Lessons learned from our accident at Fukushima Nuclear Power Stations

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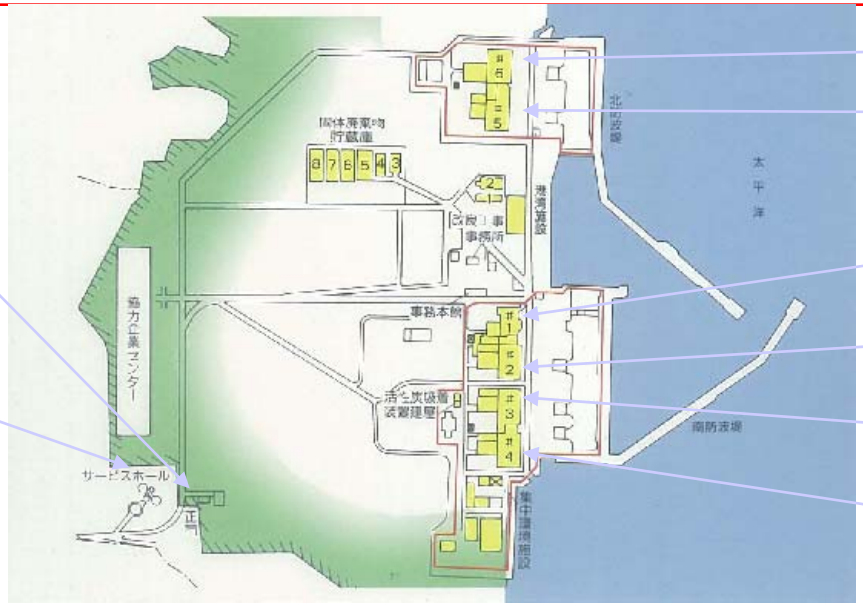
What I will present

1. Overview of TEPCO Nuclear Power Stations
2. Summary of lessons learned
3. Lesson 1: Design Consideration
4. Lesson 2: Procedures and equipments to be prepared
5. Lesson 3: Emergency Preparedness
6. References

1. Overview of Fukushima Daiichi（1F）NPS

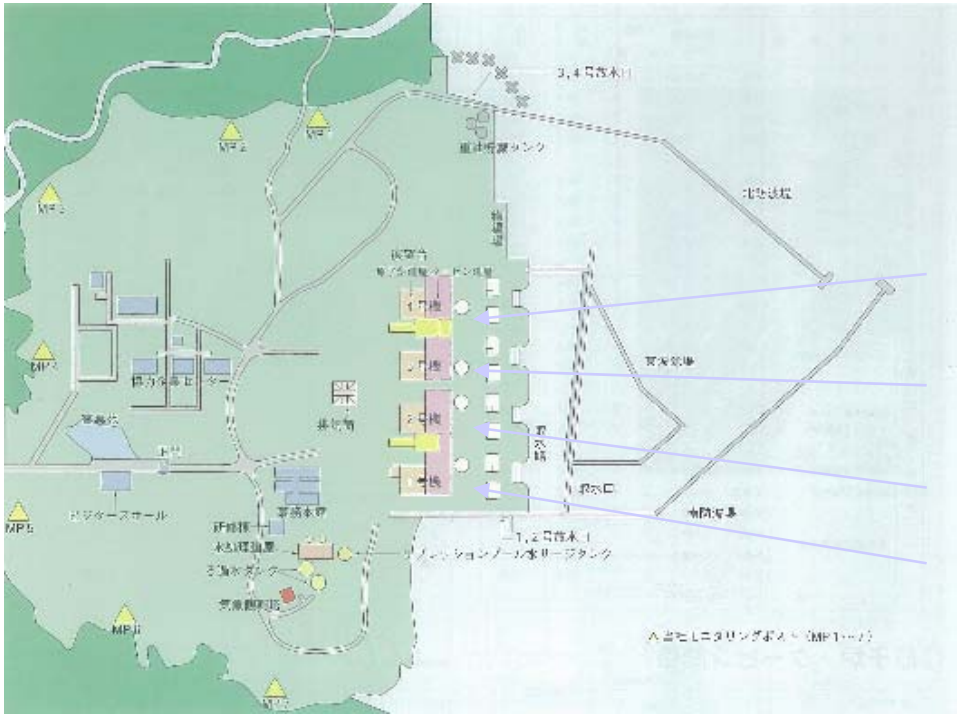
Main gate

Visitor's house



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

1. 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

2. Summary of Lessons Learned

If we express the lessons learned from our accident in one sentence:

"Carefully consider the robustness of current design of nuclear power plants and emergency preparedness against **beyond design basis events** that could lead to **common cause failures** regardless of their assumed probability demonstrating a continuous **learning organization**."

3. Lesson 1: Design Consideration

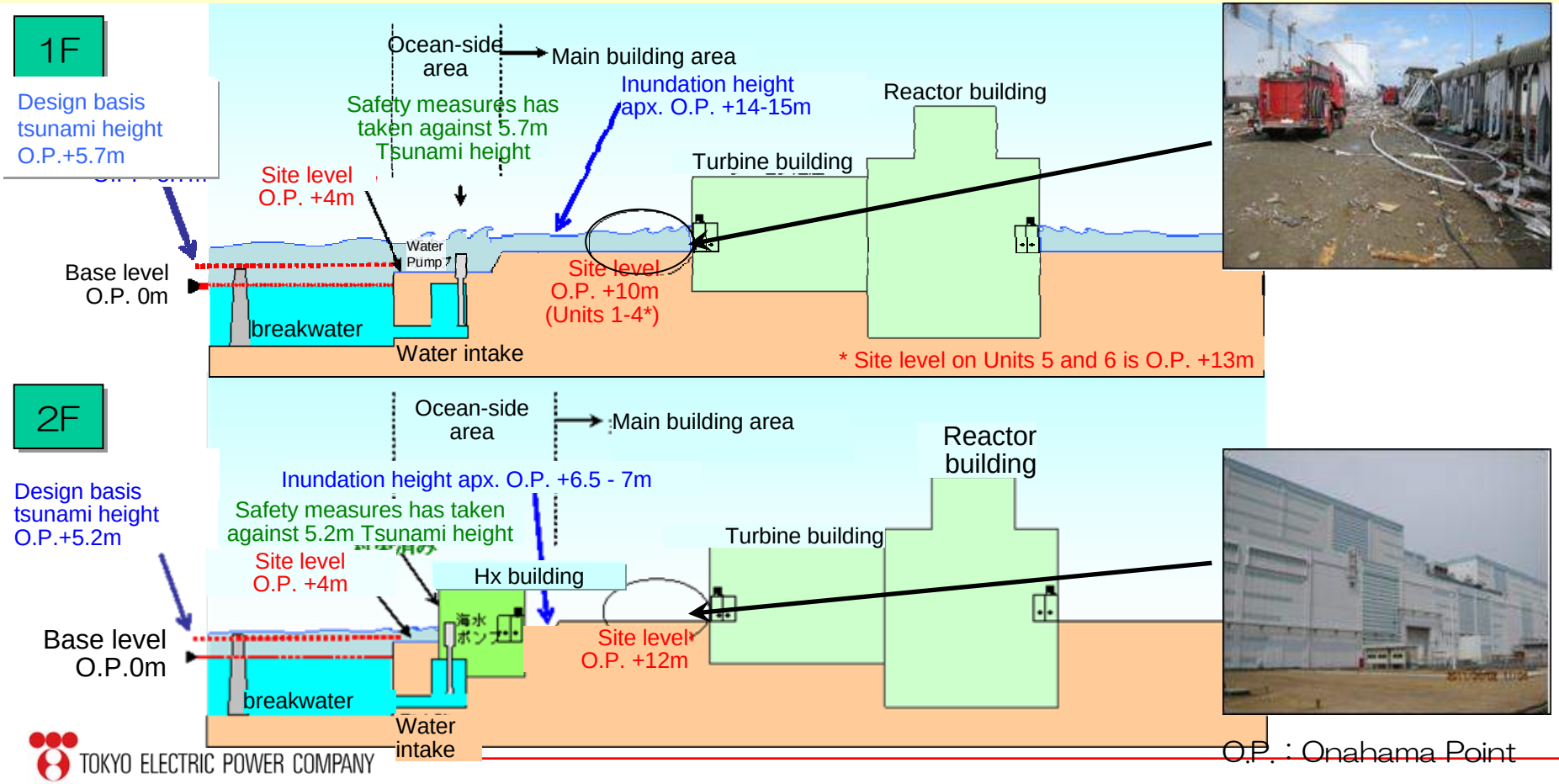
The accident at Fukushima Daiichi and Daini was caused by Tsunami far beyond the design basis. (No significant damage by earthquake)

- **The current design of external barriers might not be robust 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.**

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 (original:+3.1m), 2 F: O.P.+5.2m (original:3.1m))
- 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 struck 1F was far beyond design basis and whatever evaluation and whatever countermeasures did not matter at this time.



