The Facts in the Recovery Process of Fukushima Nuclear Accident

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@IAEA IEM, Vienna
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Tokyo Electric Power Company
What I will present

1. How the Earthquake and the Tsunami affected the Power Supply at 1F and 2F sites?

2. How the Accident Developed and was Stabilized at 1F and 2F Sites?

3. How We Responded to the Accident at 1F and 2F Sites?

4. Summary

5. Reference
1. How the Earthquake and the Tsunami Affected the Power Supply at 1F and 2F Sites?
# Overview of Fukushima Daiichi NPS (1F) and Fukushima Daini NPS (2F)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Unit</th>
<th>In Operation Since</th>
<th>Plant Type</th>
<th>Power Output (MWe)</th>
<th>Main Contractor</th>
<th>Pre-earthquake Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1F</td>
<td>1</td>
<td>1971.3</td>
<td>BWR-3</td>
<td>460</td>
<td>GE</td>
<td>Operating</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1974.7</td>
<td>BWR-4</td>
<td>784</td>
<td>GE/Toshiba</td>
<td>Operating</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1976.3</td>
<td>BWR-4</td>
<td>784</td>
<td>Toshiba</td>
<td>Operating</td>
</tr>
</tbody>
</table>
|       | 4    | 1978.10            | BWR-4      | 784                | Hitachi         | Shutdown for maintenance  
 Full core offloaded to spent fuel pool |
|       | 5    | 1978.4             | BWR-4      | 784                | Toshiba         | Shutdown for maintenance |
|       | 6    | 1979.10            | BWR-5      | 1100               | GE/Toshiba     | Shutdown for maintenance |
| 2F    | 1    | 1982.4             | BWR-5      | 1100               | Toshiba         | Operating             |
|       | 2    | 1984.2             | BWR-5      | 1100               | Hitachi         | Operating             |
|       | 3    | 1985.6             | BWR-5      | 1100               | Toshiba         | Operating             |
|       | 4    | 1987.8             | BWR-5      | 1100               | Toshiba         | Operating             |
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

The DG lost the function due to either “M/C failure,” “loss of sea water system,” or “DG main unit failure.”
Power supply of Unit 5/6 @ 1F after Tsunami

- **Shutdown by earthquake**
- **Shutdown by Tsunami**
- **Survived after tsunami**
Damages of transmission line & Shinfukushima substation by earthquake

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

- Tomioka Line: 500kV
- Iwaido Line: 66kV
- Unit #1, 2 StR
- Unit #3, 4 StR

Emergency Power for Unit #1

Emergency Power for Unit #2

Emergency Power for Unit #3

Emergency Power for Unit #4

\[ \text{P}: \text{Cooling Pumps} \]
\[ \text{D/G}: \text{Diesel Generator} \]
### Integrity of Power Supply System After the Tsunami at 1F and 2F

**1F: No off-site power available**

<table>
<thead>
<tr>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
<th>Unit 5</th>
<th>Unit 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power panel</td>
<td>Power panel</td>
<td>Power panel</td>
<td>Power panel</td>
<td>Power panel</td>
<td>Power panel</td>
</tr>
<tr>
<td>DG 1A</td>
<td>×</td>
<td>DG 2A</td>
<td>×</td>
<td>DG 3A</td>
<td>×</td>
</tr>
<tr>
<td>DG 1B</td>
<td>×</td>
<td>DG 2B</td>
<td>(air-cooled)</td>
<td>×(*1)</td>
<td>DG 3B</td>
</tr>
<tr>
<td>M/C 1B</td>
<td>×</td>
<td>M/C 2B</td>
<td>×</td>
<td>M/C 3B</td>
<td>×</td>
</tr>
<tr>
<td>M/C 1A</td>
<td>×</td>
<td>M/C 2A</td>
<td>×</td>
<td>M/C 3A</td>
<td>×</td>
</tr>
<tr>
<td>P/C 1A</td>
<td>×</td>
<td>P/C 2A</td>
<td>×</td>
<td>P/C 3A</td>
<td>×</td>
</tr>
<tr>
<td>P/C 1B</td>
<td>×</td>
<td>P/C 2B</td>
<td>×</td>
<td>P/C 3B</td>
<td>×</td>
</tr>
<tr>
<td>P/C 1S</td>
<td>×</td>
<td>P/C 2S</td>
<td>×</td>
<td>P/C 3S</td>
<td>×</td>
</tr>
<tr>
<td>P/C 1SB</td>
<td>×</td>
<td>P/C 2SB</td>
<td>×</td>
<td>P/C 3SB</td>
<td>×</td>
</tr>
</tbody>
</table>

