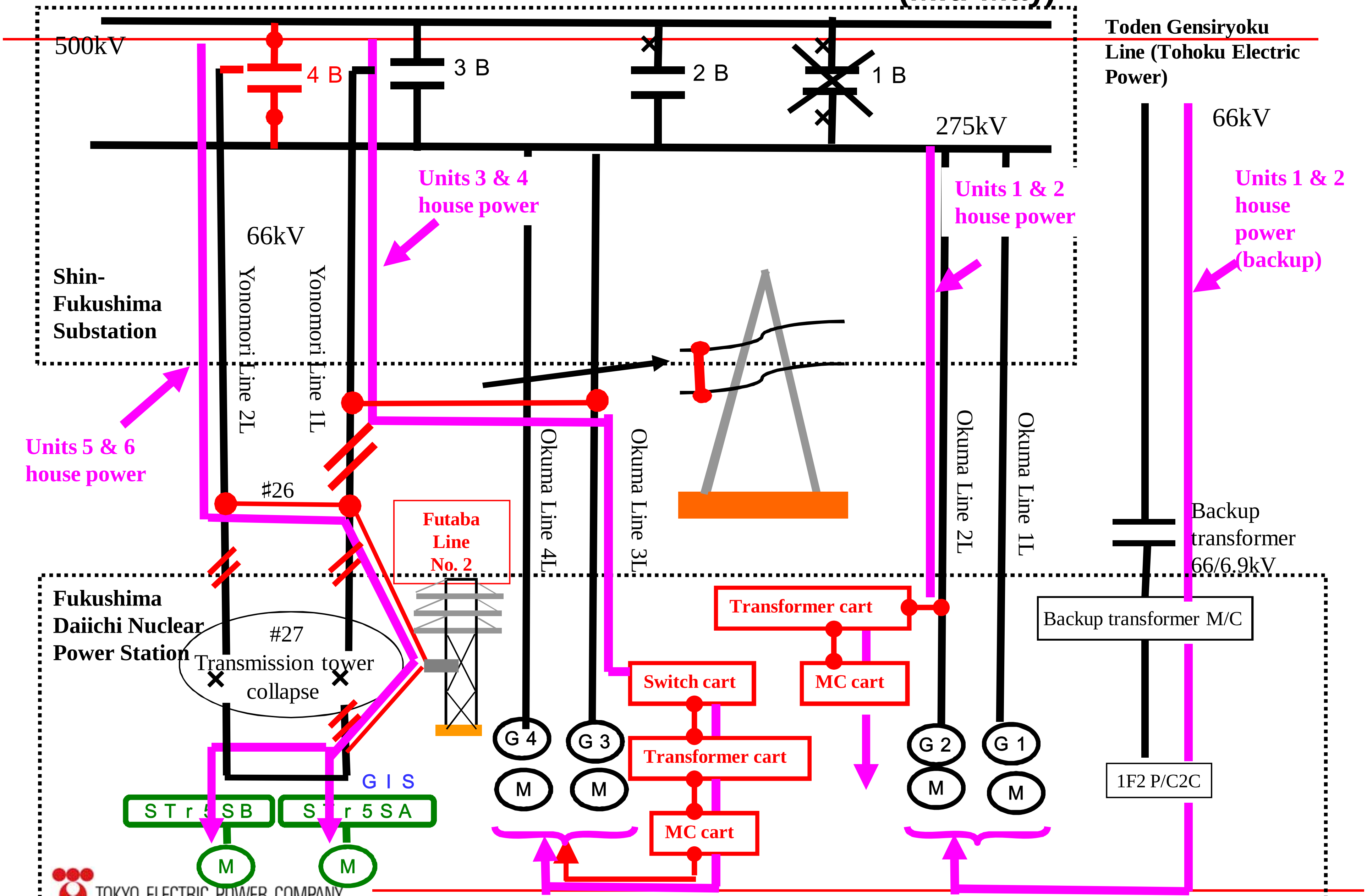
About 9 km of temporary cables were laid and motors were replaced.



1F House Power Restoration Outline Diagram
(End of March)



1F House Power Restoration Outline Diagram
(Mid-May)



4 . Current Status and Roadmap

Plant Parameters (Fukushima Daiichi)

as of July 20th at 6:00

RPV Pressure [MPa-g]

Unit 1	Unit 2	Unit 3
0.030	0.027	-0.106

RPV Temp [℃]

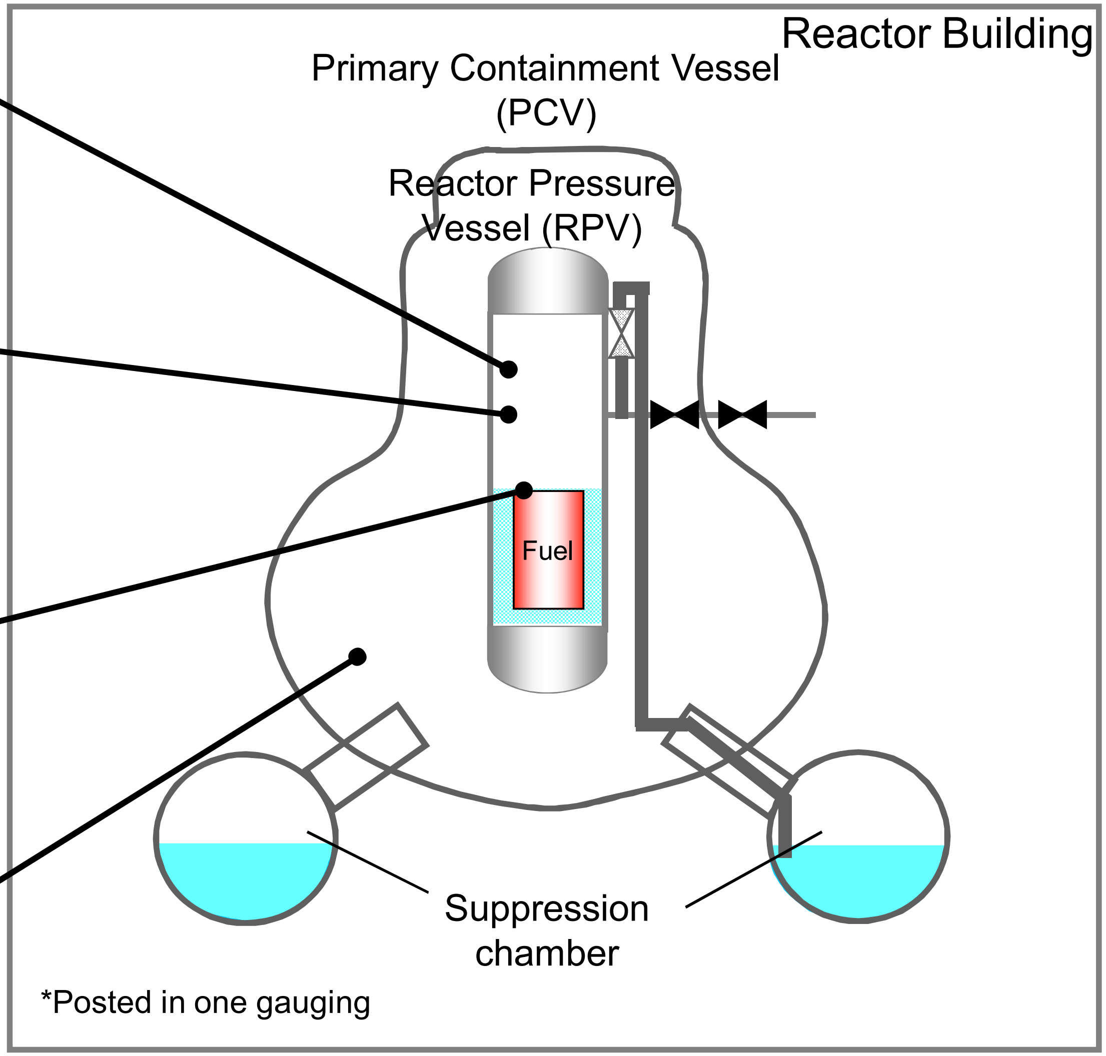
Unit 1	Unit 2	Unit 3
110.6 (Feedwater Nozzle)	126.0 (bottom of RPV)	135.4 (Feedwater Nozzle)

Reactor water level [mm]

Unit 1	Unit 2	Unit 3
Below the range	-2,150	-2,300

Drywell pressure [MPa-abs]

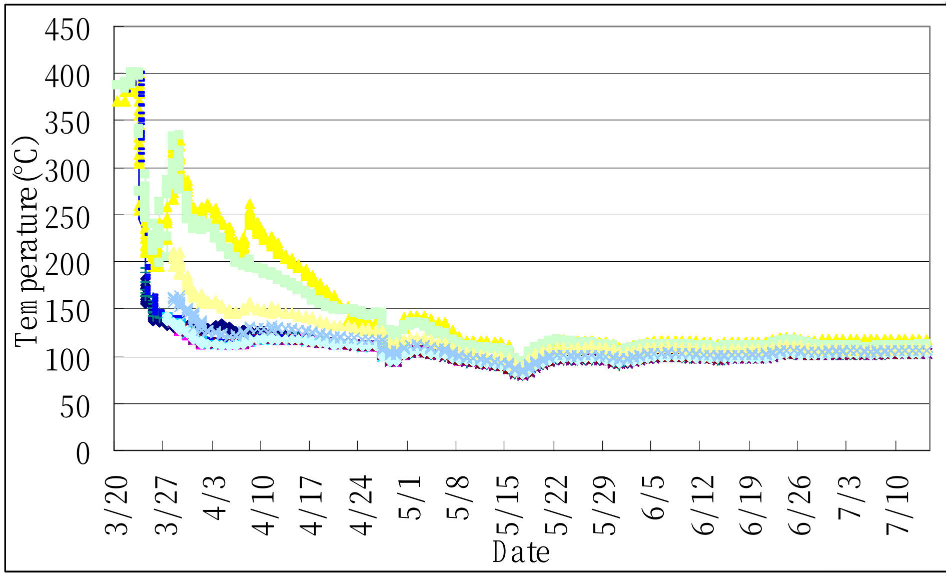
Unit 1	Unit 2	Unit 3
0.1378	0.130	0.1016