O.P. : Onahama Point

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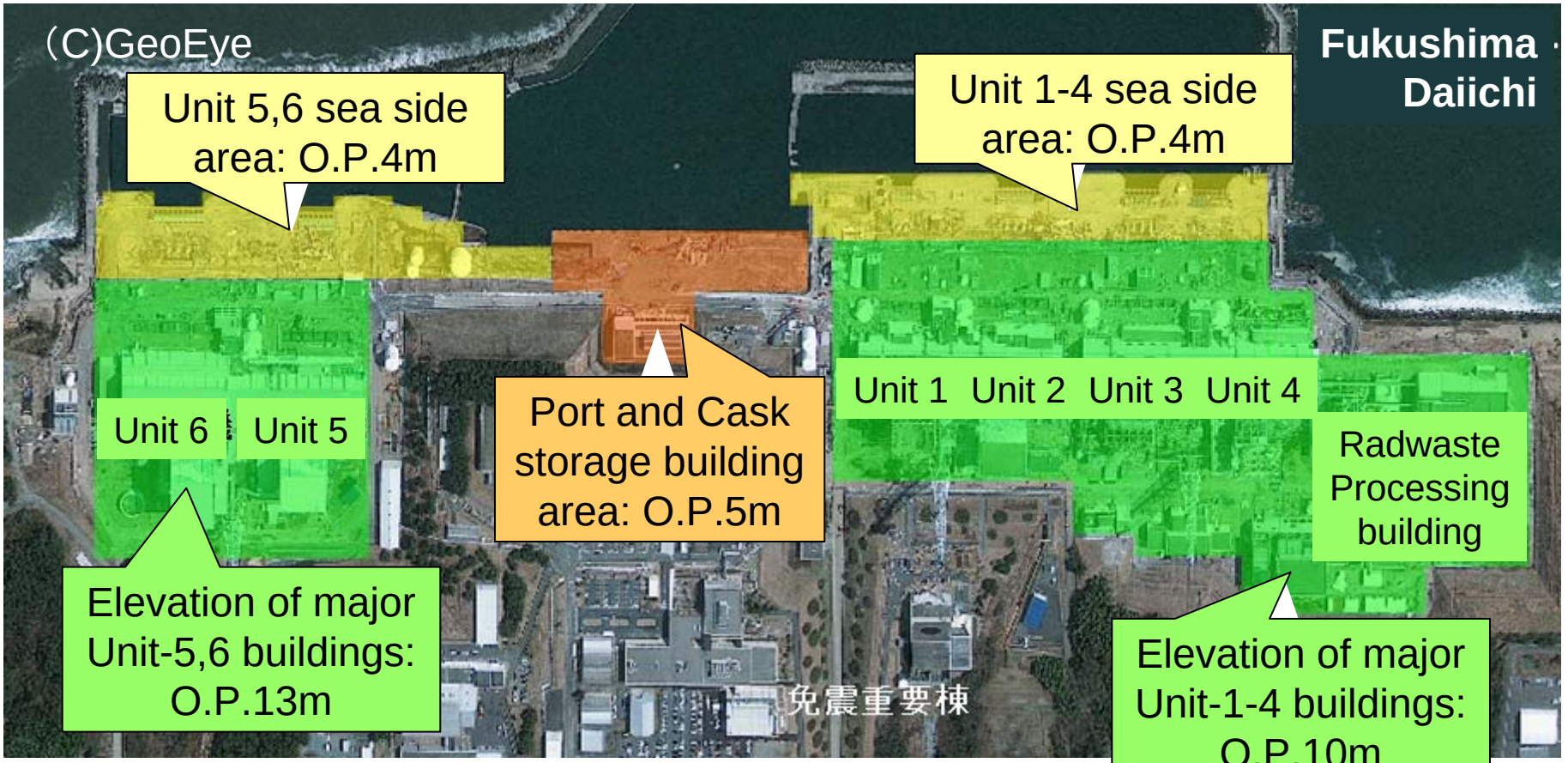
Elevation of the Fukushima Daiich NPS

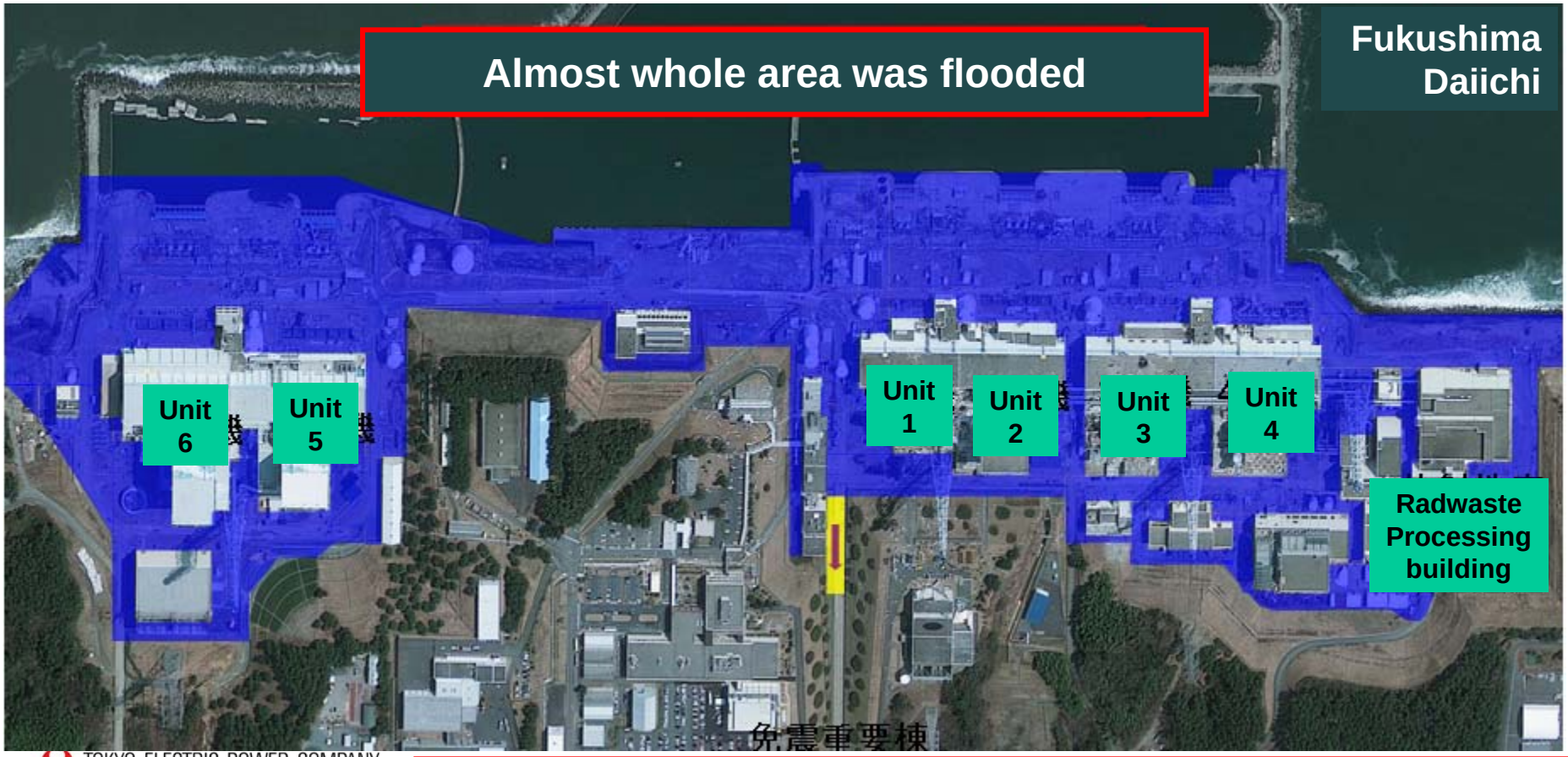


O.P.: Onahama Pile

Design-basis Tsunami height	Elevation of major buildings
5.7m	Unit 1-4：10m
	Unit 5,6：13m

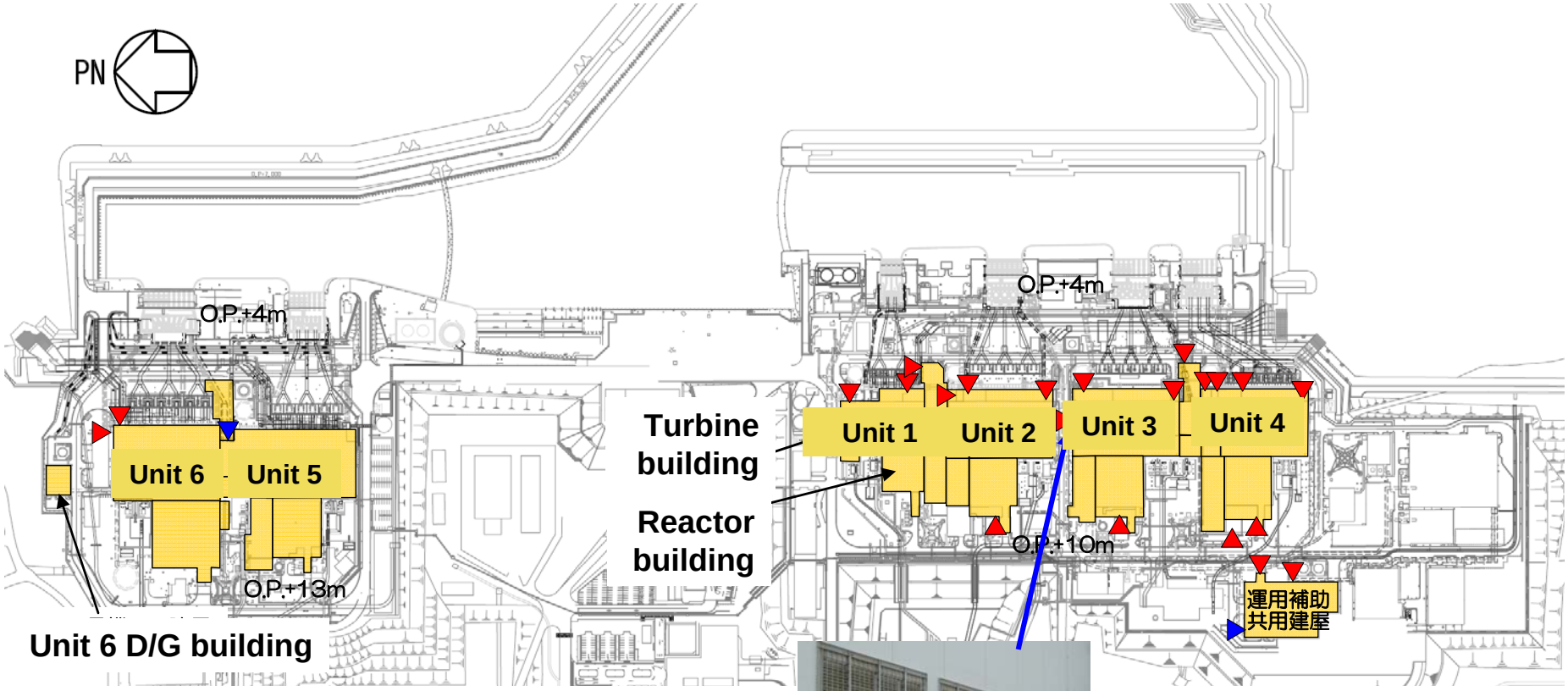
Inundated Areas at Fukushima Daiichi Nuclear Power Station

- Inundation throughout almost all areas where main buildings sited
  - ✓Units 1~4: Inundation height in areas where principal buildings sited: OP approx. 11.5m~15.5m
    (Localized inundation height in southwest area: OP approx. 16m~17m)
  - ✓Unit 5 & 6: Inundation height in areas where principal buildings sited: OP approx. 13m~14.5m



Location of Openings from which Sea Water could Flow into Main Buildings

(Fukushima Daiichi Nuclear Power Station)