**2F: Off-site power survived**

<table>
<thead>
<tr>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power panel</td>
<td>Power panel</td>
<td>Power panel</td>
<td>Power panel</td>
</tr>
<tr>
<td>DG 1A</td>
<td>×</td>
<td>DG 2A</td>
<td>×(*2)</td>
</tr>
<tr>
<td>DG 1B</td>
<td>×</td>
<td>DG 2B</td>
<td>×(*2)</td>
</tr>
<tr>
<td>M/C 1B</td>
<td>×</td>
<td>M/C 2B</td>
<td>×(*2)</td>
</tr>
<tr>
<td>M/C 1A</td>
<td>×</td>
<td>M/C 2A</td>
<td>×</td>
</tr>
<tr>
<td>P/C 1A</td>
<td>×</td>
<td>P/C 2A</td>
<td>×</td>
</tr>
<tr>
<td>P/C 1B</td>
<td>×</td>
<td>P/C 2B</td>
<td>×</td>
</tr>
<tr>
<td>P/C 1S</td>
<td>×</td>
<td>P/C 2S</td>
<td>×</td>
</tr>
<tr>
<td>P/C 1SB</td>
<td>×</td>
<td>P/C 2SB</td>
<td>×</td>
</tr>
</tbody>
</table>

**Emergency use of 6.9kV/MC**

**Regular use of 480V/PC**

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**Sea Water System**

*1: functionality lost due to inundation of power panels  
*2: functionality lost due to the damage of seawater system
2. How the accident developed and was stabilized at 1F & 2F Sites?
### Progress made by each plant towards cold shutdown (outline)

<table>
<thead>
<tr>
<th>Fukushima Daiichi Units 1 - 4</th>
<th>Fukushima Daiichi Units 5 &amp; 6</th>
<th>Fukushima Daini Units 1 - 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Units 1-3 in operation</strong></td>
<td><strong>Outage in progress</strong></td>
<td><strong>In operation</strong></td>
</tr>
<tr>
<td><strong>Unit 4: outage in progress</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[Power supply] Total loss of off-site power supply and DG</td>
<td>[Power supply] Emergency DG 6B start up</td>
<td>[Power supply] One off-site power supply system secured</td>
</tr>
<tr>
<td>[Sea water system] Total loss</td>
<td>[Sea water system] Total loss</td>
<td>[Sea water system] Total loss apart from Unit 3</td>
</tr>
<tr>
<td>Water injection using IC, RCIC, HPCI</td>
<td>Increase in spent fuel pool temperature to near 70° C</td>
<td>Water injection using RCIC</td>
</tr>
<tr>
<td>PCV Venting, SRV operation &amp; Sea water injection</td>
<td>Installation of temporary RHRS Installation of temporary power supply</td>
<td>3/12 Unit 3 cold shutdown</td>
</tr>
<tr>
<td>Switch to freshwater</td>
<td></td>
<td>Units 1, 2, 4 Water injection using MUWC</td>
</tr>
</tbody>
</table>
| - Heat removal route has been continuously improved  
- Currently the closed cycle cooling is in function | | RHRC motor was replaced Installation of temporary power supply |
| | 3/19 Alternative RHRS was started and the spent fuel pool and reactor were cooled | 3/14 RHR startup |
| | | 3/14 Units 1, 2 cold shutdown  
3/15 Unit 4 cold shutdown |

Sea water was initially injected into the spent fuel pool; currently injecting freshwater
2F Unit 1 Plant Parameter and Operation

Earthquake Tunami
(14:46) (15:23) Cold Shut Down (14:46)

Rx Water Level [mm]

Rx Pressure [MPa]

D/W & S/C Pressure [MPa]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCIC</td>
<td></td>
</tr>
<tr>
<td>HPCS</td>
<td>No Operation (Inoperative due to submersion of power source and inoperative auxiliary cooling system)</td>
</tr>
<tr>
<td>SRV</td>
<td>Pressure Control (3:50 ~ ) Depressurization</td>
</tr>
<tr>
<td>MUWC</td>
<td>(0:00 ~ )</td>
</tr>
<tr>
<td>RHR</td>
<td>Restoration of RHR system (3:45 ~ )</td>
</tr>
<tr>
<td>PCV Vent</td>
<td>▼(18:30) Vent Line Configuration Completed</td>
</tr>
</tbody>
</table>

TOKYO ELECTRIC POWER COMPANY
Response at Main Control Room and TSC

- **Operator’s initial response**
  - MSIVs closed manually, and reactor pressure controlled by SRVs.
  - RCIC actuated manually to maintain reactor water level. RCIC repeated automatic trip due to high water level signal and manual restart.
  - MUWC actuated for alternative water injection measure introduced for Accident Management, as stated in EOP manual for seamless water injection.
  - Reactor depressurized and RCIC stopped due to steam pressure decrease.
  - Water level maintained by MUWC.
Successful Reactor Cooling during Transient

Securing uninterrupted water injection throughout the depressurization process with RCIC at high pressure condition and MUWC at low pressure condition was a critical factor for successful reactor cooling.
Efforts to Control Temperature and Pressure in PCV

- S/C water temperature reached 100°C (212°F).
  - It eventually increased up to about 130°C (266°F).
- Water injected to S/C through Hydrogen Recombiner cooler discharge line in order to mitigate temperature and pressure increases.
- Alternative injection to reactor using MUWC switched to D/W spray, then S/C spray.
- S/C temperature decreased after restoration of RHR.