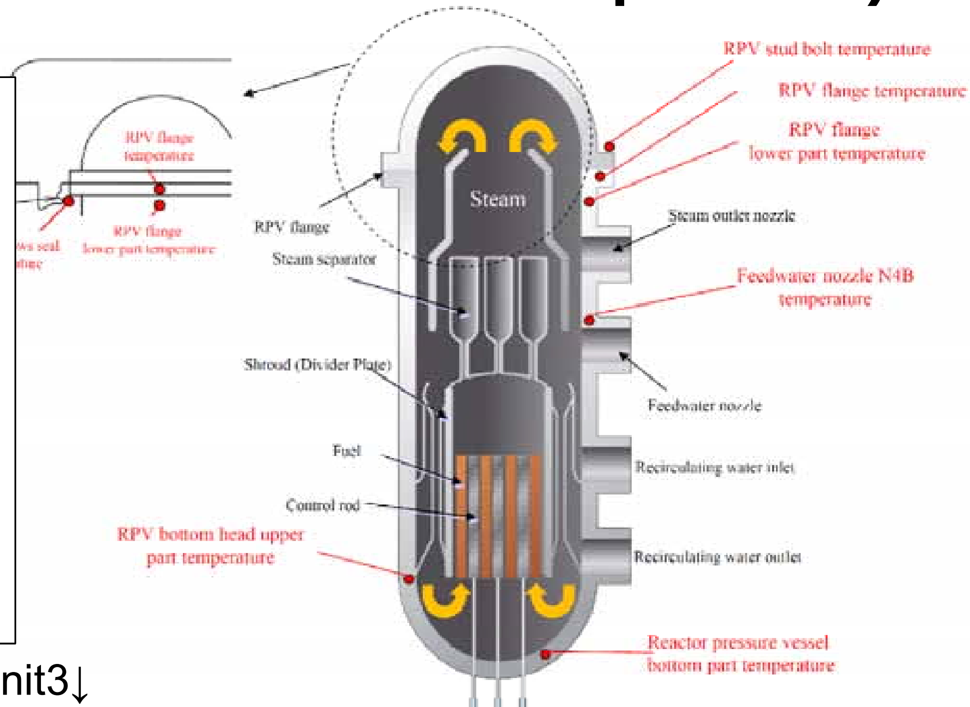


*We are judging the plant status by utilizing data obtained from multiple instruments including their changing trend in a comprehensive manner considering that some of them possibly are showing inaccurate data due to the irregular condition for use

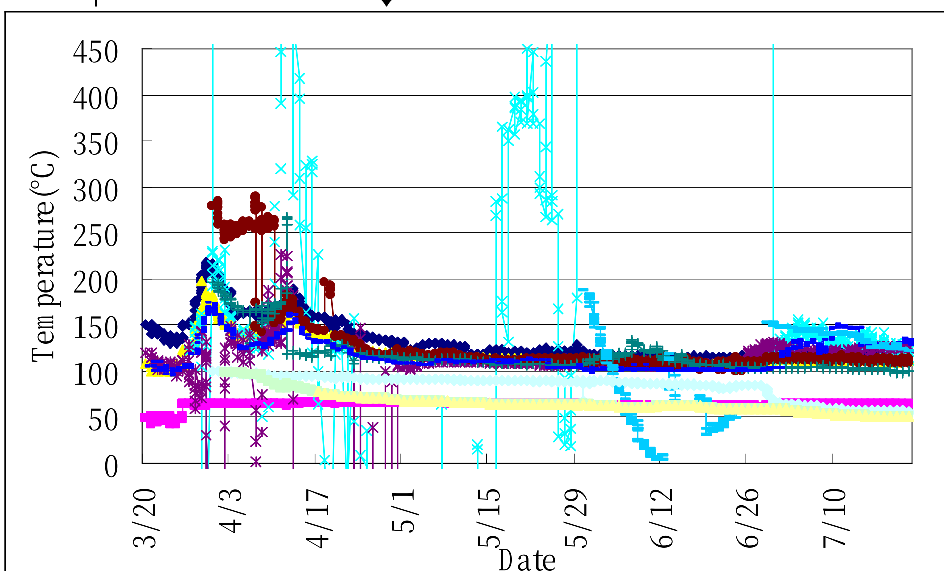
Pressure conversion: Gauge pressure (MPa-g)=absolute pressure (MPa-abs)-atmospheric pressure(0.1013Mpa)

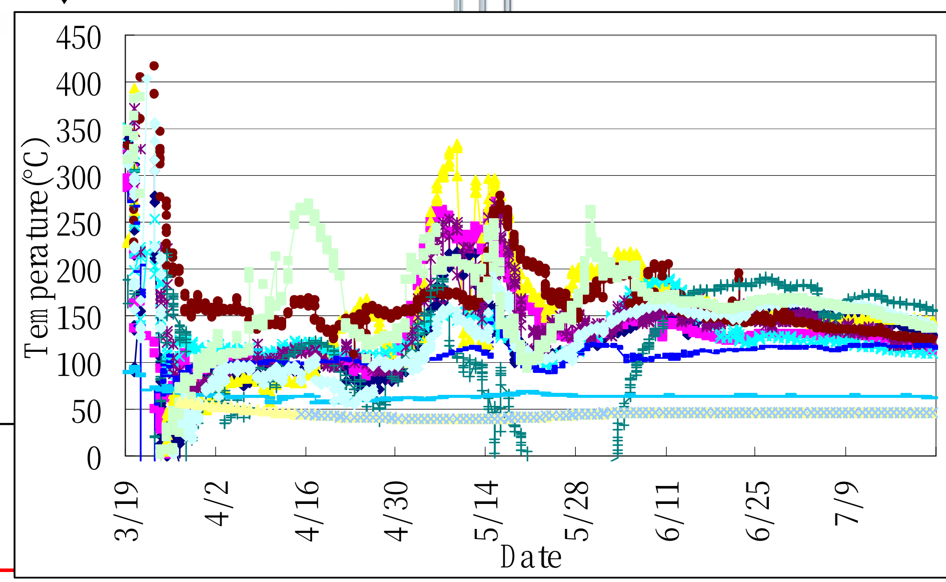
Plant Parameters (Fukushima Daiichi　RPV temperature)





↑Unit1　　　↓Unit2　　　　　　Unit3↓

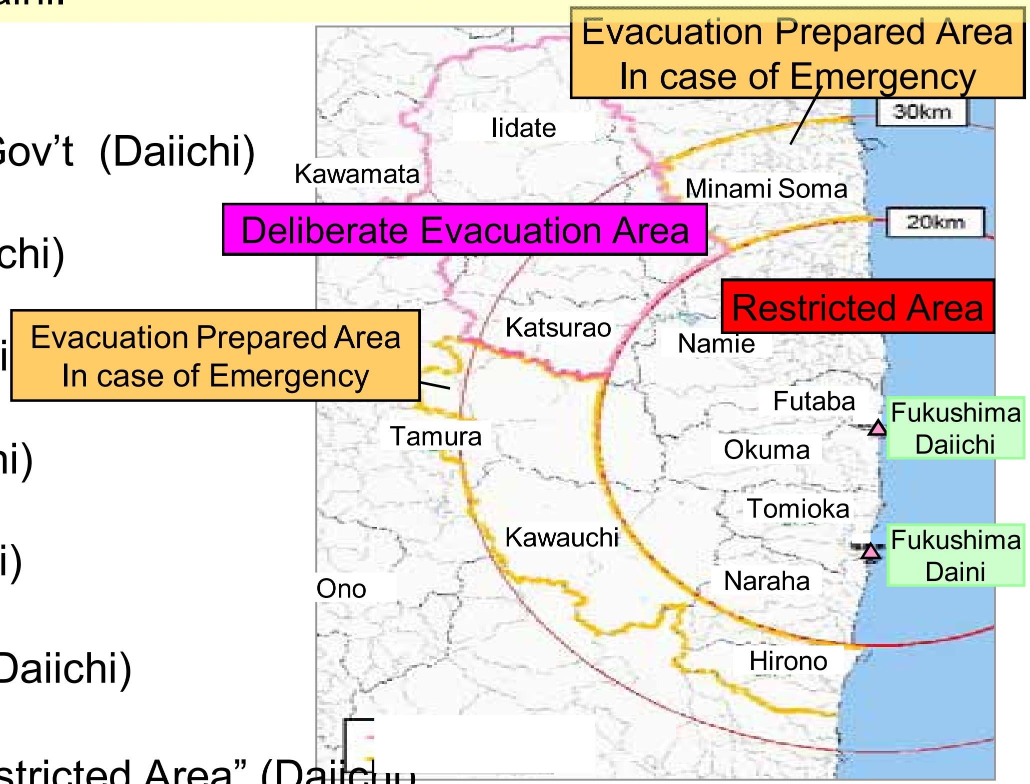




Evacuation

➢ The government took measures such as taking shelters or evacuation as follows based on the reports from Fukushima Daiichi & Daini.

- **Fri, 11 March**
- 14:46 The earthquake occurred
- 19:03 Emergency Declaration by the Gov't (Daiichi)
- 21:23 3 km radius evacuation (Daiichi)
- 10 km radius taking shelter (Daiichi)
- **Sat, 12 March**
- 5:44 10 km radius evacuation (Daiichi)
- 7:45 3 km radius evacuation (Daini)
- 10 km radius taking shelter (Daini)
- 17:39 10 km radius evacuation (Daini)
- 18:25 20 km radius evacuation (Daiichi)
- **Tue, 15 March**
- 11:00 20-30 km radius taking shelter (Daiichi)
- **Thu, 21 April**
- 11:00 20 km radius designated as "Restricted Area" (Daiichi)
- **Fri, 22 April**
- 9:44 20-30 km radius taking shelter has been lifted (Daiichi)
- Establishment of "Deliberate Evacuation Area" and "Evacuation Prepared Area in Case of Emergency"
- **Thu, 16 June**
- PM Establishment of "Specific Locations Recommended for Evacuation"