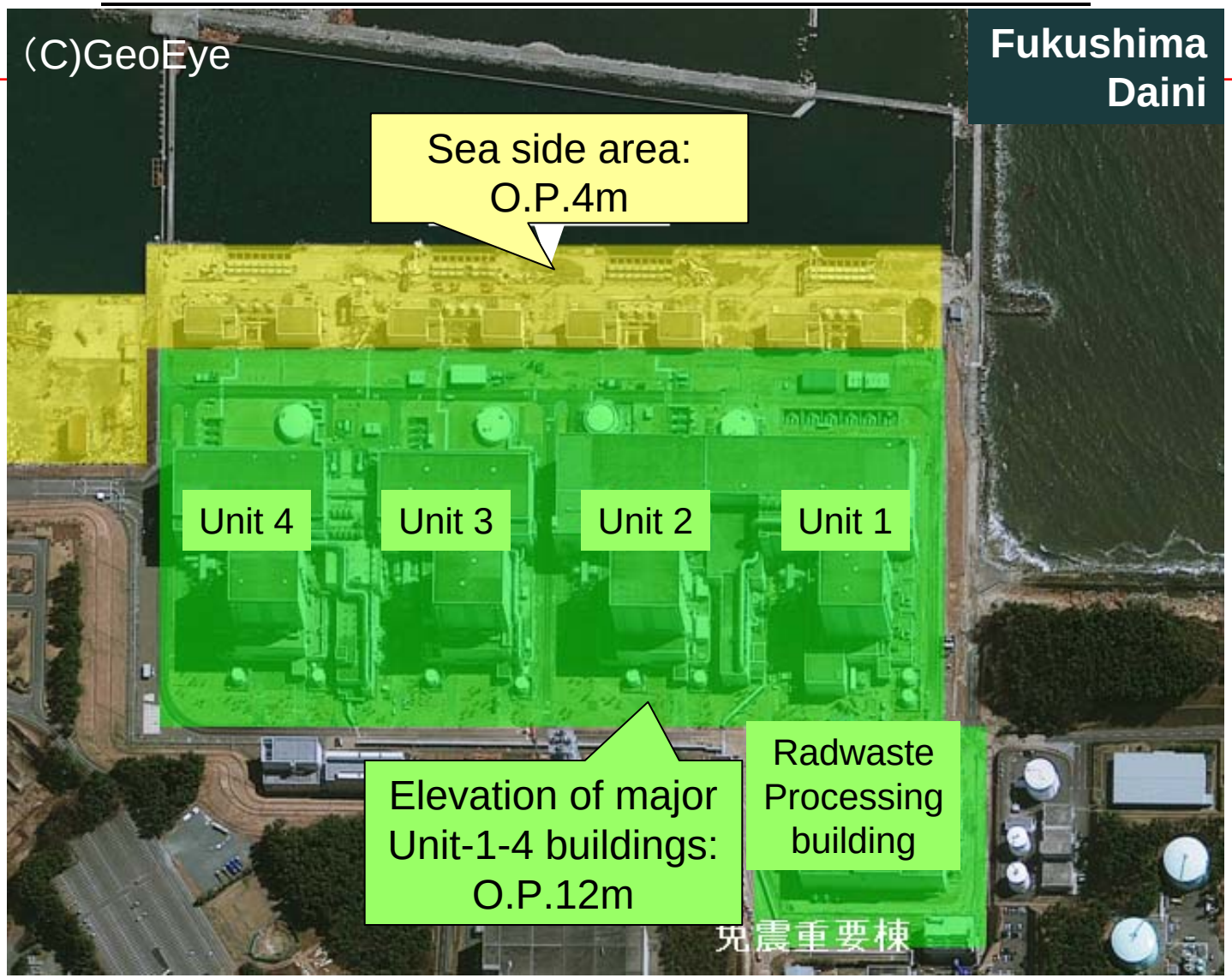


▼ : Openings at the ground level from which sea water could flow into buildings

▼ : Openings connected to underground trenches/ducts where sea water could flow into buildings

3u Emergency D/G air inlet louver

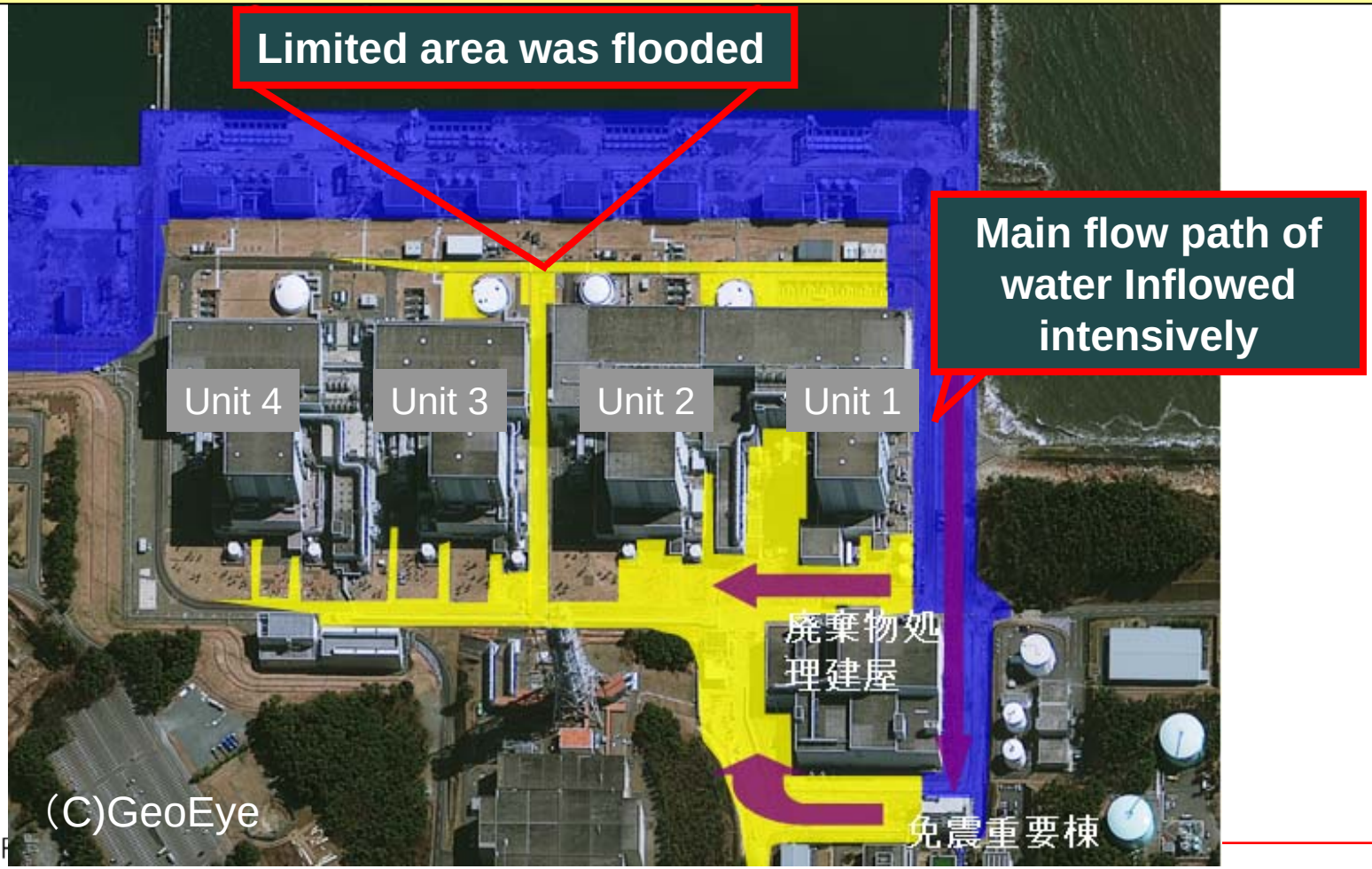
Elevation of the Fukushima Daini NPS



Design-basis Tsunami height	Elevation of major buildings
5.2m	12m

Inundated Areas at Fukushima Daini Nuclear Power

- Inundation occurred throughout all areas along the sea, but it was not observed to have inundated over the slope and into areas where major buildings are sited.
- Run up of tsunami centered on the south side of Unit 1
  - ✓Inundation height in sea side area: OP approx. +7.0~7.5m
  - ✓Inundation height in areas where principal buildings sited: OP approx. 12~14.5m
  - ✓Inundation height in area south of Unit 1: OP approx. + 15~16m



Location of Openings from which Sea Water could flow into Main Buildings

(Fukushima Daini Nuclear Power Station)

Units 3 & 4
Sea side of turbine building

Inside Unit 1 heat exchanger building

▼ : Openings at the ground level from which sea water could flow into buildings
▼ : Openings connected to underground trenches/ducts where sea water could flow into buildings

Differences in Tsunami that hit Fukushima Daiichi and Daini NPSs

Fukushima Daiichi

Fukushima Daini

Tsunami of various magnitudes at a depth of around 150m were amplified at the same rate and struck at each nuclear power station

Maximum tsunami height [m]

14
12
10
8
6
4
2
0

Peaks coinciding
↓
Tsunami height: High

Same amplification rate

10
50
100
150

Water depth [m]

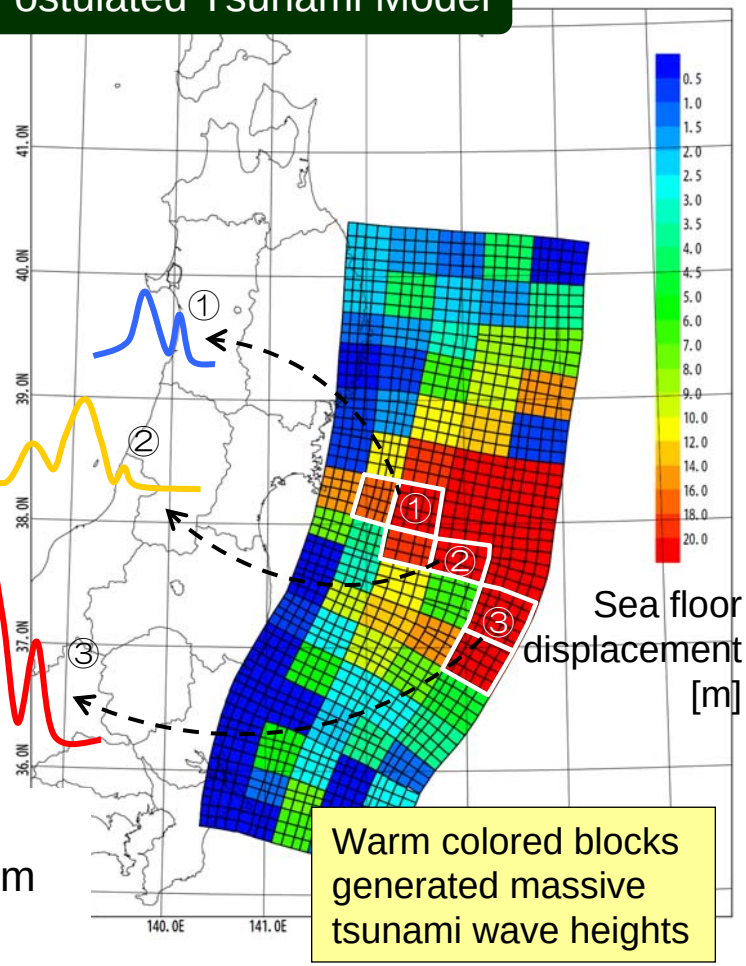
Peaks not coinciding
↓
Tsunami height: Low