EOP includes an alternative water injection measures employing MUWC. Flexible approach to cool S/C using Hydrogen Recombiner worked well.

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**S/C Pressure (Unit 1)**

- 3/12 06:20~07:47
  - S/C injection by FCS(A)
- 3/12 07:10
  - D/W spray
- 3/12 07:37
  - S/C spray
- 3/13 11:32~13:26
  - D/W spray
- 3/13 14:29~14:37
  - D/W spray
- 3/14 01:24
  - RHR(B) started with S/C cooling mode
- 3/17 00:03~20:20
  - Water transfer from Condenser to S/C via CST to monitor Condenser water level

**S/C Temperature (Unit 1)**

- 3/12 06:20~07:47
  - S/C injection by FCS(A)
- 3/12 07:10
  - D/W spray
- 3/12 07:37
  - S/C spray
- 3/13 11:32~13:26
  - D/W spray
- 3/13 14:29~14:37
  - D/W spray
- 3/17 00:03~20:20
  - Water transfer from Condenser to S/C via CST to monitor Condenser water level
PCIS and SGTS actuated to secure isolation of the PCV and maintained negative pressure of the reactor building.

Judging from the increasing PCV pressure trend and projected restoration time, as a back-up plan, TSC decided to make PCV vent line up ready.

PCV pressure went up to about 280 kPa [gage] before restoration of RHR, but did not reach its design maximum pressure 310 kPa [gage].

PCV vent line up was made ready as a back-up plan.  
→ This would enable feed and breed cooling to avoid potential core damage.  
(As restoration of cooling capability was successful and cold shutdown was achieved, venting was not conducted actually.)
1F Unit 1 Plant Parameter and Operation

Earthquake (14:46)  Tunami (15:27)  Core Damage Started due to MAAP Analysis  Unit 1 R/B Explosion (15:36)

Rx Water Level [mm]

Rx water level data revealed incorrect afterward

Rx Pressure [MPa]

D/W & S/C Pressure [MPa]

IC (14:52)  HPCI No Operation  SRV No Operation  FP/Fire Engine Operation Unclear

Order for Vent Preparation (0:06) ▼ Order for Vent ▼ (8:03) (14:30) D/W Pr decrease confirmed

Fresh Water [80t]  Sea Water
1F Unit 2 Plant Parameter and Operation

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**Earthquake** (14:46)
**Tsunami** (15:27)
**Unit 1 R/B Explosion** (15:36)
**Core Damage Started due to MAAP Analysis**
**Impact sound** (6:00-6:10)

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**Rx Water Level [mm]**

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**Rx Pressure [MPa]**

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**D/W & S/C Pressure [MPa]**

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**RCIC**

- Operation confirmed (13:25)

**HPCI**

- No Operation

**SRV**

- Order for Sea Water Injection Preparation (12:05)

**FP/Fire Engine**

- Sea Water (19:54)

**PCV Vent**

- Order for Vent Preparation (17:30)

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1F Unit 3 Plant Parameter and Operation

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**Event Timeline**

- **Earthquake** (14:46)
- **Tsunami** (15:27)
- **Unit 1 R/B Explosion** (15:36)
- **Core Damage Started due to MAAP Analysis**
- **Unit 3 R/B Explosion** (11:01)

**Graphs**

- **Rx Water Level (mm)**
- **Rx Pressure (MPa)**
- **D/W & S/C Pressure (MPa)**

**Key Events**

- **RCIC**
  - (16:03) Trip
  - Automatic Start
  - (2:42) Stop

- **HPCI**
  - (11:36) Trip

- **SRV**
  - (9:08) Depressurization

- **D/D-FP**
  - Order for Preparation ▼(17:12)
  - Fresh Water (9:25)
  - Sea Water (13:12)
  - Sea Water (16:30)

- **FP/Fire Engine**
  - (17:12) Fresh Water

- **PCV Vent**
  - Order for Vent Preparation ▼(17:30)
  - (8:41) Vent Line Configuration Completed

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After HPCI shut down, water injection using D/D FP was implemented, however not possible due to high reactor pressure.
3. How We Responded to the Accident at 1F & 2F Sites?

- What difficulties existed
- What were effectively utilized
- How the difficulties were overcome
- Testimonies
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)～

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 instrumentations.

Scram response

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting
Major Activities at 1F

~Factors disturbing initial recovery of instrumentations and power supply~

- Used **batteries taken from cars** for recovery of important instrumentations.
- Put **Engine-Generators** to provide power for the **control room lightings** and **PCV vent valve actuation**.
- Tried to connect a **mobile power supply vehicle** to P/C 2C/4D with temporary cable. The hydrogen explosion of Unit 1&3 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**

*Image of a power supply cart*
Number of Aftershocks Greater than M 5.0

On March 11th alone
155 times > M 5.0
37 times > M 6.0
3 times > M 7.0

Total during first week
358 times > M 5.0
Major Activities at Fukushima Daiichi Unit 1

~Factors disturbing the recovery work (inside the buildings) ~

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
**Major Activities at 1F Unit 1**