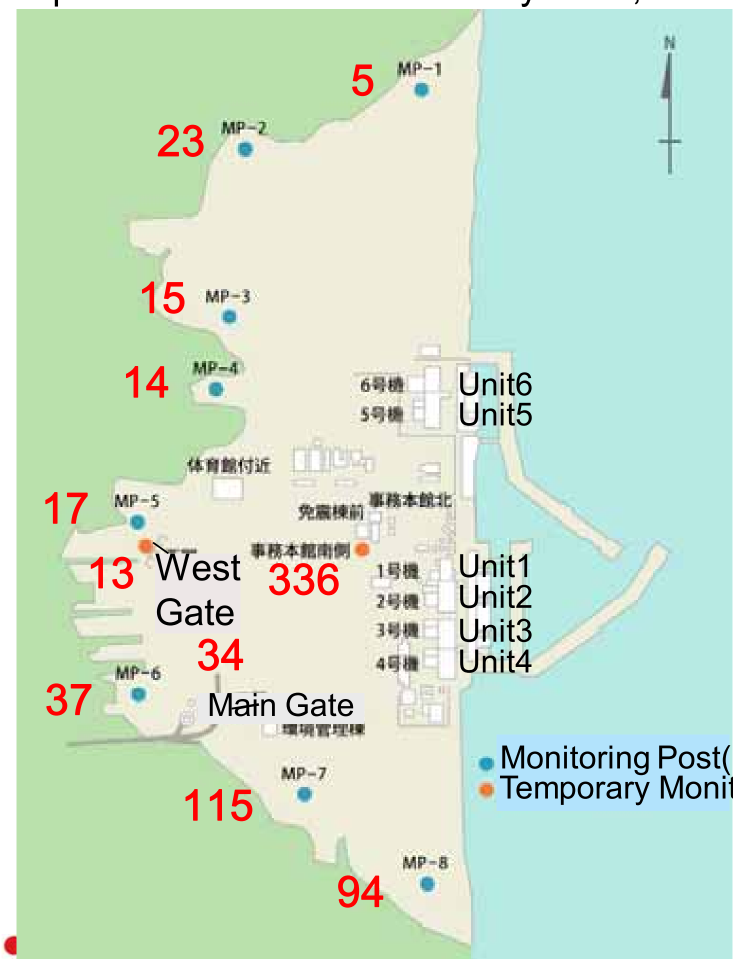
Source: NISA website

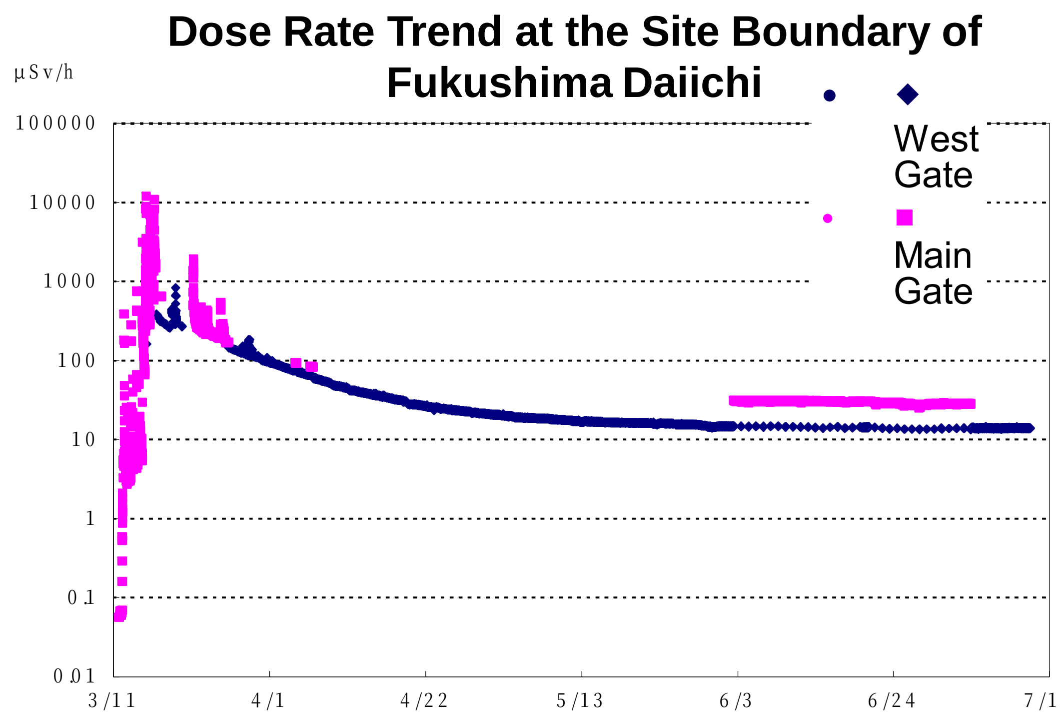
Monitoring Data (at Site Boundary of Fukushima Daiichi)

➢ Monitoring data at the site boundary of Fukushima Daiichi shows continuous decrease at each monitoring post.

air dose rate measured at on-site monitoring posts

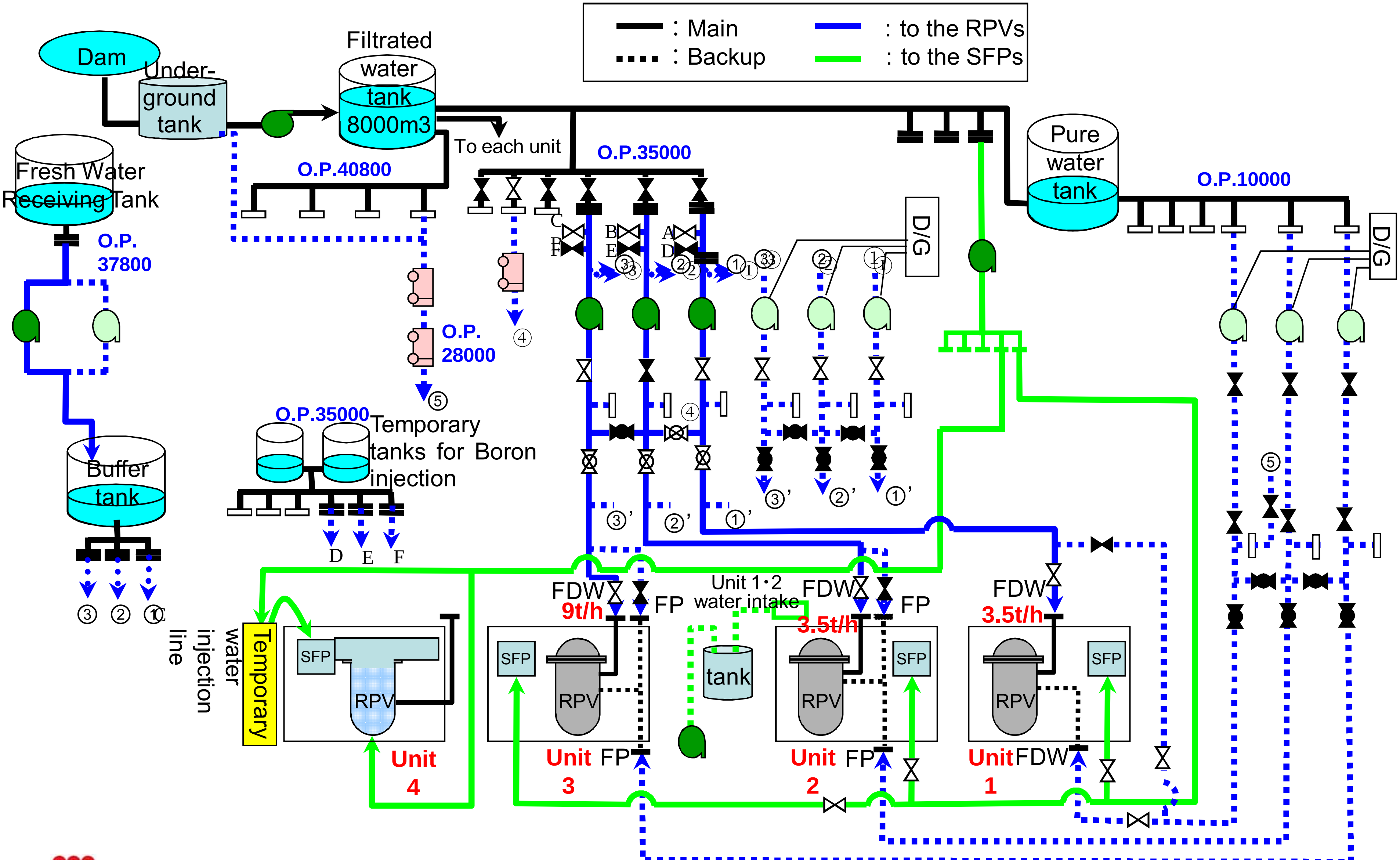
:μSv/h as of 9:00 am on July 12th , 2011