①＋②＋③

Time T

Water level fluctuation from each block

Postulated Tsunami Model



Sea floor displacement [m]

Warm colored blocks generated massive tsunami wave heights

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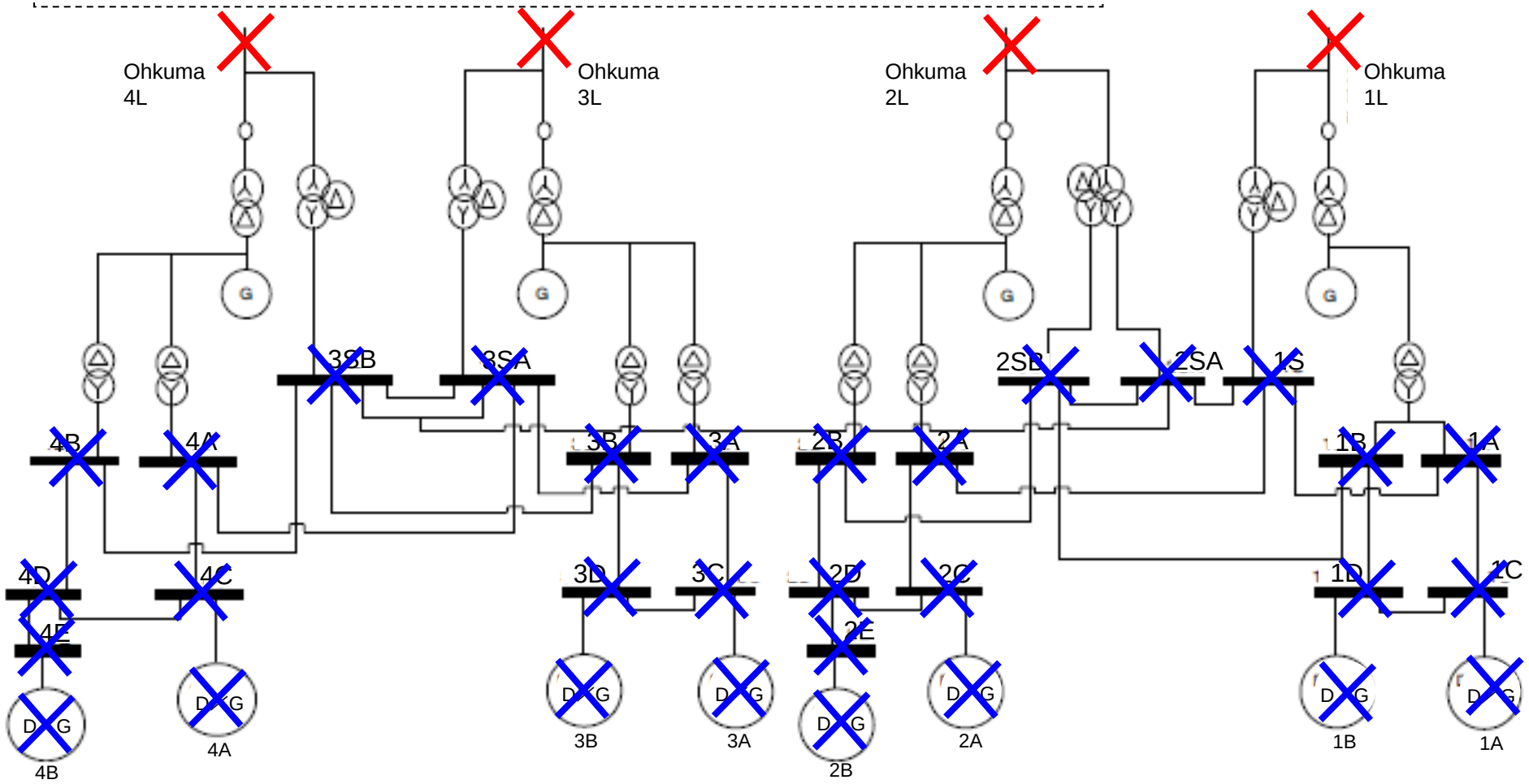
Power supply of Unit 1-4 @ 1F after Tsunami

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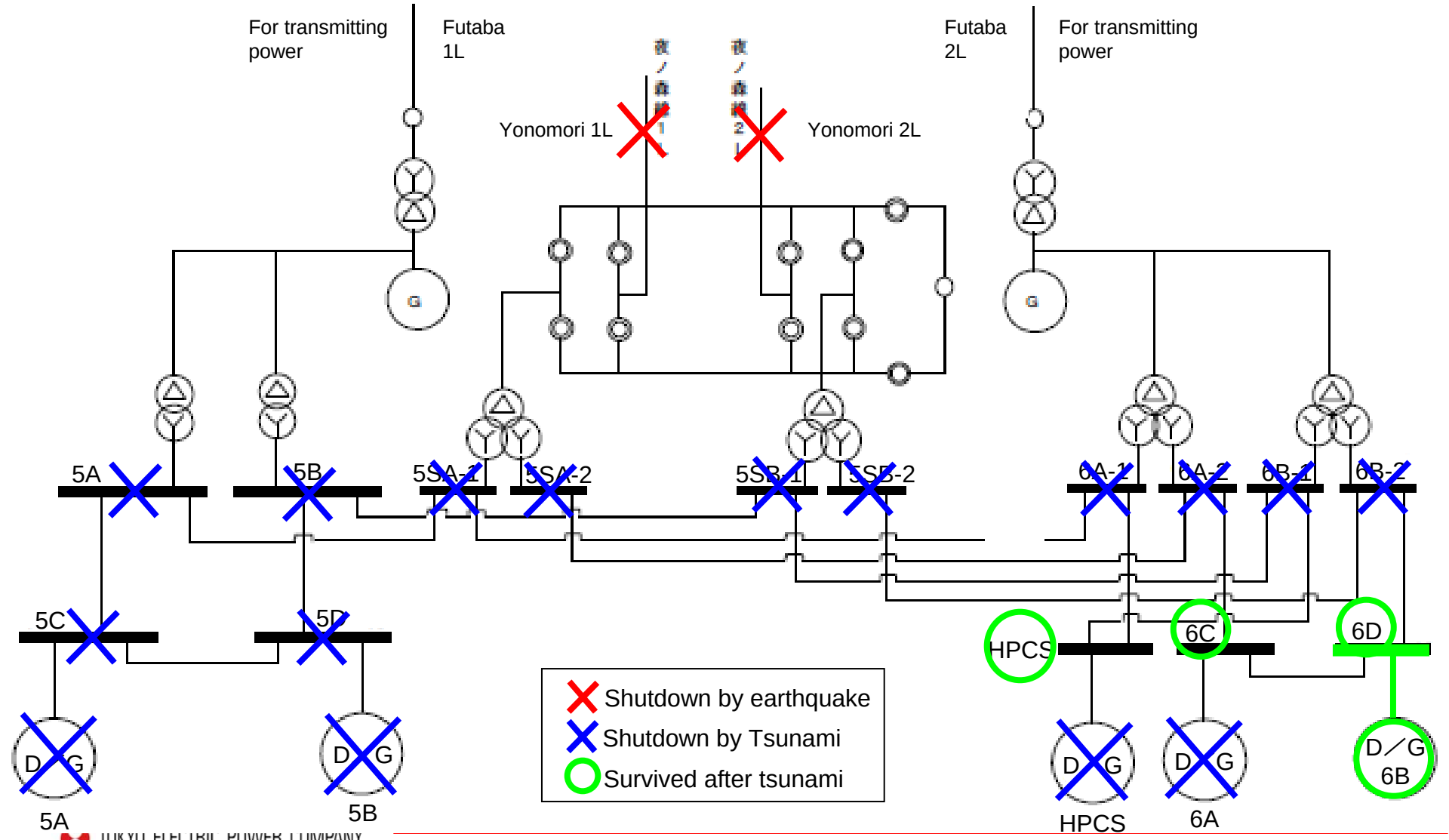
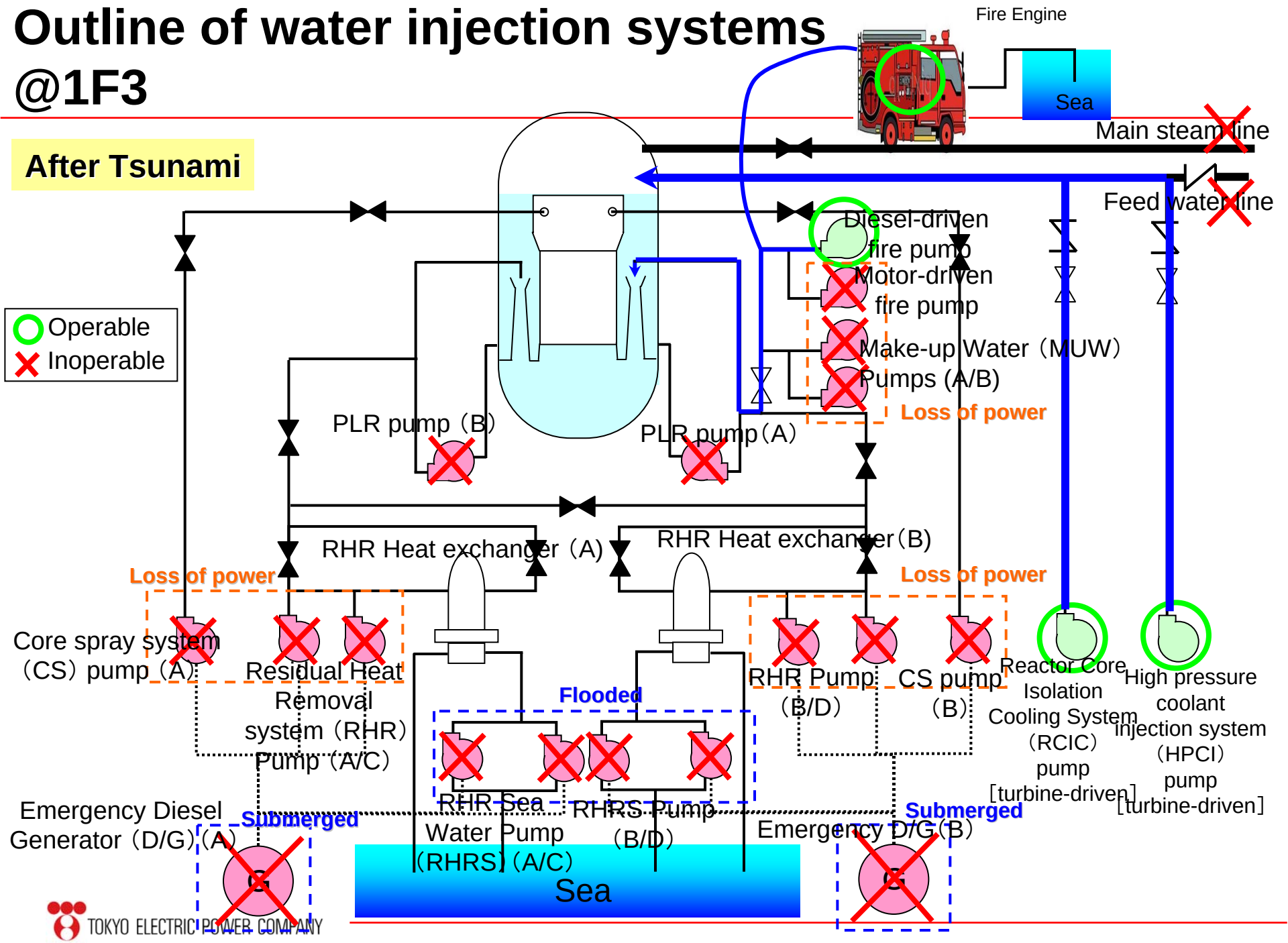
Power supply of Unit 5/6 @ 1F after Tsunami