<factors disturbing recovery work (outside the building)>

- Many obstacles on access routes disturbed access to the field.
- Vehicles had to avoid passing over fire protection hoses laid in the field.
- Most of the prepared communication tools between the ERC and the control room were unavailable.
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 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.
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

Manual opening operation successful

Preparations for venting

- Water injection started

Preparations for water injection

Deteriorating operability due to the tsunami

Scram response

Major Activities at Fukushima Daiichi Unit 1

~Containment Vessel Venting Operation (2) ~

Ruptured disc

Broke at 0.549MPabs

Air stack

D/W maximum operating pressure

0.528MPabs

Venting pressure

0.954MPabs

PCV vent valve

(MO valve)

Solenoid valve

Cylinder

D/W

IA

Deteriorating operability due to the tsunami

Preparations for water injection

Preparations for venting

Scram response

To 2nd level by southeast stairs

South-side double door

To 2nd level by southeast stairs

PCV vent valve (MO valve)

North-side double door

Access route to PCV vent valve (MO valve)

R/B 1st level

R/B 2nd level
Major Activities at Fukushima Daiichi Unit 1
~Containment Vessel Venting Operation (3)~

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.

Preparations for venting

- Water injection started
- Venting

Preparations for water injection

Scram response

Deteriorating operability due to the tsunami

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)

Manual opening operation successful

Ruptured disc

Closed

Manual opening operation abandoned due to high dose

D/W maximum operating pressure
0.528 MPabs

Venting pressure
0.954 MPabs

Air stack

R/B 1st floor

Access route to S/C vent valve (AO valve)
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.
# System Status after the Tsunami at 2F

<table>
<thead>
<tr>
<th>System</th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHR(A) including cooling systems</td>
<td>× inoperable due to the loss of power source and cooling system</td>
<td>× inoperable due to the loss of power source and cooling system</td>
<td>× inoperable due to the loss of power source and cooling system</td>
<td>× inoperable due to the loss of power source and cooling system</td>
</tr>
<tr>
<td>RHRC/RCRS(A,C)</td>
<td>× inoperable due to the submerge of power source and motor</td>
<td>× inoperable due to the submerge of power source and motor</td>
<td>× inoperable due to the submerge of power source and motor</td>
<td>× inoperable due to the submerge of power source and motor</td>
</tr>
<tr>
<td>EECW(A)</td>
<td>× inoperable due to the submerge of power source and motor</td>
<td>× inoperable due to the submerge of power source and motor</td>
<td>× inoperable due to the submerge of power source and motor</td>
<td>× inoperable due to the submerge of power source and motor</td>
</tr>
<tr>
<td>LPCS</td>
<td>× inoperable due to the loss of power source and cooling system</td>
<td>× inoperable due to the loss of power source and cooling system</td>
<td>× inoperable due to the loss of power source and cooling system</td>
<td>× inoperable due to the loss of power source and cooling system</td>
</tr>
<tr>
<td>EDG(A)</td>
<td>× inoperable due to submerge</td>
<td>× inoperable due to the loss of power source and cooling system</td>
<td>× inoperable due to the loss of power source and cooling system</td>
<td>× inoperable due to the loss of power source and cooling system</td>
</tr>
<tr>
<td>RHR(B) including cooling systems</td>
<td>△ inoperable due to the loss of cooling system</td>
<td>o stand-by</td>
<td>△ inoperable due to the loss of cooling system</td>
<td>△ inoperable due to the loss of cooling system</td>
</tr>
<tr>
<td>RHRC/RCRS(B,D)</td>
<td>× inoperable due to the submerge of power source and motor</td>
<td>o stand-by</td>
<td>× inoperable due to the submerge of power source and motor</td>
<td>× inoperable due to the submerge of power source and motor</td>
</tr>
<tr>
<td>EECW(B)</td>
<td>× inoperable due to the submerge of power source and motor</td>
<td>o operation</td>
<td>× inoperable due to the submerge of power source and motor</td>
<td>× inoperable due to the submerge of power source and motor</td>
</tr>
<tr>
<td>RHR(C)</td>
<td>△ inoperable due to the loss of cooling system</td>
<td>o stand-by</td>
<td>△ inoperable due to the loss of cooling system</td>
<td>△ inoperable due to the loss of cooling system</td>
</tr>
<tr>
<td>EDG(B)</td>
<td>× inoperable due to submerge</td>
<td>o operation</td>
<td>△ inoperable due to the loss of cooling system</td>
<td>△ inoperable due to the loss of cooling system</td>
</tr>
<tr>
<td>RWCU</td>
<td>△ inoperable due to the loss of cooling system</td>
<td>△ inoperable due to the loss of cooling system</td>
<td>△ inoperable due to the loss of cooling system</td>
<td>△ inoperable due to the loss of cooling system</td>
</tr>
<tr>
<td>MUWC (alternative water injection)</td>
<td>o stand-by</td>
<td>o stand-by</td>
<td>o stand-by</td>
<td>o stand-by</td>
</tr>
<tr>
<td>RCIC</td>
<td>o stand-by</td>
<td>o stand-by</td>
<td>o stand-by</td>
<td>o stand-by</td>
</tr>
</tbody>
</table>

〇: secure (power, pump and motor all working)  △: malfunction (inoperable due to factor other than power, pump or motor)  
×: loss of function (power, pump or motor inoperable)
Field Walkdown

In order to establish a well-prioritized restoration strategy, degree of damage and possibility of short-term restoration must be understood through walkdown.