Schematic Diagram of Current Water Supply System

as of July 7th



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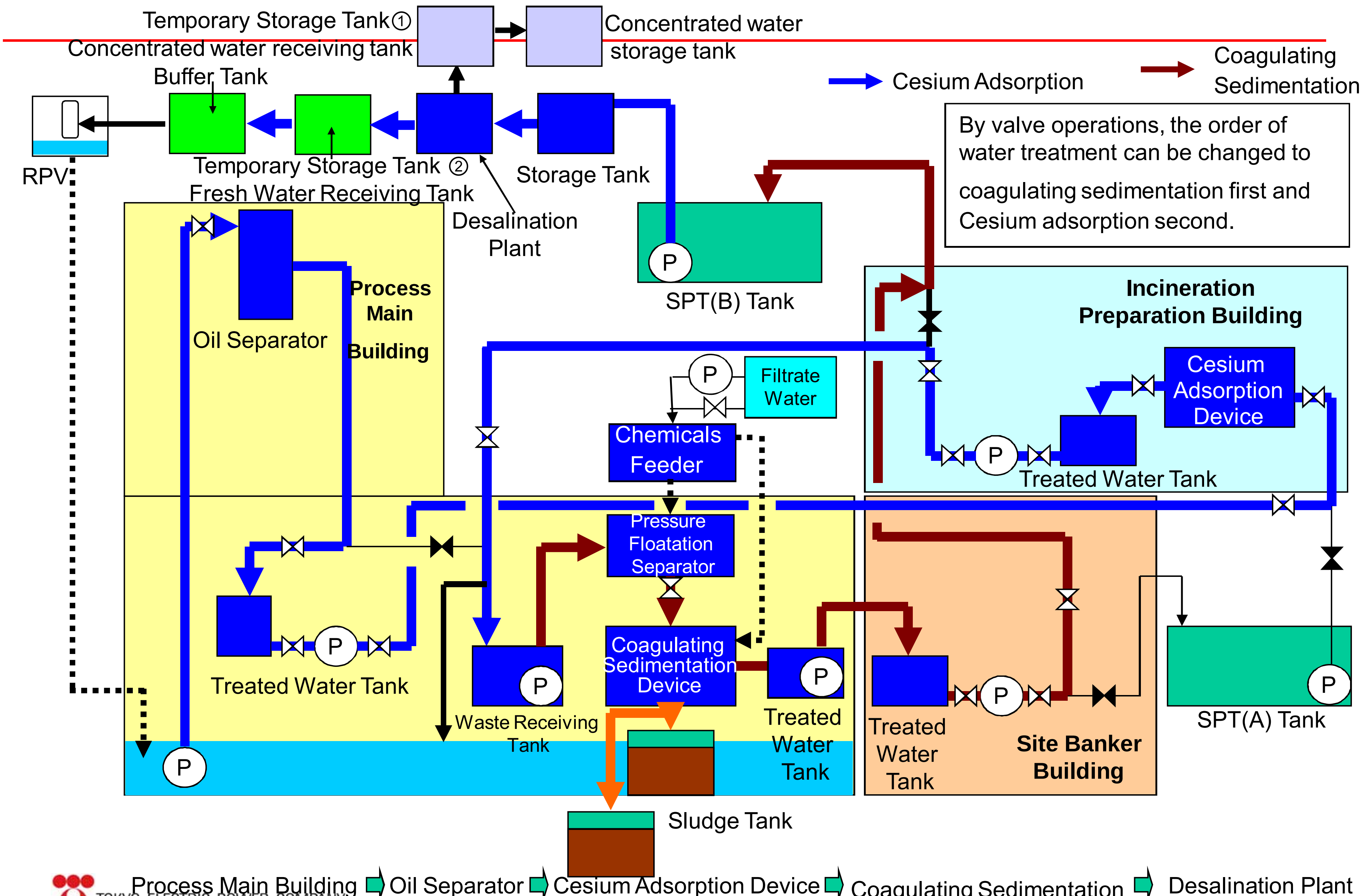
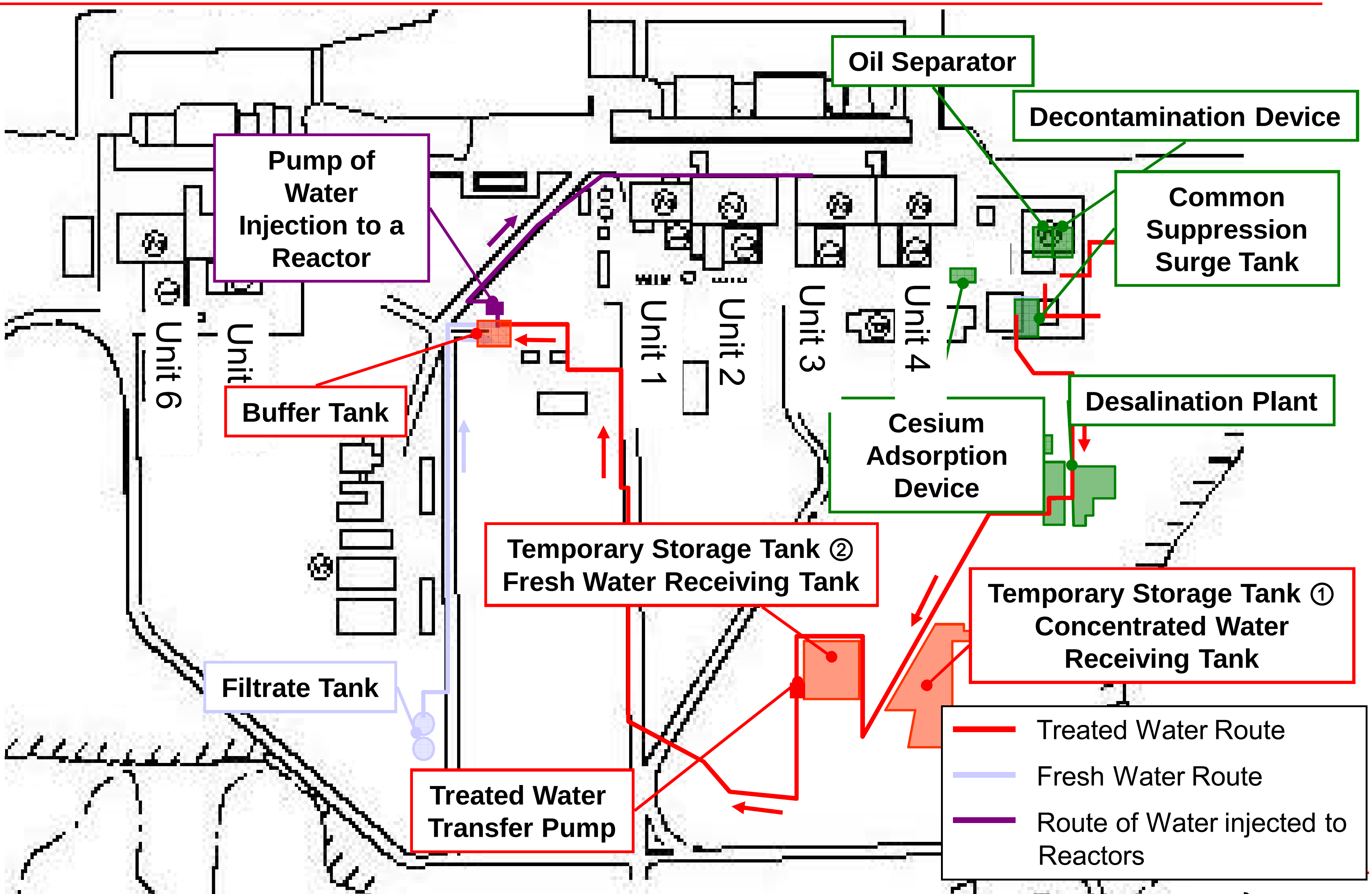
Outline of Water Treatment Facility System (Highly Contaminated Water)



Water Flow of Overall Water Treatment Facility



Current Status of "Roadmap towards Restoration from the Accident at Fukushima Daiichi Nuclear Power Station, TEPCO" (Revised on July 19th)

Red colored: newly added to the previous version, ☆: already reported to the government

Issues		As of April 17	Step 1 (around 3 months)		Step 2 (around 3 to 6 months after achieving Step1) current status (as of July 17)		Mid-term issues (around 3 years)
I. Cooling	(1) Reactor	Fresh water Injection	Cooling by minimum injection rate (injection cooling) Consideration and preparation of reuse of accumulated water Circulating Injection Cooling (start) ☆ Nitrogen gas injection ☆ Improvement of work environment ☆	Stable cooling	Circulating Injection Cooing (continued)	Cold shutdown condition	**Continuous cold shutdown condition** Protection against corrosion cracking of structural materials* *partially ahead of schedule
	(2) Spent Fuel Pool	Fresh water injection	Reliability improvement in injection operation / remote-control operation *ahead of schedule Circulation cooling system ☆ (installation of heat exchanger) *partially ahead of schedule	Stable cooling	Remote-controlled injection operation Consideration / installation of heat exchanging function	More stable cooling	**Start of removal work of fuels**
II. Mitigation	(3) Accumulated Water	Transferring water with high radiation level Storing water with low radiation level	Installation of storage / processing facilities ☆ Installation of storage facilities / decontamination processing	Secure storage place	Expansion **/ consideration of full-fledged processing facilities** Decontamination ☆ / desalt processing (reuse), etc Storage ☆ / management of sludge waste etc. Mitigation of contamination in the ocean	Reduction of total amount of contaminated water	Installation of full-fledged water processing facilities Continuous processing of accumulated water Research of processing of sludge waste etc. Mitigation of contamination in the ocean
	(4) Ground water		Mitigation of contamination of groundwater Consideration of method of shielding wall of groundwater	Mitigate ocean contamination	(Sub-drainage management with ... of storage / processing facilities) **Design / start of ... of shielding wall of groundwater**	Mitigate ocean Contamination (continued)	Solidification of contaminated soil, etc Establishment of shielding wall of groundwater
	(5) Atmosphere / Soil		Dispersion of inhibitor Removal of debris	Mitigate scattering	Installation of reactor building cover **(Unit 1)** ☆ **Removal of debris (top of Unit 3&4 R/B)** Consideration of reactor building container	Mitigate scattering (continued)	**Removal of debris / installation of reactor building cover (Unit 3&4)** **Start of installation work of reactor building container**

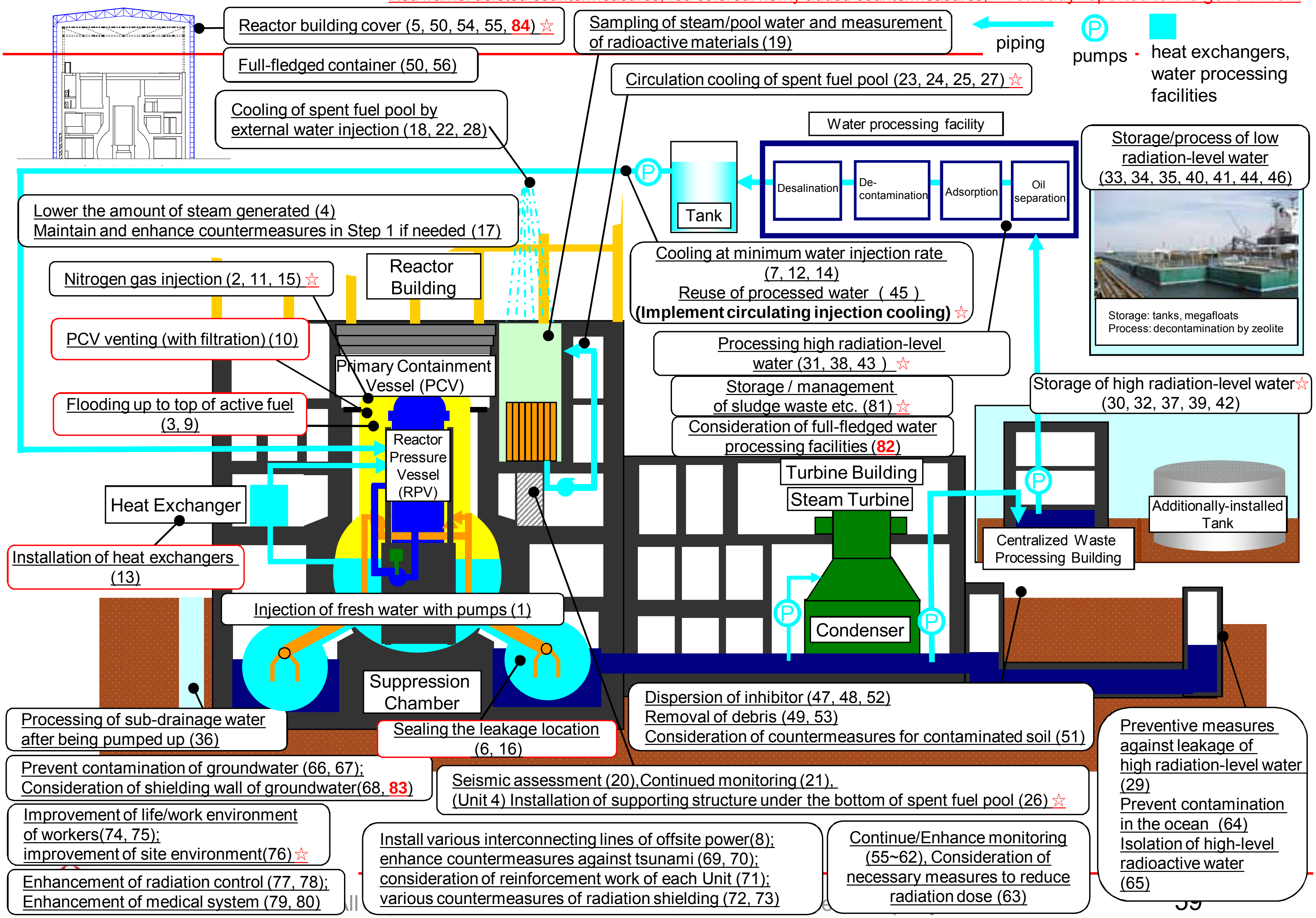
Current Status of "Roadmap towards Restoration from the Accident at Fukushima Daiichi Nuclear Power Station, TEPCO" (Revised on July 19th)