Outline of water injection systems @1F3

After Tsunami



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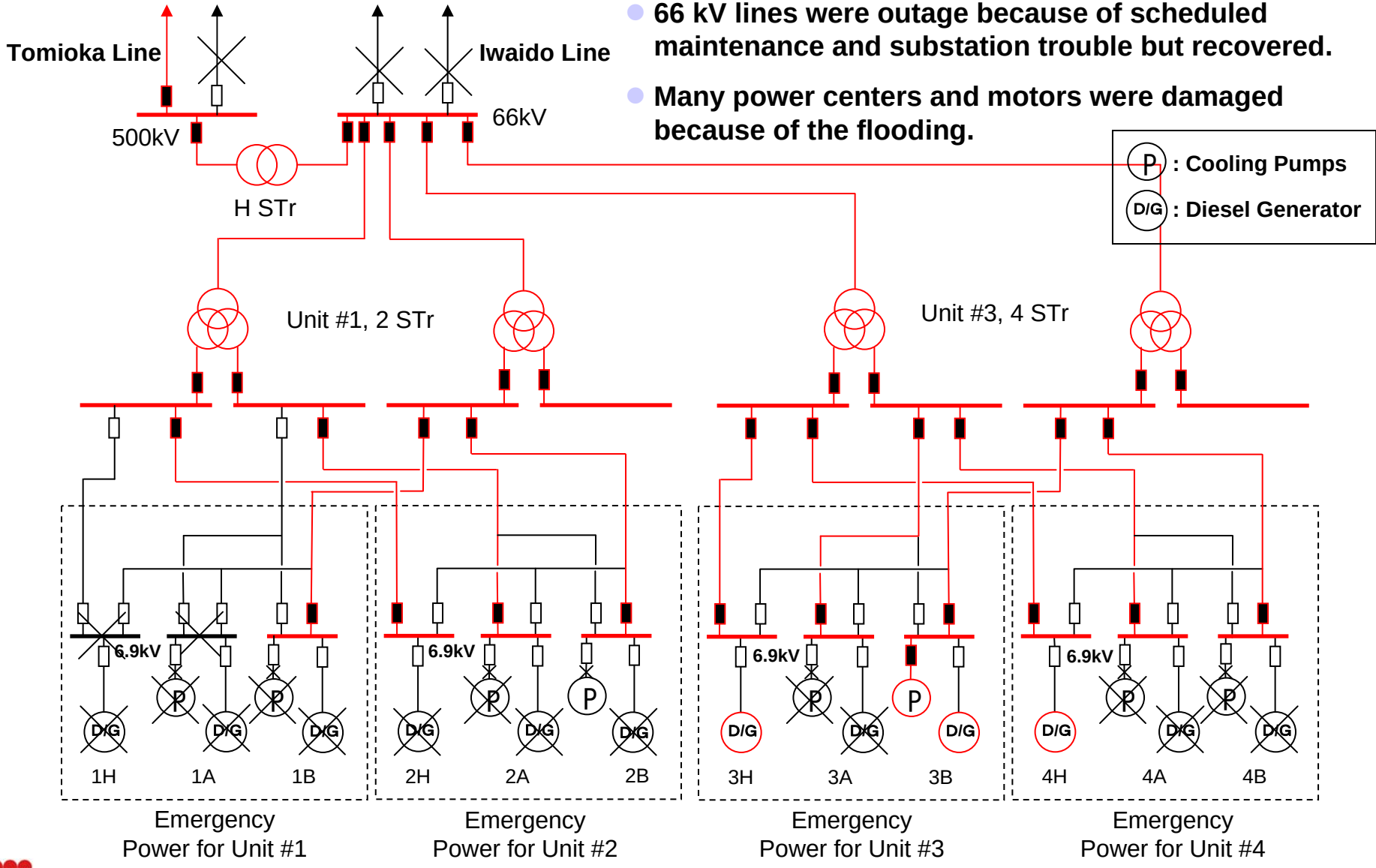
2F Offsite Power was secured after the Tsunami

Offsite Power

- **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.**



What made the difference between 1F and 2F

	Tsunami hgt. [m]	Off site Power	D/G		M/C Location	Battery Location
			Location	Status		
1F-1	14 - 15	All Lost	T/B B1F O.P.1900	Damaged by flooding	T/B 1F	T/B B1F
1F-2			T/B B1F O.P.1900	Damaged by flooding	T/B 1F	T/B B1F
			SP/B 1F※ O.P.10200	Out of function due to M/C submerged	SP/B B1F	
1F-3			T/B B1F O.P.1900	Damaged by flooding	T/B B1F	T/B MB1F
1F-4			T/B B1F O.P.1900	Damaged by flooding	T/B B1F	T/B B1F
			SP/B 1F※ O.P.10200	Out of function due to M/C submerged	SP/B B1F	
1F-5			T/B B1F O.P.1900	Out of function due to loss of cooling pump	T/B B1F	T/B MB1F
1F-6			R/B B1F O.P.1000	Out of function due to loss of cooling pump	R/B B1,B2F,1F	T/B MB1F
			DG/B 1F ※ O.P.13200	**Survived**		
2F-1	6.5 – 7	**Survived**: One power line & Step down Transformer	R/B B2F O.P.0000	Damaged by flooding	(A),(H):R/B B1F	(H):R/B B2F
					(B): R/B B1F	(A),(B):C/B 1F
2F-2	Tsunami Ran up more than 14m at the south side of Unit1		R/B B2F O.P.0000	Out of function due to loss of cooling pump	R/B B1F	R/B B2F,C/B 1F
2F-3			R/B B2F O.P.0000	(A): Out of function due to loss of cooling pump	R/B B1F	R/B B2F,C/B 1F
				(B),(H): **Survived**		
2F-4			R/B B2F O.P.0000	(A)(B): Out of function due to loss of cooling pump	R/B B1F	R/B B2F,C/B 1F
				(H): **Survived**		

※: Air cooled Diesel Generator, SP/B: Shared Pool building, DG/B: Independent DG building

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3. Lesson 1: Design Consideration

● **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.**

★Other design features to be considered:

- Hydrogen detonation/deflagration outside of PCV
- Operability of venting system
- Internal barriers for separation of important equipments, such as RCIC, DDFP, MUWC, FPC, M/C, P/C, battery etc.
- Accident instrumentation

4. Lesson 2: Procedures and equipments to be prepared

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, air cylinders and batteries, 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.**

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

Major Activities at Fukushima Daiichi Unit 1
～Factors disturbing the recovery work (inside the building)～

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting

Activities were done in complete darkness due to lack of power sources.

Work in complete darkness
In the service building. Many scattered objects were also on the floor.

Temporary power supply
Connect temporary batteries to recover instruments.