• Challenges in conducting field walkdown
  – Under continuous tsunami alerts, walkdown must be done in the field where a lot of debris, openings and flooding areas existed in the dark.
  – Preparation for emergency evacuation in case of further tsunami and other safety measures for personnel going out to the field.
  – Successful access to the field was 6 hours after the tsunami flooding.

• Field walkdown after the tsunami
  – Plant equipment status checked / component functionality verified.
  – Results were summarized and shared at TSC.
  – TSC set priorities on recovery of RHR (B) cooling systems by replacing motors and supplying power from survived electrical buses and mobile power vehicles through temporary cable.
Logistics in Emergency Situation

• **Procurement and transportation of Materials and Equipment**
  – Emergency procurement of motors, cable, mobile power vehicles, fuel oil and mobile transformers with close cooperation between site TSC and corporate ERC.
  – Rated output of some motors were not the same as that of the original motors. → TSC determined to install them based on the evaluation of actual load conditions.

• **Difficulties experienced in logistics**
  – Motors were transported from Toshiba by a chopper of SDF and from Kashiwazaki Kariwa NPP by trucks.
  – Securing redundant communication measures were critically important when major highway was damaged and public cell phone services were disrupted.

- **Mobile Power Vehicles**
- **Necessary materials and equipment prioritized and listed**
- **Fuel oil delivery to the site**
Emergency Restoration Efforts in the Field

- Pumps of RHR cooling systems (RHRC, RHRS, EECW) were inspected.
- Motors were replaced for pumps in RHRC and EECW.
- In order to restore the inundated electrical buses, temporary cable and high voltage mobile power vehicles were deployed.
- Temporary cable was laid from survived power cubicles in Rad-Waste Building and Unit 3 Heat Exchanger Building.

Motor replacement
Recovering Electricity

• Temporary cable of 9 km length was laid by about 200 personnel within a day. *Usually this size of cable laying requires 20 personnel and more than 1 month period.*

• After the pumps for RHR cooling systems were restored and temporary cable was laid, RHR (B) of Unit 1 started up at 1:24 on March 14 and other units followed.

• Finally at 15:42 on March 14 with the start up of Unit 4 RHR, RHR of all four reactors of Fukushima Daini started operation.
About 9 km of temporary cables were laid and motors were replaced.
# System Status after Emergency Restoration at 2F

<table>
<thead>
<tr>
<th>System</th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RHR(A)</strong> including cooling systems</td>
<td>×  inoperable due to loss of power source and cooling system</td>
<td>●  inoperable due to loss of cooling system</td>
<td>●  inoperable due to loss of cooling system</td>
<td>●  inoperable due to loss of cooling system</td>
</tr>
<tr>
<td><strong>RHRC/RCRS(A,C)</strong></td>
<td>×  inoperable due to submerge of power source and motor</td>
<td>×  inoperable due to submerge of power source and motor</td>
<td>×  inoperable due to submerge of power source and motor</td>
<td>×  inoperable due to submerge of power source and motor</td>
</tr>
<tr>
<td><strong>EECW(A)</strong></td>
<td>×  inoperable due to submerge of power source and motor</td>
<td>×  inoperable due to submerge of power source and motor</td>
<td>×  inoperable due to submerge of power source and motor</td>
<td>×  inoperable due to submerge of power source and motor</td>
</tr>
<tr>
<td><strong>LPCS</strong></td>
<td>×  inoperable due to loss of power source and cooling system</td>
<td>●  inoperable due to loss of cooling system</td>
<td>●  inoperable due to loss of cooling system</td>
<td>●  inoperable due to loss of cooling system</td>
</tr>
<tr>
<td><strong>EDG(A)</strong></td>
<td>×  inoperable due to submerge</td>
<td>●  inoperable due to loss of cooling system</td>
<td>●  inoperable due to loss of cooling system</td>
<td>●  inoperable due to loss of cooling system</td>
</tr>
<tr>
<td><strong>RHR(B)</strong> including cooling systems</td>
<td>●  operation</td>
<td>●  operation</td>
<td>●  operation</td>
<td>●  operation</td>
</tr>
<tr>
<td><strong>RHRC/RCRS(B,D)</strong></td>
<td>●  operation</td>
<td>●  operation</td>
<td>●  operation</td>
<td>●  operation</td>
</tr>
<tr>
<td><strong>EECW(B)</strong></td>
<td>●  operation</td>
<td>●  operation</td>
<td>●  operation</td>
<td>●  operation</td>
</tr>
<tr>
<td><strong>RHR(C)</strong></td>
<td>●  stand-by</td>
<td>●  stand-by</td>
<td>●  stand-by</td>
<td>●  stand-by</td>
</tr>
<tr>
<td><strong>EDG(B)</strong></td>
<td>●  operable using tie-line from unit #2</td>
<td>●  stand-by</td>
<td>●  stand-by</td>
<td>●  stand-by</td>
</tr>
<tr>
<td><strong>RWCU</strong></td>
<td>●  inoperable due to the loss of purge line</td>
<td>●  inoperable due to the loss of purge line</td>
<td>●  inoperable due to the loss of purge line</td>
<td>●  inoperable due to the loss of purge line</td>
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<tr>
<td><strong>MUWC</strong> (alternative water injection)</td>
<td>●  stand-by</td>
<td>●  stand-by</td>
<td>●  stand-by</td>
<td>●  operation</td>
</tr>
<tr>
<td><strong>MUWC(B)</strong></td>
<td>●  stand-by</td>
<td>●  stand-by</td>
<td>●  stand-by</td>
<td>●  operation</td>
</tr>
<tr>
<td><strong>RCIC</strong></td>
<td>×  inoperable for loss of core pressure</td>
<td>×  inoperable for loss of core pressure</td>
<td>×  inoperable for loss of core pressure</td>
<td>×  inoperable for loss of core pressure</td>
</tr>
</tbody>
</table>