Red colored: newly added to the previous version, ☆: already reported to the government

Issues		As of April 17	Step 1 (around 3 months)	Step 2 (around 3 to 6 months after achieving Step1) current status (as of July 17)	Mid-term issues (around 3 years)
III. Monitoring/ Decontamination	(6) Measurement, Reduction and Announcement	Expansion, enhancement and announcement of radiation dose monitoring in and out of the power station		Start of full-fledged decontamination Decontamination	Continuous environmental monitoring Continuous decontamination
IV. Countermeasures against aftershocks, etc	(7) Tsunami, Reinforcement, etc	Enhancement of countermeasures against aftershocks and tsunami, preparation for various countermeasures for radiation shielding	(Unit 4 spent fuel pool) Installation of supporting structure ☆	Consideration / implementation of reinforcement work of each Unit Mitigate disasters	Continue various countermeasures for radiation shielding Reinforcement work of each Unit
V. Environment improvement	(8) Life/work environment		Improvement of workers' life / work environment	Enhancement of environment Improvement	Improvement of workers' life / work environment
	(9) Radiation control / Medical care		Improvement of radiation control / medical system	Enhancement of Healthcare	Improvement of radiation control / medical system
Measures for Mid-term issues				Government's concept of securing safety Establishing plant operation plan based on the safety concept	Response based on the plant operation plan

Overview of Major Countermeasures in the Power Station

Red frame: deleted countermeasures, red colored: newly added countermeasures, ☆: already reported to the government



5 . Summary

Summary (1/3)

1. The accident at Fukushima Daiichi and Daini was caused by Tsunami far beyond the design basis. (No significant damage by earthquake)

- **The current design of external barriers were not enough to cope with hydrodynamic forces of flooding and large debris impact.**

- **The current design of safety-related electric and I&C equipment might not be robust enough to prevent common cause failure by severe external flooding and their layout, diversity and internal barriers for separation need to be reviewed.**

Summary (2/3)

2. Several implementable countermeasures/modifications that could have lessened the damage at the unforeseeable accident have been identified.

- **Mobile power vehicles could be considered as redundant measures against extended SBO situation from the defense in depth viewpoint.**
- **Emergency water injection and cooling capability, against extended SBO situation, such as fire engines and air cylinders, should be considered.**
- **Better preplanning, staging and logistics of emergency and spare equipment would make a quicker recovery possible.**
- **Greater consideration should be given to redundant communication measures for organized actions.**

Summary (3/3)

3. Without newly built Emergency Response Center, the post-accident activities could not have been carried out.

- **Measures taken after Niigata Chuetsu Oki Earthquake were effective:**
  - **Emergency response center in robust building (Seismic isolation, Shielding, Communication, etc.)**
  - **Underground water tank** (16 units/site×40 m3/site) and **Fire Engines** (3/site)
  - **Emergency Response Drills**

6. References

- Damage status of electric equipments
- Restoration process
    - Electric equipment
    - I&C
- Measures to ensure safe shutdown @2F
- Chronology

Damage Status of Unit 1 & 2 Emergency DG and Emergency High Voltage Switchboard (Immediately after the Tsunami)

	Unit 1					Unit 2				
	Equipment	Installed building	Installed floor	Possibility of use	Status	Equipment	Installed location	Installed floor	Possibility of use	Status
DG	**DG 1A**	T/B	B1FL	×	Submerged	**DG 2A**	T/B	B1FL	×	Submerged
	DG 1B	T/B	B1FL	×	Submerged	**DG 2B**	Shared pool	1FL	×	M/C submerged cannot be used
	-	-	-	-	-	-	-	-	-	-
(M/C) Emergency high voltage switchboard	**M/C 1C**	T/B	1FL	×	Water damage	**M/C 2C**	T/B	B1FL	×	Submerged
	M/C 1D	T/B	1FL	×	Water damage	**M/C 2D**	T/B	B1FL	×	Submerged
	-	-	-	-	-	**M/C 2E**	Shared pool	B1FL	×	Submerged

Damage Status of Unit 3 & 4 Emergency DG and Emergency High Voltage Switchboard (Immediately after the Tsunami)

	Unit 3					Unit 4				
	Equipment	Installed location	Installed floor	Possibility of use	Status	Equipment	Installed location	Installed floor	Possibility of use	Status
DG	**DG 3A**	T/B	B1FL	×	Submerged	**DG 4A**	T/B	B1FL	×	Submerged (Construction in progress)
	DG 3B	T/B	B1FL	×	Submerged	**DG 4B**	Shared pool	1FL	×	M/C submerged cannot be used
	-	-	-	-	-	-	-	-	-	-
(M/C) Emergency high voltage switch board	**M/C 3C**	T/B	B1FL	×	Submerged	**M/C 4C**	T/B	B1FL	×	Submerged (Inspection in progress)
	M/C 3D	T/B	B1FL	×	Submerged	**M/C 4D**	T/B	B1FL	×	Submerged
	-	-	-	-	-	**M/C 4E**	Shared pool	B1FL	×	Submerged

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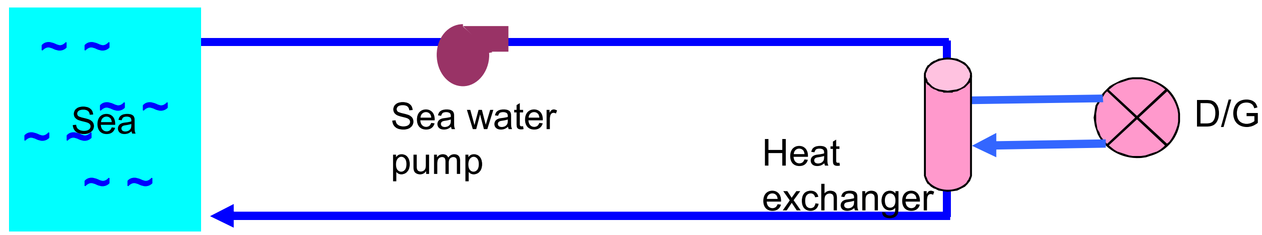
Damage Status of Unit 5 & 6 Emergency DG and Emergency High Voltage Switchboard (Immediately after the Tsunami)

	Unit 5					Unit 6				
	Equipment	Installed location	Installed floor	Possibility of use	Status	Equipment	Installed location	Installed floor	Possibility of use	Status
D G	**DG 5A**	T/B	B1FL	×	Related equipment Water damage	**DG 6A**	R/B	B1FL	×	Related equipment Water damage
	DG 5B	T/B	B1FL	×	Related equipment Water damage	**DG 6B**	DG building	1FL	○	-
	-	-	-	-	-	**HPCSD/G**	R/B	B1FL	×	Related equipment Water damage
(M/C) Emergency high voltage switchboard	**M/C 5C**	T/B	B1FL	×	Submerged	**M/C 6C**	R/B	B2FL	○	-
	M/C 5D	T/B	B1FL	×	Submerged	**M/C 6D**	R/B	B1FL	○	-
	-	-	-	-	-	**HPCS DG M/C**	R/B	1FL	○	-

Fukushima Daiichi: DG System Outline

Sea water-cooled DG (10)

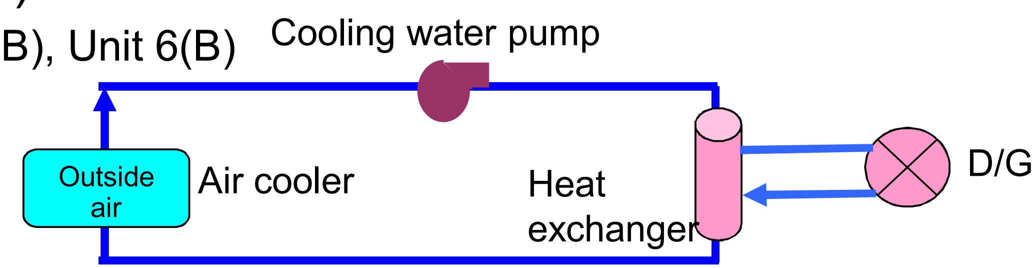
Unit 1 (A)(B), Unit 2 (A), Unit 3 (A)(B), Unit 4 (A), Unit 5 (A)(B), Unit 6 (A)(H)



All function was lost after the tsunami

Air-cooled DG (3)

Unit 2 (B), Unit 4 (B), Unit 6(B)

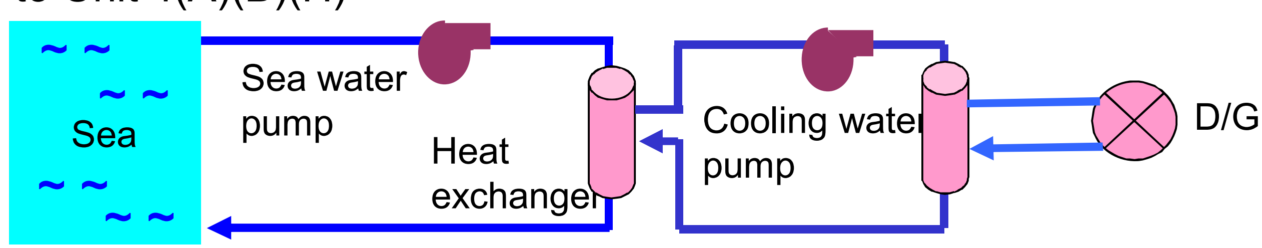


Power was secured in Unit 6 (B) only

[Fukushima Daini: DG System Outline]

Sea water-cooled DG (12)

Unit 1 to Unit 4(A)(B)(H)