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Major Activities at Fukushima Daiichi Unit 1
～Factors disturbing the recovery work (inside the buildings) ～

Scram response

Deteriorating operability due to the tsunami

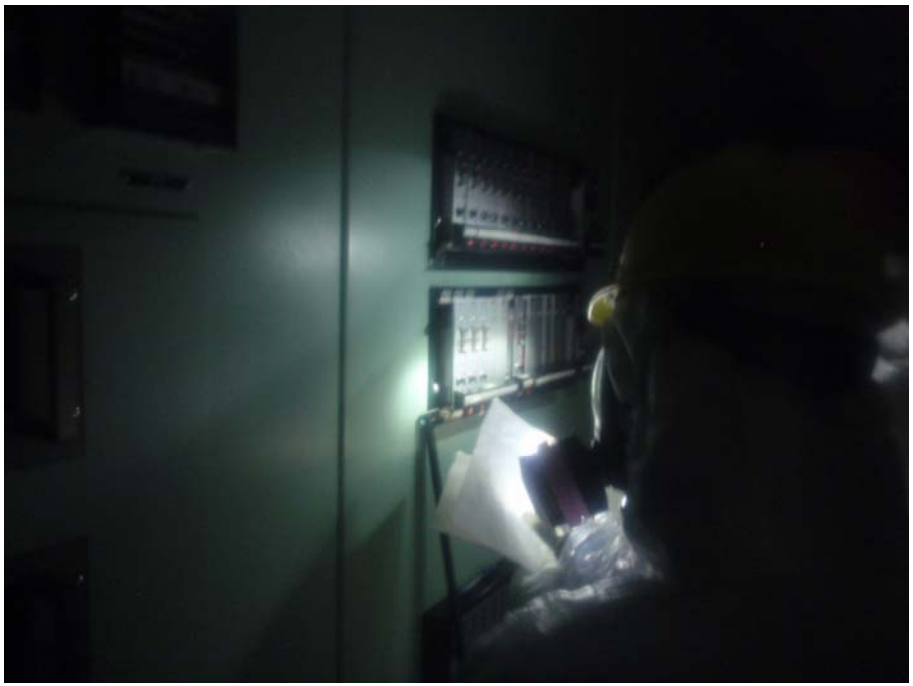
Preparations for water injection

Preparations for venting

Water injection started

Venting

Instruments were monitored wearing a full face mask with a flashlight in complete darkness



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

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Major Activities at Fukushima Daiichi Unit 1
～Factors disturbing the recovery work (outside the buildings)～

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting

- Many obstacles on access routes disturbed the access.
- Most of the prepared communication tools between the TSC and the control room were unavailable.

Obstacles on access routes

Debris caused difficulties moving equipment such as fire hoses but after the explosions additional rubble and damaged fire engines made it more difficult.

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

- 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 be 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.

Scram response

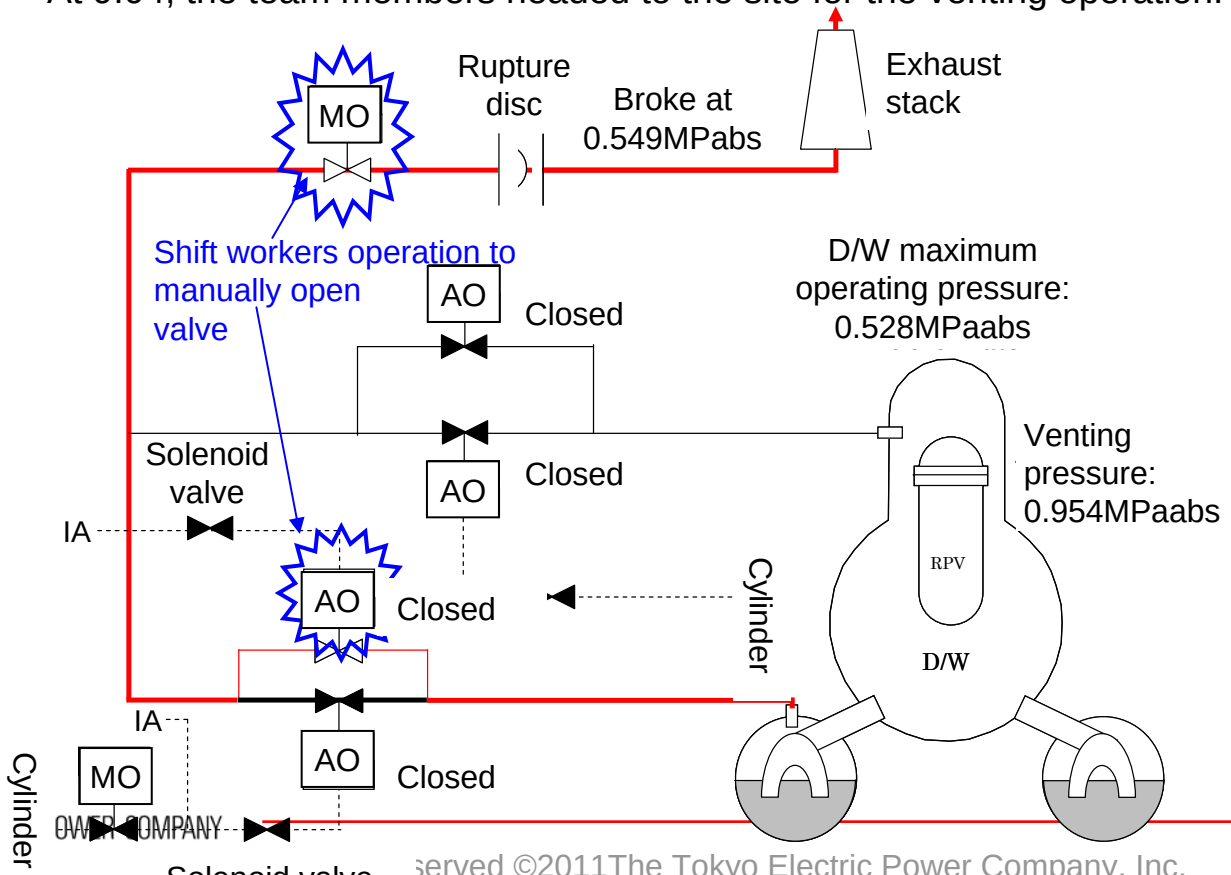
Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting



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

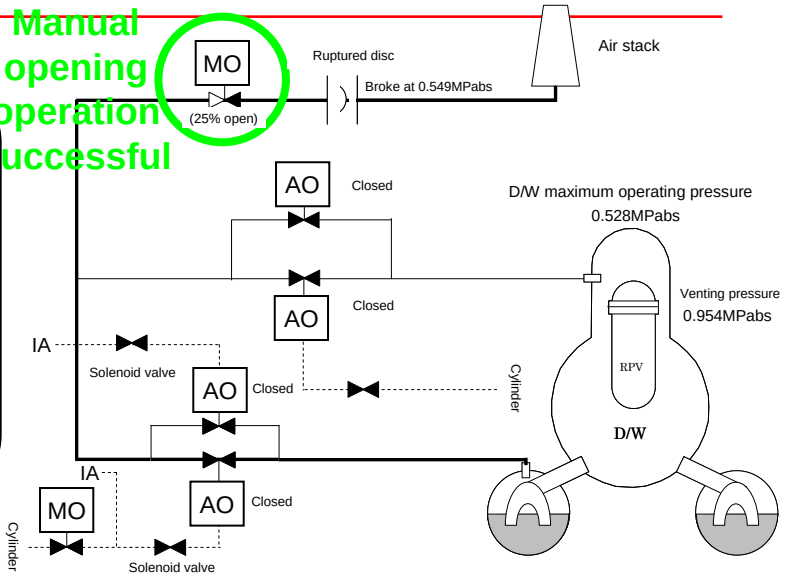
Water injection started

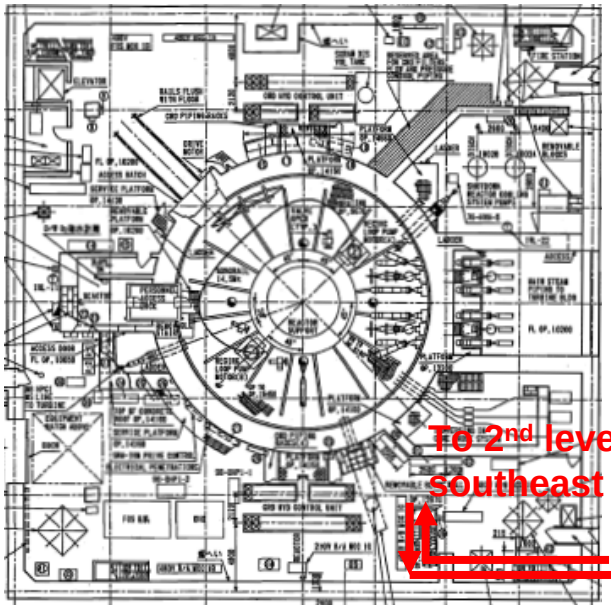
Venting

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



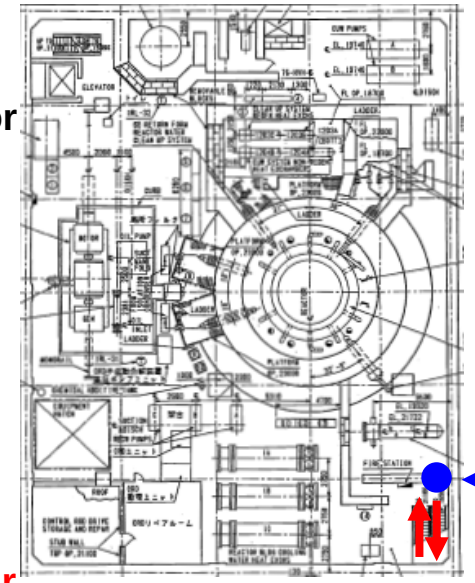


North-side double door

To 2nd level by southeast stairs

South-side double door

R/B 1st level



PCV vent valve (MO valve)