○ ; secure (power, pump and motor all working)  △ ; malfunction (inoperable due to factor other than power, pump or motor)  × ; loss of function (power, pump or motor inoperable)
Overview of the 10-Unit Simultaneous Accidents

<table>
<thead>
<tr>
<th>Date</th>
<th>1F</th>
<th>2F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Station Black-Out</strong></td>
<td></td>
</tr>
<tr>
<td>3/12</td>
<td>3/12 15:36 Unit 1 Explosion</td>
<td></td>
</tr>
<tr>
<td>3/13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/14</td>
<td>3/14 11:01 Unit 3 Explosion</td>
<td></td>
</tr>
<tr>
<td>3/15</td>
<td>3/15 6:00-6:10 Unit 4 Explosion (?)</td>
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</tr>
<tr>
<td>3/16-19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/20</td>
<td>3/20 15:46 P/C-2C</td>
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</tr>
<tr>
<td></td>
<td>3/20 15:46 P/C-2C</td>
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<tr>
<td></td>
<td>3/22 10:36 P/C-4D</td>
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<tr>
<td></td>
<td>3/22 10:35 P/C-4D</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Lost of Ultimate Heat Sink**

**Cold Shutdown**
Testimonies from the Field (Operators)

“In an attempt to check the status of Unit 4 D/G, I was trapped inside the security gate compartment. Soon the tsunami came and I was a few minutes before drowning, when my colleague smash opened the window and saved my life.”

“In total darkness, I could hear the unearthly sound of SRV dumping steam into the torus. I stepped on the torus to open the S/C spray valve, and my rubber boot melted.”

“The radiation level in the main control room was increasing 0.01 mSv (1 mrem) every 3 seconds but I couldn’t leave—I felt this was the end of my life.”

“I asked for volunteers to manually open the vent valves. Young operators raised their hands as well; I was overwhelmed.”

“Unit 3 could explode anytime soon, but it was my turn to go to the main control room. I called my dad and asked him to take good care of my wife and kids should I die.”
Testimonies from the Field (Maintenance Persons)

- “We saw our car crashed by the explosion of the Unit 3. If we had gotten on the car a few minutes earlier, all of us would have been dead.”

- We were replacing fire hoses when the explosion of Unit 3 occurred. We felt almost dying since many large rubbles were falling down to us. I urgently ran underneath a nearby fire engine. One of my colleagues got injuries in his leg and stomach.”

- “There were so many manholes opened by the tsunami. In order to lay cables, we had to proceed step by step carefully checking safety in the complete darkness.”

- “We were working in the Unit 3/4 control room when the explosion occurred. I was resigned to my fate. Dose rate was going up in the room after the explosion and we desperately tried to find places with lower dose rate.”

- “After replacing an air cylinder for the PCV ventilation of Unit 3, I heard sound of steam and saw white mist around us. I got into a panic for a while.”
4. Summary
The 1F accident was caused by the simultaneous loss of multiple safety functions due to far beyond design basis of tsunami. The main factors of the accident are “the simultaneous loss of total AC power and DC power for an extended period of time” and “the loss of the heat removal function of the emergency seawater system for an extended period of time.”

Preparations had been previously made to receive power from neighboring units in the event that AC power and DC power were not available. During the accident, direct tsunami damage was so widespread that the neighboring units were all in the same condition.

“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.”
Success path regarding Cooling and Heat Removal from the Reactor

1) Promptly initiate core injection methods using high-pressure cooling water injection equipment.
2) Initiate depressurization methods before losing function of high-pressure cooling water injection.
3) Stable low-pressure cooling water injection methods should be available during the depressurization stage.
4) Provide reliable PCV venting methods (heat removal through the atmospheric discharge of heat).
5) Provide measures to restore the cooling function using sea water.
6) Provide measures which enable necessary monitoring for those operation and plant conditions.