Power was secured in Unit 3 (B)(H) and Unit 4 (H) only

Integrity of electricity supply system after the tsunami attack

		Fukushima Daiichi												Fukushima Daini							
		Unit 1		Unit 2		Unit 3		Unit 4		Unit 5		Unit 6		Unit 1		Unit 2		Unit 3		Unit 4	
		Power panel	Can/can not be used	Power panel	Can/can not be used	Power panel	Can/can not be used	Power panel	Can/can not be used	Power panel	Can/can not be used	Power panel	Can/can not be used	Power panel	Can/can not be used	Power panel	Can/can not be used	Power panel	Can/can not be used	Power panel	Can/can not be used
Emergency DG		DG 1A	×	DG 2A	×	DG 3A	×	DG 4A	×	DG 5A	×	DG 6A	×	DG 1A	×	DG 2A	×	DG 3A	×	DG 4A	×
		DG 1B	×	DG 2B	×	DG 3B	×	DG 4B	×	DG 5B	×	DG 6B	○	DG 1B	×	DG 2B	×	DG 3B	○	DG 4B	×
		—	—	—	—	—	—	—	—	—	—	HPCS DG	×	DG 1H	×	DG 2H	×	DG 3H	○	DG 4H	○
M/C	Emergency use	M/C 1C	×	M/C 2C	×	M/C 3C	×	M/C 4C	×	M/C 5C	×	M/C 6C	○	M/C 1C	×	M/C 2C	○	M/C 3C	○	M/C 4C	○
		M/C 1D	×	M/C 2D	×	M/C 3D	×	M/C 4D	×	M/C 5D	×	M/C 6D	○	M/C 1D	○	M/C 2D	○	M/C 3D	○	M/C 4D	○
		—	—	M/C 2E	×	—	—	M/C 4E	×	—	—	HPCS DG M/C	○	M/C 1H	×	M/C 2H	○	M/C 3H	○	M/C 4H	○
	Regular use	M/C 1A	×	M/C 2A	×	M/C 3A	×	M/C 4A	×	M/C 5A	×	M/C 6A-1	×	M/C 1A-1	○	M/C 2A-1	○	M/C 3A-1	○	M/C 4A-1	○
												M/C 6A-2	×	M/C 1A-2	○	M/C 2A-2	○	M/C 3A-2	○	M/C 4A-2	○
		M/C 1B	×	M/C 2B	×	M/C 3B	×	M/C 4B	×	M/C 5B	×	M/C 6B-1	×	M/C 1B-1	○	M/C 2B-1	○	M/C 3B-1	○	M/C 4B-1	○
												M/C 6B-2	×	M/C 1B-2	○	M/C 2B-2	○	M/C 3B-2	○	M/C 4B-2	○
		M/C 1S	×	M/C 2SA	×	M/C 3SA	×	—		M/C 5SA-1	×	—		M/C 1SA-1	○	-		M/C 3SA-1	○	-	
										M/C 5SA-2	×			M/C 1SA-2	○			M/C 3SA-2	○		
				M/C 2SB	×	M/C 3SB	×			M/C 5SB-1	×			M/C 1SB-1	○			M/C 3SB-1	○		
										M/C 5SB-2	×			M/C 1SB-2	○			M/C 3SB-2	○		
P/C	Emergency use	P/C 1C	×	P/C 2C	○	P/C 3C	×	P/C 4C	○	P/C 5C	×	P/C 6C	○	P/C 1C-1	×	P/C 2C-1	○	P/C 3C-1	○	P/C 4C-1	○
		P/C 1D	×	P/C 2D	○	P/C 3D	×	P/C 4D	○	P/C 5D	×	P/C 6D	○	P/C 1C-2	×	P/C 2C-2	×	P/C 3C-2	×	P/C 4C-2	×
		—	—	P/C 2E	×	—	—	—	—	—	—	P/C 6E	○	P/C 1D-1	○	P/C 2D-1	○	P/C 3D-1	○	P/C 4D-1	○
	Regular use	P/C 1A	×	P/C 2A	○	P/C 3A	×	P/C 4A	○	P/C 5A	×	P/C 6A-1	×	P/C 1D-2	×	P/C 2D-2	×	P/C 3D-2	○	P/C 4D-2	×
				P/C 2A-1	×	HVAC P/C 3A	△	HVAC P/C 4A	△	P/C 5A-1	○	P/C 6A-2	×	P/C 1A-1	○	P/C 2A-1	○	P/C 3A-1	○	P/C 4A-1	○
		P/C 1B	×	P/C 2B	○	P/C 3B	×	P/C 4B	○	P/C 5B	×	P/C 6B-1	×	P/C 1A-2	○	P/C 2A-2	○	P/C 3A-2	○	P/C 4A-2	○
		—	—	—	—	HVAC P/C 3B	△	HVAV P/C 4B	△	P/C 5B-1	○	P/C 6B-2	×	P/C 1B-1	○	P/C 2B-1	○	P/C 3B-1	○	P/C 4B-1	○
		P/C 1S	×	—	—	P/C 3SA	×	—	—	P/C 5SA	×	—	—	P/C 1B-2	○	P/C 2B-2	○	P/C 3B-2	○	P/C 4B-2	○
		—	—	—	—	—	—	—	—	P/C 5SA-1	×	—	—	P/C 1SA	○	-		P/C 3SA	○	-	
		—	—	P/C 2SB	×	P/C 3SB	×	—	—	P/C 5SB	×	—	—	P/C 1SB	○			P/C 3SB	○		
		—	—	—	—	—	—	—	—	—	—	—	—	Water intake equipment P/C	×			Water intake equipment P/C	×		
DC power supply	125V DC	DC125V main bus panel A	×	DC125V P/C 2A	×	DC125V main bus panel 3A	○	DC125V main bus panel 4A	×	DC125V P/C 5A	○	DC125V DIST CENTER 6A	○	DC125V main bus panel A	○	DC125V main bus panel A	○	DC125V main bus panel A	○	DC125V main bus panel A	○
		DC125V main bus panel B	×	DC125V P/C 2B	×	DC125V main bus panel 3B	○	DC125V main bus panel 4B	×	DC125V P/C 5B	○	DC125V DIST CENTER 6B	○	DC125V main bus panel B	○	DC125V main bus panel B	○	DC125V main bus panel B	○	DC125V main bus panel B	○
Sea water system	A	CCS A	×	RHRS A	×	RHRS A	×	RHRS A	×	RHRS A	×	RHRS A	×	RHRS A	×	RHRS A	×	RHRS A	×	RHRS A	×
	B	CCS B	×	RHRS B	×	RHRS B	×	RHRS B	×	RHRS B	×	RHRS B	×	RHRS B	×	RHRS B	×	RHRS B	○	RHRS B	×

Power Access/Restoration Status Immediately after 1F-1,2 Shutdown

Date	Operation and Restoration Status
March 11	Temporary MCR lighting on (Temporary small engine generator)
March 12	Power source for Unit 1 Instrument restored (Temporary small engine generator)
	Power source for Unit 1 Instrument restored (power source cart)
	Temporary small engine generator destroyed by H2 explosion
	Temporary MCR lighting on (another temporary small engine generator)
March 19	Backup transformer ~ Unit 1 & 2 temporary M/C (A) cable laid
March 20	Off-site power restored (P/C2C power received)

Power Access/Restoration Status Immediately after 1F-3,4 Shutdown

Date	Operation and Restoration Status
March 11	Temporary MCR lighting on (Temporary small engine generator)
March 13	P/C 4D restored (power source cart)
March 14	Yonomori Line 1L step-down transformer cart (66/6.9kW) connected to the Shin-Fukushima Substation
	Yonomori Line 1L ~ Okuma Line 3L connected
	Power source for Unit 1 Instrument restored (power source cart) The power source cart destroyed by H2 explosion
March 18	Unit 3 & 4 MC, Switch installation location
March 22	Off-site power restored (P/C4D power received)

Power Access/Restoration Status Immediately after 1F-6 Shutdown

Date	Operation and Restoration Status
March 11	DG6B startup (6A and 6H were shut down by the tsunami, 6B is an air-cooled type)
	SGTS(B) startup, DC125V/250V (B system) restoration
March 12	DC125V/250V (A system) restoration
March 13	MUWC(B) startup
March 19	RHR 6B startup, temporary RHRS alternative pump startup (power source cart)
	DG6A startup (March 21 shutdown)
March 20	Cold shutdown condition
March 22	Off-site power restored (M/C6C, 6D power received)
March 23	Temporary RHRS alternative pump switched to off-site power

Power Access/Restoration Status Immediately after 1F-5 Shutdown

Date	Operation and Restoration Status
March 12	DC125V/250 restoration
March 13	MUWC(A), SGTS(A) startup
March 18	Temporary RHRS alternative pump startup (power source cart)
March 19	RHR 5C startup
March 20	Cold shutdown condition
March 22	Off-site power restored (M/C6C, 6D power received)
March 23	Temporary RHRS alternative pump switched to off-site power

Recovery Process of I&C equipments @1F (1/2)

- After tsunami → Total loss of instrumentations due to loss of offsite power and DC 125V
- March 11-14: to install temporary batteries to important instrumentations, such as reactor water level, reactor pressure, D/W pressure, S/C pressure etc. (1F-1-3: March 11, 1F-5/6: March 14) and to start to obtain plant data
- March 22-25: to recover AC 120V bus for I&C (1F1: March 23, 1F2: March 25, 1F3/4: March 22)
- ~ Present: to prioritize the recovery of redundant instrumentations for their reliability and to change step by step from temporary battery to original power source

Recovery Process of I&C equipments @1F (2/2)

- May 9: to go into R/B to calibrate the D/W pressure instrument @1F1
- May 10-12: to calibrate the fuel zone reactor water level instrument @1F1

  - water level assumed as lower than -500cm of TAF

- June 3-4: to install the temporary reactor pressure and Δpressure instrument at the test line of fuel zone reactor water level instrument @1F1, to obtain more precise data on reactor pressure and water level
- June 22-24: to install the temporary reactor pressure and Δpressure instrument at the test line of fuel zone reactor water level instrument @1F2

  - not successful due to rapid evaporation of water inside instrumentation line by high PCV temperature

Current status of important instrumentations @1F

Paramete r/unit	1F1	1F2	1F3	1F4	1F5	1F6
Reactor water level	A : ◎ B : △	A : △ B : △	A : △ B : △	N/A	○	○
Reactor pressure	A : ◎	A : ○	A : △ B : △	N/A	○	○
Reactor water temp.	Not sampled	Not sampled	Not sampled	N/A	○	○
Temperature around RPV	○	○	○	N/A	N/A	N/A
D/W pressure	◎	△	○	N/A	N/A	N/A
S/C pressure	○	×	○	N/A	N/A	N/A
CAMS rad monitor	D/W : × S/C : ○	D/W : ○ S/C : ○	D/W : ○ S/C : ○	N/A	N/A	N/A
S/C temparature	○	○	○	-	-	-

◎ : calibrated, ○ : assumed to be intact, △ : under continuous observation, × : failure

Measures to ensure Safe Shutdown @2F

- Tsunami Accident Management Guideline / Procedures and Drills
- Emergency Power Supply Capability under Tsunami SBO

  - Mobile power trucks with a total capacity of 8250 kVA for cooling system. (Required capacity: 6880 kVA)
- Emergency Water Injection and Cooling Capability under Tsunami SBO
  - Five fire engines with a total capacity of 120 m^3/h at 0.85 MPa as back-up injection capability. (Required capacity: 30 m^3/h at 0.7 MPa)
  - Spare air cylinders to drive AO valves for PCV venting
- Spare Motors and Bearings for Cooling Pumps
- Wheel Loader and Excavator to clear Debris
- Embankment

Chronology at Fukushima Daiichi Unit 1

Prior to earthquake In rated power operation

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting

March 11, 2011 14:46 Great East Japan Earthquake occurred, **reactor automatically scrammed**

【SHUTDOWN】

15:37 Station black out due to tsunami

(Sea water systems also

strike

lost)

Water injection **【COOLING】**

Venting **【CONTAINMENT】**

March 11 17:12
Superintendent directed consideration for injection of water into reactors using fire protection lines and vehicles

March 12 5:46
Fire-fighting vehicle started injection of fresh water (water source: fire cistern)

March 12 0:06
As D/W pressure might have exceeded 600kPa abs, Station Director directed preparations for PCV venting

10:17
Containment vessel venting commenced
14:30
D/W pressure decreased.
Containment vessel venting successful

March 12 15:36 Explosion Occurred

March 12 19:04 Injection of sea water started

Major Activities at Fukushima Daiichi Unit 1

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting

Prior to earthquake	In rated power operation
March 11, 2011 14:46	Great East Japan Earthquake occurred, **reactor automatically scrammed**
14:47	Due to loss of offsite power, **emergency D/G started up**
14:52	**Isolation condenser (IC) started up**※1

※1: Cooling system for emergencies which cools steam from the reactor and returns it to the reactor.