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

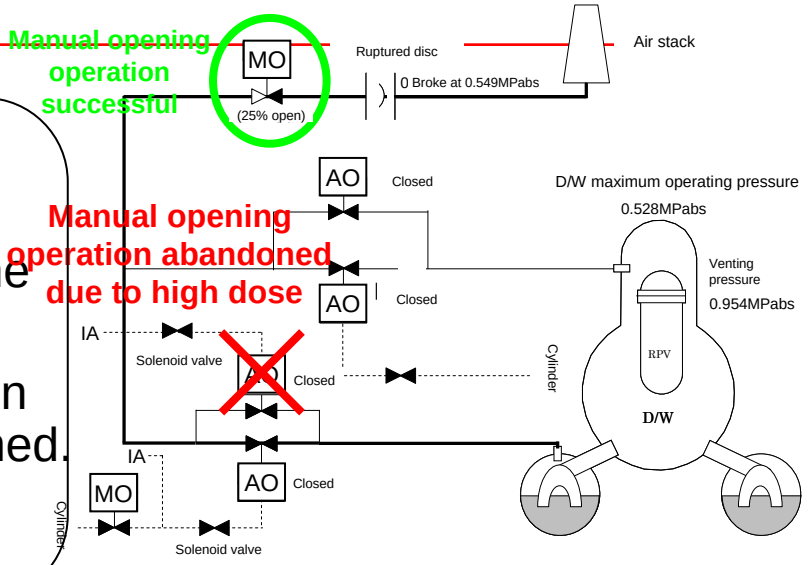
Water injection started

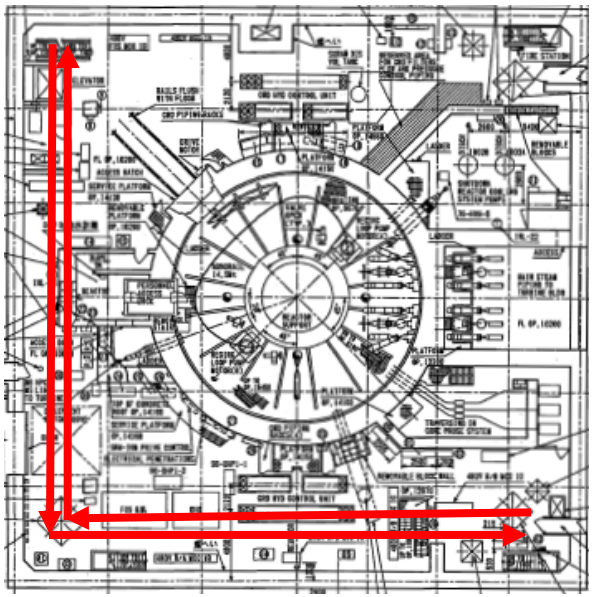
Venting

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 was selected**

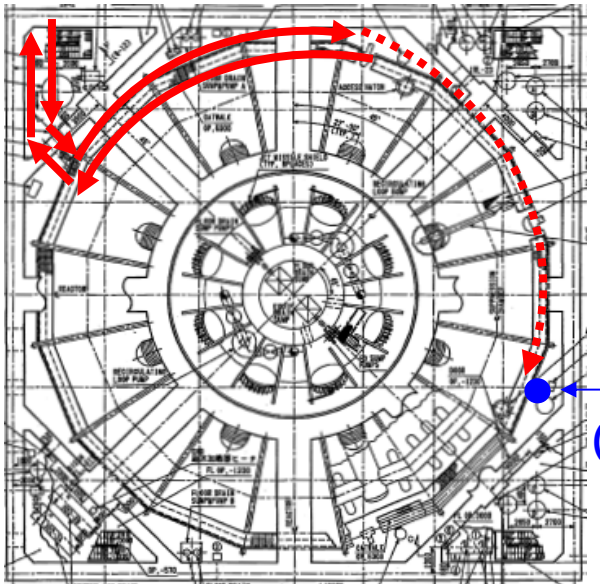




North-side double door

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

South-side double door



R/B 1st floor

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

R/B B1F

Temporary Power Supply and Motor Replacement @2F

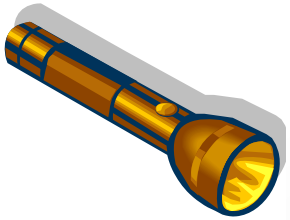
About 9 km of temporary cables were laid and motors were replaced.

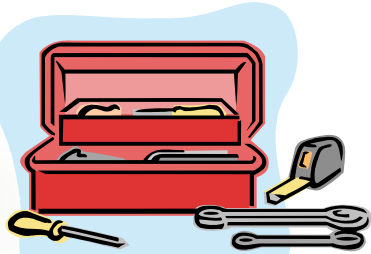
What were available for the recovery work after the tsunami?

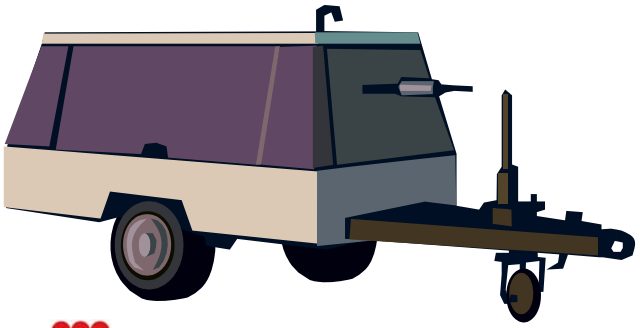
There were only the following limited number of devices and tools available !

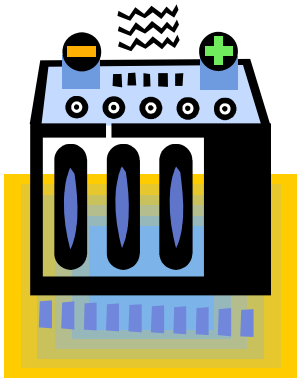
- Fire Engines: only a few people knew how to operate them.
- Flashlights
- Cable
- Tools (screwdrivers, etc.)
- Batteries taken from cars
- Engine driven Generators*
- Engine driven Air Compressors*

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









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4. Lesson 2: Procedures and equipments to be prepared

- **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, air cylinders and batteries, 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.**

★Procedures not robust enough against beyond design basis events:

- EOP - SAMG - EDMG (not thoroughly prepared yet in Japan)
- internal events - external events

5. Lesson 3: Emergency Preparedness

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**

Effective Measures taken after Niigata Chuetsu Oki Earthquake

Measure taken after Chuetsu Offshore Earthquake	Description of measure	Status of application in the Fukushima accident
Construction of a seismic-isolation building 	Installation of facilities which are seismically isolated structures having an emergency response room, communication equipment (dedicated lines to concerned institutions both inside and outside the company), power source equipment (gas turbine generators), radiation control devices (radiation measuring devices, whole-body counters, etc.)	At Fukushima Daiichi, responses during the accident have been able to be properly undertaken without loss of communication equipment or lighting in the emergency response room
Deployment of fire engines 	Deployment of chemical fire engines and fire tankers	Fire engines were effectively used in order to transport cooling water and also as fresh / sea water injection pumps
Installation of additional fire cisterns 	Installation of additional fire cisterns for backup when fireplugs cannot be used	Tanks were utilized as a source o f injecting water when injecting fresh water into Fukushima Daiichi Unit 1

6. References

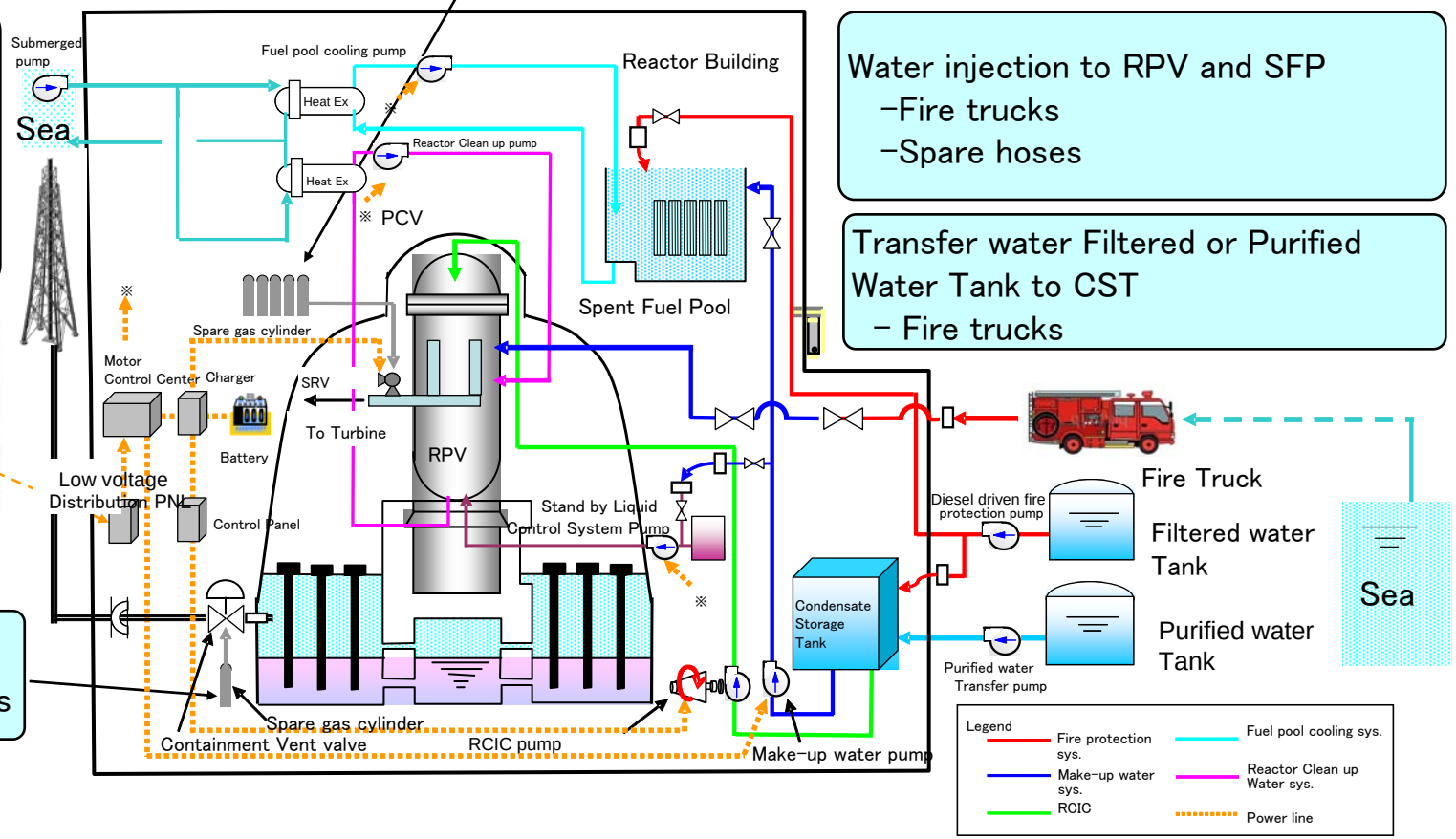
Measures to ensure Safe Shutdown @KK

Spare pump for sea water pump
- Submerged pumps
- Spare hoses

To Depressurize RPV
-Spare gas cylinders

Emergency Power Supply Capability under Tsunami SBO
- High voltage power trucks
- Portable generators
- spare cables

Mobile power trucks



To Depressurize PCV
- Spare gas cylinders

Water injection to RPV and SFP
-Fire trucks
-Spare hoses

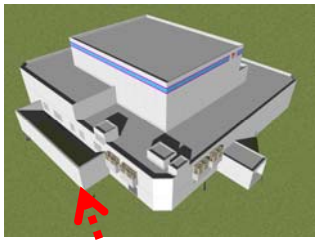
Transfer water Filtered or Purified Water Tank to CST
- Fire trucks

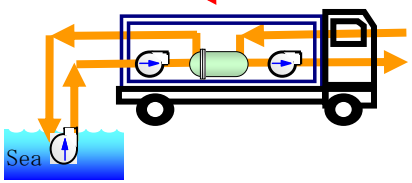
Further enhancement of plant reliability @KK

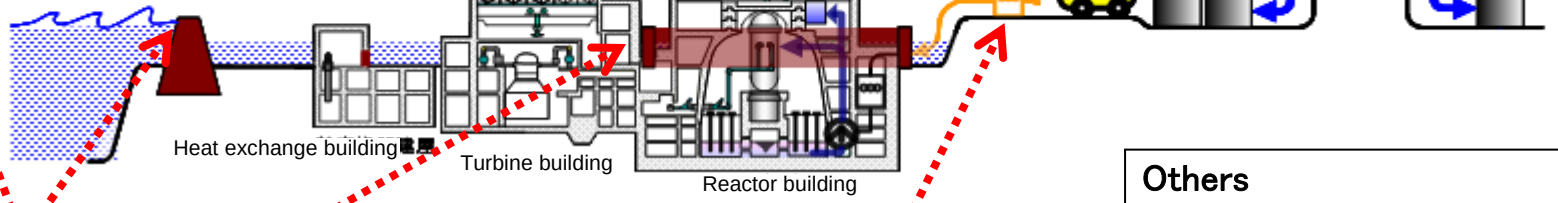
Enforcement of injection and heat removal
- Submerged pump
- Heat exchanger truck
- Spare hose

Prevention of accumulating Hydrogen
(1)Top vent on Reactor Building

Enforcement of injection and heat removal
(2)Reservoir in site.