It is inevitable to maintain water injection and core cooling function thoroughly and continuously even in poor environmental conditions.
2F Key Success Factors

Organization and Management Features

- Accident mitigation by applying EOP and AMG
- Prioritized restoration strategy based on Field Walkdown
- Prompt restoration with success of emergency procurement for materials and equipment
- Logistics for long term emergency response
- Organizational integrity: Leadership, Communication, Accountability, Professionalism

Design/Engineering Features

- Availability of most of M/C, P/C and Battery
- Availability of off-site power
Website Information

- TEPCO English website

- Internal Investigation Committee Interim Report (Dec. 2\textsuperscript{nd}, 2011)

- Report on initial responses to the accident (Dec. 22\textsuperscript{nd}, 2011)
- The Latest version of accident Timeline (Dec. 22\textsuperscript{nd}, 2011)
  English version will be on the following website soon.

- INPO—Special Report on Fukushima Daiichi Nuclear Power Station

- EPRI—Fukushima Daini Independent Review and Walkdown
Thank you for your attention!
5. References
## Intensity of the earthquake at the power stations

In Fukushima Daiichi the observed data partially exceeded the maximum response acceleration with respect to the design-basis earthquake, however most data was below the baseline.

<table>
<thead>
<tr>
<th>Observation Point (The lowest basement of reactor buildings)</th>
<th>Observed Data</th>
<th>Maximum Response Acceleration against Basic Earthquake Ground Motion (Gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum Response Acceleration (gal)</td>
<td>Horizontal (N-S)</td>
</tr>
<tr>
<td></td>
<td>Horizontal (N-S)</td>
<td>Horizontal (E-W)</td>
</tr>
<tr>
<td><strong>Fukushima Daiichi</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit 1</td>
<td>460</td>
<td>447</td>
</tr>
<tr>
<td>Unit 2</td>
<td>348*</td>
<td>550*</td>
</tr>
<tr>
<td>Unit 3</td>
<td>322*</td>
<td>507*</td>
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<tr>
<td>Unit 4</td>
<td>281*</td>
<td>319*</td>
</tr>
<tr>
<td>Unit 5</td>
<td>311*</td>
<td>548*</td>
</tr>
<tr>
<td>Unit 6</td>
<td>298*</td>
<td>444*</td>
</tr>
<tr>
<td><strong>Fukushima Daini</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit 1</td>
<td>254</td>
<td>230*</td>
</tr>
<tr>
<td>Unit 2</td>
<td>243</td>
<td>196*</td>
</tr>
<tr>
<td>Unit 3</td>
<td>277*</td>
<td>216*</td>
</tr>
<tr>
<td>Unit 4</td>
<td>210*</td>
<td>205*</td>
</tr>
</tbody>
</table>

*: The records were stopped approximately 130-150 seconds after recording started.

Note) Standard ground motion Ss: Seismic motion that was newly established to evaluate seismic safety, taking into account the earthquakes, etc., that could occur around the power station, based on the revised seismic design review guidelines.
In Fukushima daiich observation record partially exceeded the design-basis earthquake ground motion, however it was confirmed to be almost the same level.

Intense of the earthquake at the power stations.
**Inundated Areas at 1F**

- 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

---

Almost whole area was flooded

Elevation of major Unit-5,6 buildings: O.P.13m

Elevation of major Unit-1-4 buildings: O.P.10m
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
Inundated Areas at 2F

- 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

Limited area was flooded

Inflowed intensively

Elevation of major Unit-1-4 buildings: O.P. 12m

(C)GeoEye
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

▼: 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

Unit 4
Unit 3
Unit 2
Unit 1

Heat exchanger building
Turbine building
Reactor building
Inside Unit 1 heat exchanger building
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.
Differences in Tsunami that hit Fukushima Daiichi and Daini NPSs

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

Peaks coinciding
↓
Tsunami height: High

Peaks not coinciding
↓
Tsunami height: Low

Water level fluctuation from each block

Same amplification rate

Postulated Tsunami Model

Warm colored blocks generated massive tsunami wave heights
Permitted Design Basis(1)… Tsunami assessment

- Historical tsunamis of Iwate and Miyagi coast were larger than that of Fukushima
- Approved design basis at Fukushima NPS was 3.1-3.7m

**Historical tsunami heights (m)**

3.11.2011 tsunami heights (m)

**Tsunami assessment in construction permit**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Ground Level</th>
<th>Tsunami Height[m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1F 1-4</td>
<td>10.2</td>
<td>4</td>
</tr>
<tr>
<td>1F 5-6</td>
<td>13.2</td>
<td>4</td>
</tr>
<tr>
<td>2F1-4</td>
<td>12</td>
<td>7</td>
</tr>
</tbody>
</table>

Preliminary results by The 2011 Tohoku Earthquake Tsunami Joint Survey Group( http://www.coastal.jp/ttjt/) 07 May 2011
Permitted Design Basis(2)… Tsunami assessment

Tsunami Assessment was revised based on the JSCE (Japan Society of Civil Engineers) Method, 2002

In JSCE- 2002, assumed 8 earthquakes individually. March 11 Earthquake occurred over several areas simultaneously.