Plant shutdown (“Shutdown” function operated normally)
DG & IC start-ups (“cooling” function operated normally)

Plant response to the earthquake was normal

Major Activities at Fukushima Daiichi Unit 1

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting

March 11, 2011 15:37 **Station Black Out due to tsunami strike**

(Sea water systems also lost)

Loss of power to the main control room and instruments

Main control room: lighting off, monitoring instrumentation shut down, and operation panels disabled

Building interior: building interior lighting off, no power source for equipments

Building exterior: Debris and other obstacles scattered around due to the tsunami, manhole covers missing, etc.

•Most monitoring and operating functions in the main control room lost

•Tsunami debris dispersed around the unit, work environment deteriorated

•Activities restricted due to frequent aftershocks

Major Activities at Fukushima Daiichi Unit 1

Scram response	March 11, 2011 16:36	Reactor water level could not be maintained and water injection status became unclear. Accordingly, it was determined that **failure of the emergency core cooling system to inject cooling water** had occurred.
Deteriorating operability due to the tsunami	17:12	Site superintendent **directed considering injection of water into reactors using fire protection lines and vehicles**

Coolant injection means predetermined for use in an operation at the time of an accident cannot be used
Use of fire-fighting vehicles also evaluated as a practical operation

Preparations for water injection Preparations for venting	21:19	Reactor water level determined, top of active fuel ＋200mm
	23:00	**Rise in radiation dose** in turbine building
Water injection started Venting		

Rise in dose on site, deteriorating work environment, and frequent aftershocks

Major Activities at Fukushima Daiichi Unit 1

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting

March 12, 2011 0:06 As D/W pressure might have exceeded 600kPa abs, **Site superintended directed preparations for PCV venting**

Pressure in the containment vessel increased and venting operation became unavoidable

Around 1:30 Venting operation proposed by TEPCO, and approved by the government

Preparation for venting

Confirmation of venting procedures

Confirmation of dose rate of the working environment

Confirmation of necessary working time in the building

Assessment of exposure dose to surrounding area during venting, etc.

In addition to the above, impact on residents in surrounding area was considered and the status of evacuation of residents in proximity to the station were checked

Major Activities at Fukushima Daiichi Unit 1
~ Containment Vessel Venting Operation (1) ~

Scram response

Deteriorating operability due to the tsunami

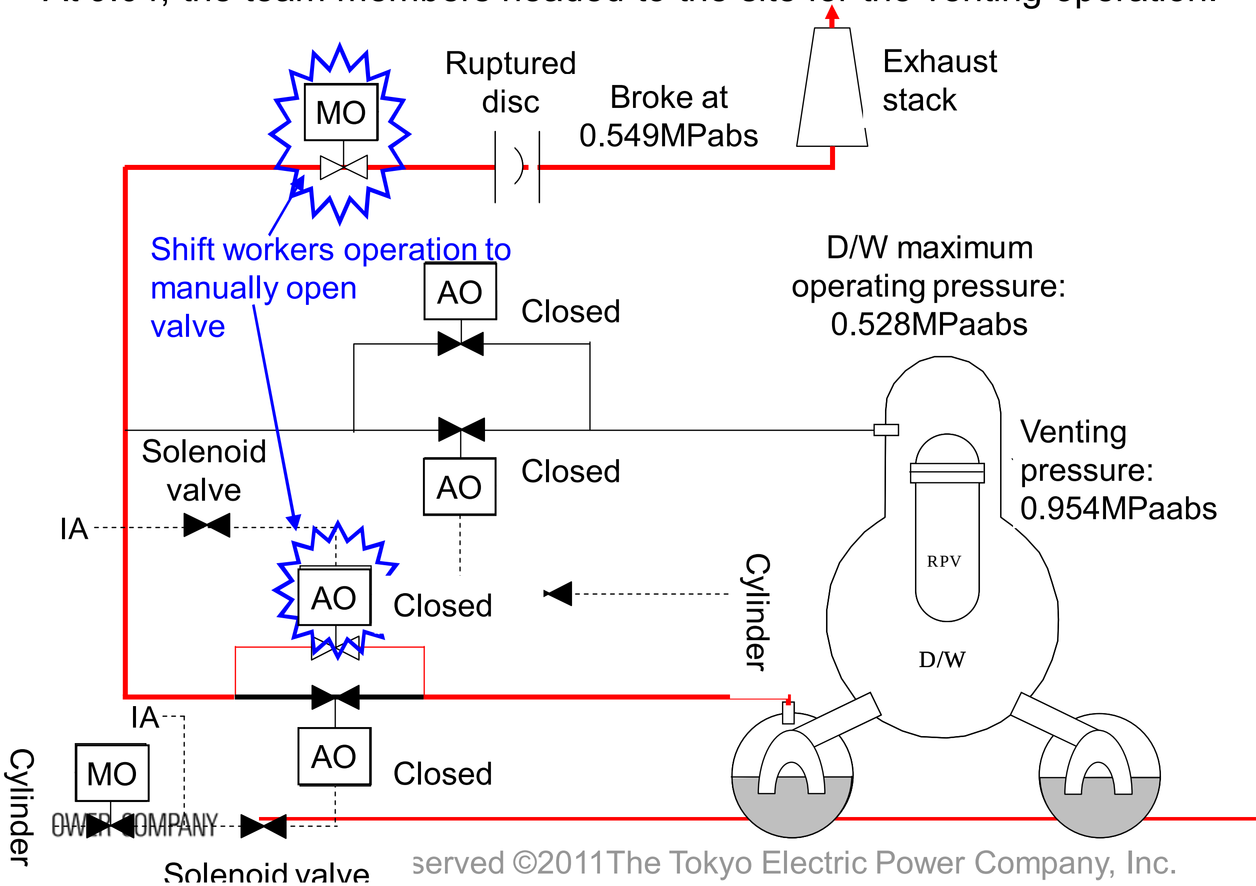
Preparations for water injection

Preparations for venting

Water injection started

Venting

- Two valves, a PCV vent valve (MO valve) and a S/C vent valve (AO valve: small) were selected as the target for manual PCV venting operation .
- Manual valve operation were planned to be conducted by 3 teams with 2 shift workers per team (one worker per team would be difficult due to the total darkness) and shift supervisors and vice-supervisors were selected to the team members.
- Equipment for the teams included fire-resistant clothing, self-contained breathing apparatus, APD, survey meter and flash light.
- At 9:03, it was confirmed that evacuation from the vicinity of south side of the NPS completed. At 9:04, the team members headed to the site for the venting operation.



Self-contained breathing apparatus

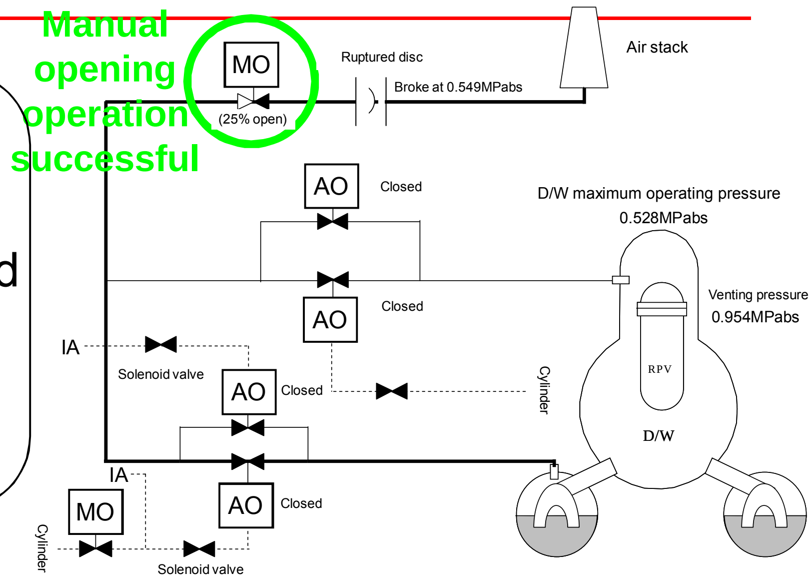
Major Activities at Fukushima Daiichi Unit 1
~ Containment Vessel Venting Operation (2) ~

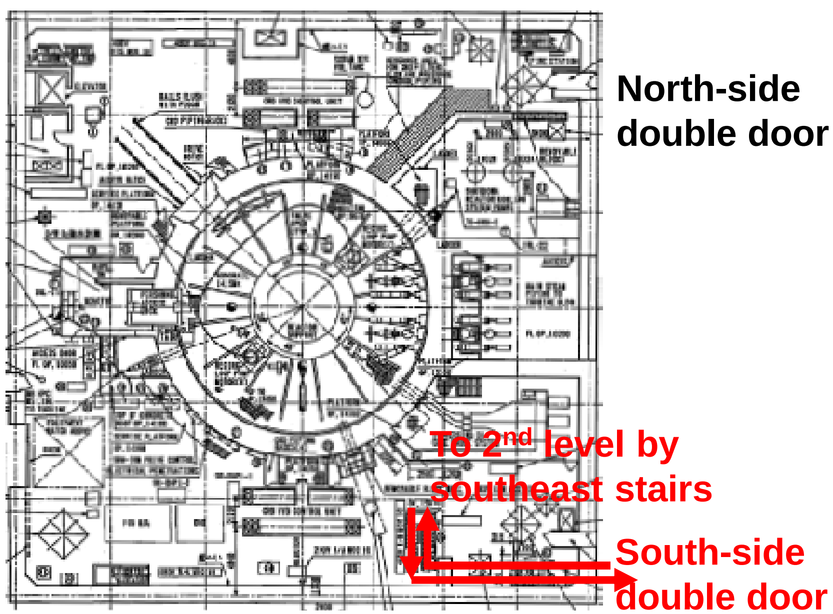
- Scram response
- Deteriorating operability due to the tsunami
- Preparations for water injection
- **Preparations for venting**
- Water injection started
- Venting