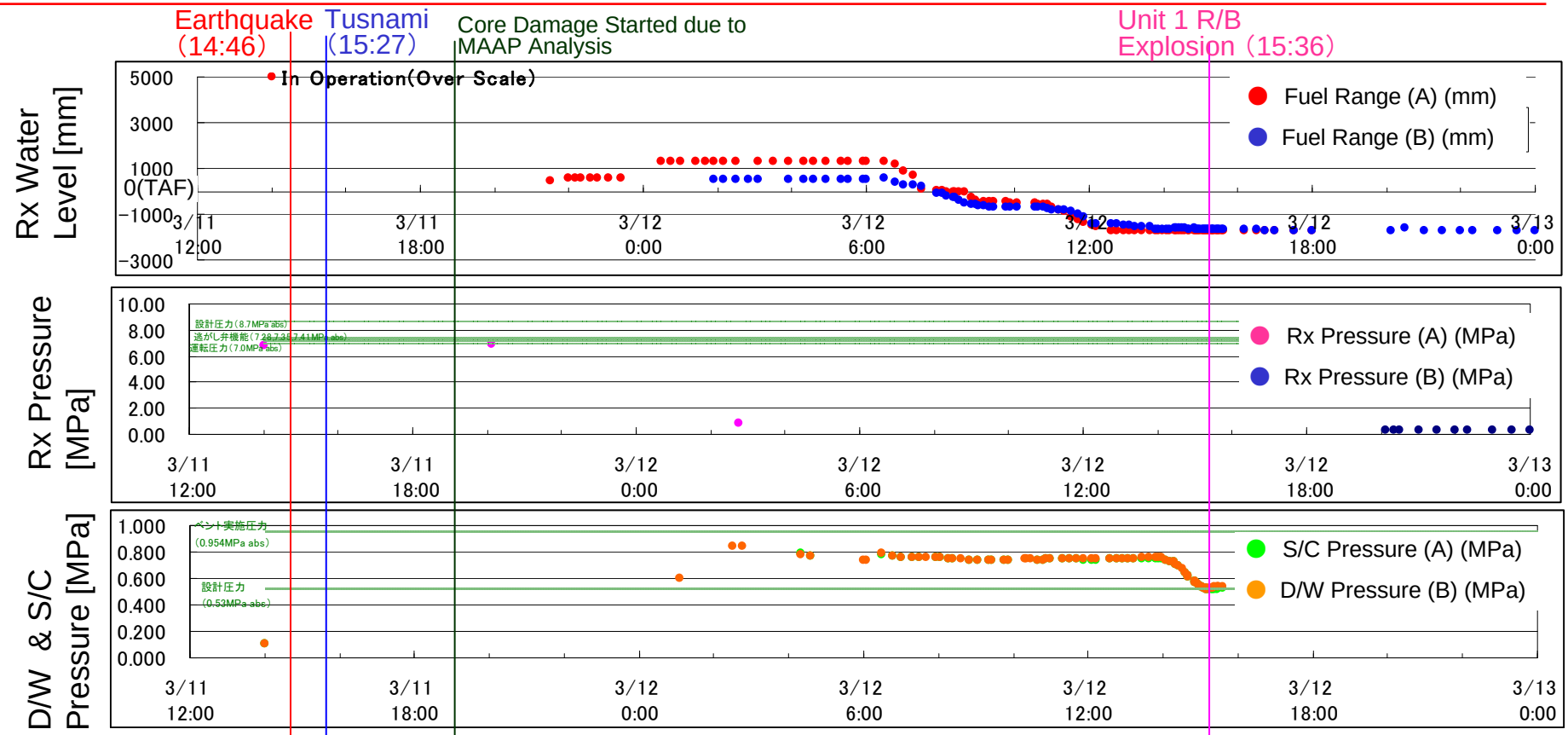
Enforcement of protection for flooding
(1)Embankment
(2)Wall
(3)Water tight doors in Reactor Building

Enforcement of power source
(1)GT driven generator truck
(2)Emergency high voltage distribution panel
(3)Cable from emergency high voltage panel for RHR

Others
(1)Additional monitoring cars

(2)Additional warehouse for emergency materials on the hill

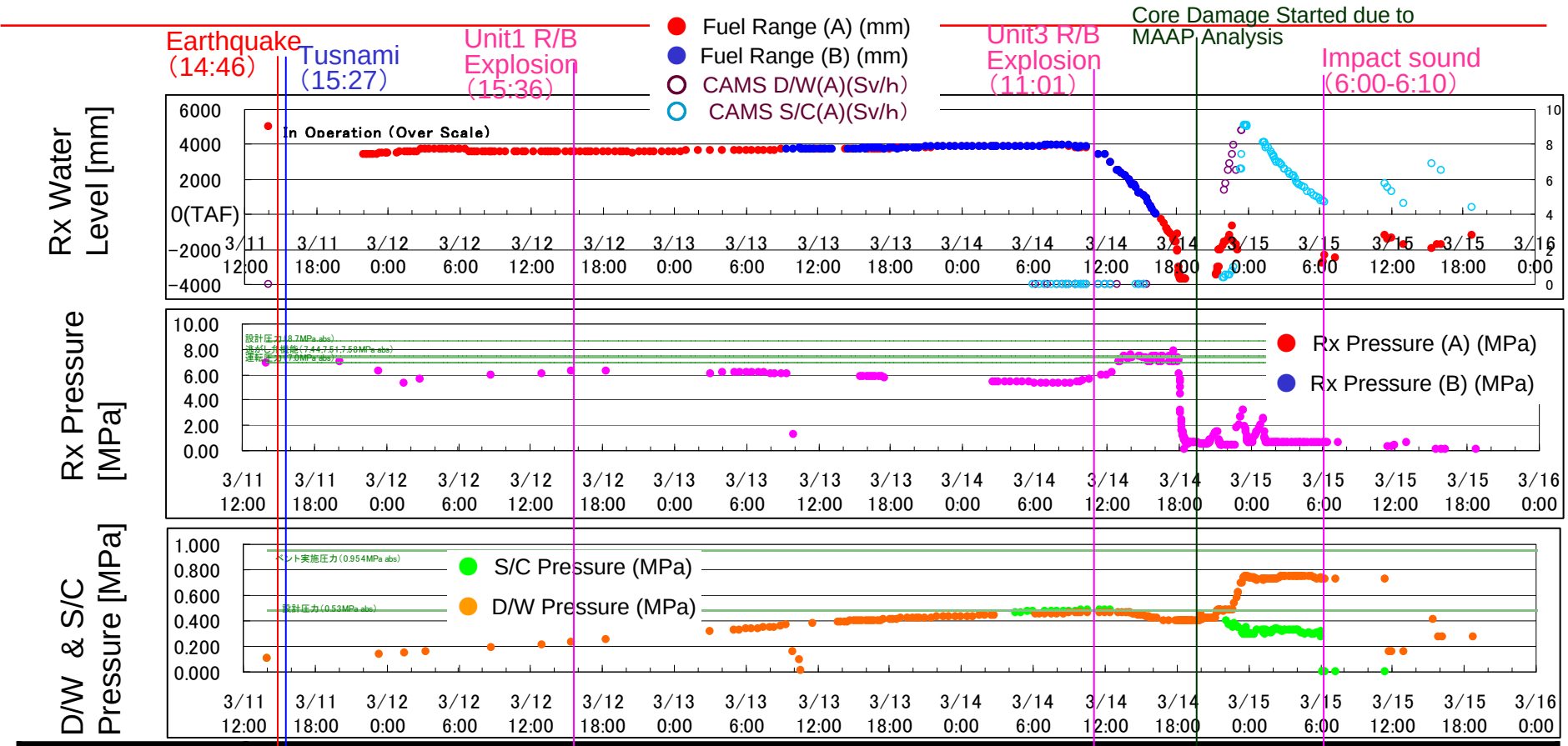
Fukushima Daiichi Unit 1 Plant Parameter and Operation



IC	(14:52) (18:18 - 25) (21:30) Operation Unclear	
HPCI	No Operation	
SRV	No Operation	
FP/Fire Engine		(5:46) Fresh Water [80t] (14:53) (19:04) Sea Water
PCV Vent	Order for Vent Preparation (0:06) ▼	Order for Vent ▼ (8:03) (14:30) D/W Pr decrease confirmed

TOKYO ELECTRIC POWER COMPANY

Fukushima Daiichi Unit 2 Plant Parameter and Operation



RCIC	▼(2:55) Operation confirmed (13:25)Out of Service Judged
HPCI	No Operation
SRV	Depressurization (~18:00) Valve Condition Unclear 2Valves Open
FP/Fire Engine	Order for Sea Water Injection Preparation (12:05)▼ (19:54) Sea Water
PCV Vent	Order for Vent Preparation ▼ (17:30) ▼(11:00) Vent Line Configuration Completed Small Vent Valves Opened

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Fukushima Daiichi Unit 3 Plant Parameter and Operation