Operation to manually open PCV vent valve (MO valve)

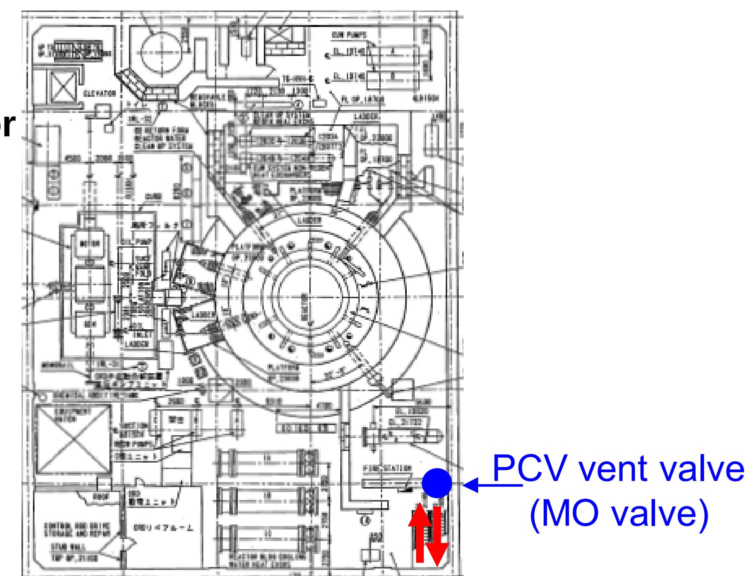
■ 1st team proceeded to site to operate PCV vent valve (MO valve) on the 2nd level of the R/B, and implemented operation to open the valve manually.

➡ **Operation to open PCV vent valve (MO valve) successful**





R/B 1st level



R/B 2nd level

Access route to PCV vent valve (MO valve)

Major Activities at Fukushima Daiichi Unit 1
~ Containment Vessel Venting Operation (3) ~

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

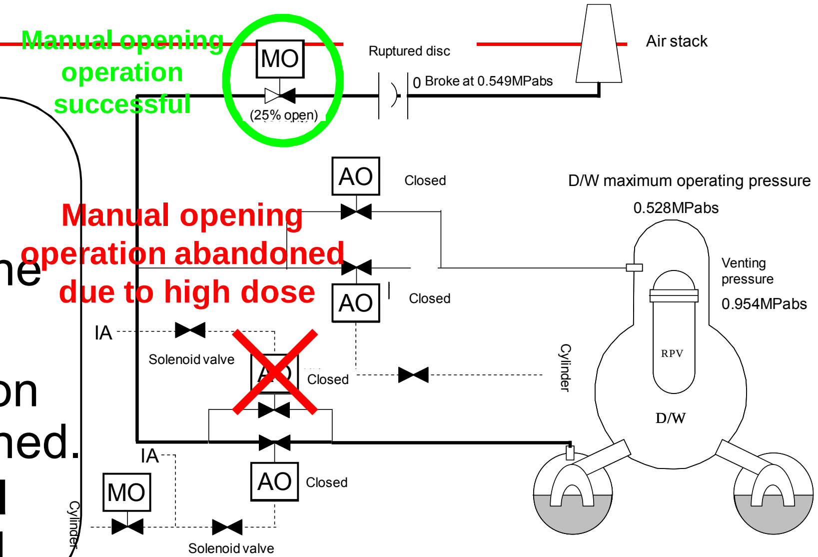
Water injection started

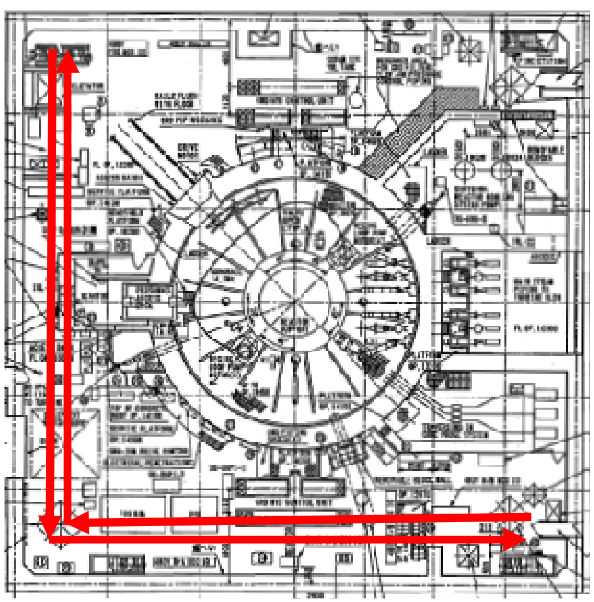
Venting

Operation to manually open S/C vent valve (AO valve) valves

- 2nd team entered the torus room (R/B B1F), but the valve was located at a direction of 180 degrees from where the team entered the torus room.
- The survey meter rose up to the limit on the way, and the team members returned.

➡ **Manual operation was abandoned and another means were selected**

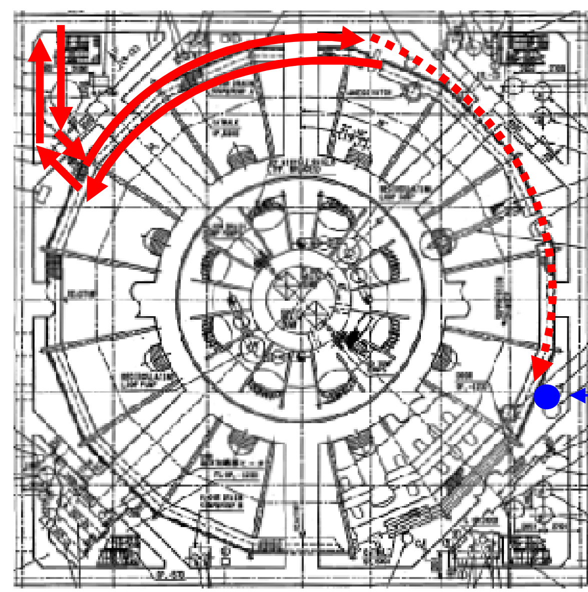




North-side double door

Dose at the north-side double door was high, and south-bound course was selected

South-side double door



S/C vent valve (AO valve)

R/B 1st floor

Access route to S/C vent valve (AO valve)

R/B B1F

Major Activities at Fukushima Daiichi Unit 1

Scram response	March 12	5:46	Fire-fighting vehicle **commenced injection of fresh water (water source: fire cistern)**
Deteriorating operability due to the tsunami		10:17	Containment vessel venting commenced
Preparations for water injection; Preparations for venting		14:30	D/W pressure decreased. **Containment vessel venting succeeded**
Water injection started; Venting			

Without any power source and in a very poor working environment with continuing aftershocks, "venting successful" and "alternative injection of cooling water into reactor commenced"

Major Activities at Fukushima Daiichi Unit 1
~ Fresh Water and Sea Water Injection ~

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting

March 12 14:53 80,000L (total) of **fresh water injection completed**

14:54 Site superintendent **directed sea water injection** into the reactor

[Fresh water injection]

- Fresh water injections were initially conducted using a fire cistern and the water was repeatedly injected through the fire-protection system water outlets.
- Rubbles and debris due to the earthquake and tsunami prevented fire engines from moving back and forth. Therefore a long fire hose was used to form a continuous water injection line between the fire-protection system water outlets and the fire cistern.

Line constructed and fresh water injected

[Sea water injection]

- Prior to the direction by the superintendent, preparations for injecting sea water have been conducted since the amount of fresh water in the fire cistern was limited.
- Judging from the condition of the roads and the distance between Unit 1and the sea, it was decided not to take sea water directly from the sea, but to use a pit in front of the Unit 3 turbine building as the water source, in which sea water was accumulated due to the tsunami,.
- Three fire engines were lined in a series in order to inject sea water into the reactor.

Preparation for injecting sea water undertaken at an early stage

Major Activities at Fukushima Daiichi Unit 1

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting

March 12 **15:36** **Explosion occurred.**
Hoses prepared for injecting sea water were damaged.

- Evacuation from around the reactor building, rescue and transport of injured workers
- Site investigation of the impact of the explosion in order to ensure safety
- Laying out sea-water injection hoses again

19:04 **Injection of sea water started**

Chronology at Fukushima Daiichi Unit 2

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting

Water injection using RCIC

Prior to earthquake		In rated power operation
March 11, 2011	14:46	Great East Japan Earthquake occurred
	14:47	Reactor automatically scrammed, and loss of offsite power supply caused emergency D/G start up
	15:39	RCIC manually started
	15:41	Tsunami caused station black out
	17:12	Site superintendent directed considering cooling water injection using fire protection lines and vehicles
	21:02	Due to uncertainty about the water level and RCIC operating status, the authorities were informed that TAF might be reached
	22:00	Reactor water level confirmed to be TAF+3400mm, so it was judged that it would some take time to reach TAF
March 12	2:55	RCIC was confirmed to be operating
	17:30	Site superintendent directed preparation for venting operation
March13	10:15	Site superintendent directed for venting operation
	11:00	Construction of a venting line was completed except for a ruptured disk
	12:05	Site superintendent directed preparation for sea water injection
March 14	11:01	Due to explosion at Unit 3, vent valves were closed and water injection line became unusable
	19:54	Injection of sea water was commenced using fire-fighting vehicles from the fire-extinguishing system line

Chronology at Fukushima Daiichi Unit 3

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting

Water injection using RCIC/HPCI

Prior to earthquake	In rated power operation
March 11, 2011 14:46	Great East Japan Earthquake occurred
	14:47 Reactor automatically scrammed
Approx. 14:48	Loss of offsite power supply caused emergency D/G to start up
15:38	Tsunami caused station black out
	16:03 RCIC manually started
March 12	11:36 RCIC tripped
	12:35 HPCI automatically started (low reactor water level)
17:30	Site superintendent directed preparation for venting operation
March13 2:42	HPCI tripped
	5:15 Site superintendent directed venting line to be constructed except for a ruptured disk
	8:41 Construction of a venting line was completed except for the ruptured disk
Approx. 9:20	Venting operation confirmed decrease in the D/W pressure
	9:25 Injection of fresh water commenced using fire-fighting vehicles from fire-extinguishing line (~12:00)
	13:12 Injection of sea water commenced using fire-fighting vehicles from fire-extinguishing line
March 14	11:01 Explosion in the reactor building (fire-fighting vehicles and hoses damaged)
Approx. 16:30	Fire-fighting vehicles and hoses were replaced and injection of sea water recommenced