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>Magnitude</th>
<th>Earthquake</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>8.2</td>
<td>1952 Nemuro-oki</td>
</tr>
<tr>
<td>#2</td>
<td>8.4</td>
<td>1968 Tokachi-oki</td>
</tr>
<tr>
<td>#3</td>
<td>8.3</td>
<td>1896 Meiji-Sanriku</td>
</tr>
<tr>
<td>#4</td>
<td>8.6</td>
<td>1611 Keicho-Sanriku</td>
</tr>
<tr>
<td>#5</td>
<td>8.2</td>
<td>1793 Miyagi-oki</td>
</tr>
<tr>
<td>#6</td>
<td>7.7</td>
<td>1978 Miyagi-oki</td>
</tr>
<tr>
<td>#7</td>
<td>7.9</td>
<td>1938 Fukushima-oki</td>
</tr>
<tr>
<td>#8</td>
<td>8.1</td>
<td>1677 Enpo-Bousou</td>
</tr>
</tbody>
</table>

[Diagram of source area](http://outreach.eri.u-tokyo.ac.jp/eqvolc/201103_tohoku/#Inversion 2011/3/18)
## Damage Status of Unit 1 & 2 Emergency DG and Emergency High Voltage Switchboard  (Immediately after the Tsunami)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Installed building</th>
<th>Installed floor</th>
<th>Possibility of use</th>
<th>Status</th>
<th>Equipment</th>
<th>Installed location</th>
<th>Installed floor</th>
<th>Possibility of use</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG 1A</td>
<td>T/B</td>
<td>B1FL</td>
<td>×</td>
<td>Submerged</td>
<td>DG 2A</td>
<td>T/B</td>
<td>B1FL</td>
<td>×</td>
<td>Submerged</td>
</tr>
<tr>
<td>DG 1B</td>
<td>T/B</td>
<td>B1FL</td>
<td>×</td>
<td>Submerged</td>
<td>DG 2B (Shared pool)</td>
<td></td>
<td>1FL</td>
<td>×</td>
<td>M/C submerged cannot be used</td>
</tr>
<tr>
<td>M/C 1C</td>
<td>T/B</td>
<td>1FL</td>
<td>×</td>
<td>Water damage</td>
<td>M/C 2C</td>
<td>T/B</td>
<td>B1FL</td>
<td>×</td>
<td>Submerged</td>
</tr>
<tr>
<td>M/C 1D</td>
<td>T/B</td>
<td>1FL</td>
<td>×</td>
<td>Water damage</td>
<td>M/C 2D</td>
<td>T/B</td>
<td>B1FL</td>
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<td>Submerged</td>
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<tr>
<td>M/C 2E</td>
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<td>M/C 2E (Shared pool)</td>
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<td>B1FL</td>
<td>×</td>
<td>Submerged</td>
</tr>
<tr>
<td></td>
<td>Equipment</td>
<td>Installed location</td>
<td>Installed floor</td>
<td>Possibility of use</td>
<td>Status</td>
<td>Equipment</td>
<td>Installed location</td>
<td>Installed floor</td>
<td>Possibility of use</td>
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</tr>
<tr>
<td><strong>DG</strong></td>
<td>DG 3A</td>
<td>T/B</td>
<td>B1FL</td>
<td>×</td>
<td>Submerged</td>
<td>DG 4A</td>
<td>T/B</td>
<td>B1FL</td>
<td>×</td>
</tr>
<tr>
<td></td>
<td>DG 3B</td>
<td>T/B</td>
<td>B1FL</td>
<td>×</td>
<td>Submerged</td>
<td>DG 4B</td>
<td>Shared pool</td>
<td>1FL</td>
<td>×</td>
</tr>
<tr>
<td>(M/C) Emergency high voltage switch board</td>
<td>M/C 3C</td>
<td>T/B</td>
<td>B1FL</td>
<td>×</td>
<td>Submerged</td>
<td>M/C 4C</td>
<td>T/B</td>
<td>B1FL</td>
<td>×</td>
</tr>
<tr>
<td></td>
<td>M/C 3D</td>
<td>T/B</td>
<td>B1FL</td>
<td>×</td>
<td>Submerged</td>
<td>M/C 4D</td>
<td>T/B</td>
<td>B1FL</td>
<td>×</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>M/C 4E</td>
<td>Shared pool</td>
<td>B1FL</td>
<td>×</td>
</tr>
</tbody>
</table>
## Damage Status of Unit 5 & 6 Emergency DG and Emergency High Voltage Switchboard (Immediately after the Tsunami)

<table>
<thead>
<tr>
<th></th>
<th>Unit 5</th>
<th>Unit 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td><strong>Installed location</strong></td>
<td><strong>Installed location</strong></td>
</tr>
<tr>
<td>DG DG 5A</td>
<td>T/B B1FL</td>
<td>DG 6A R/B B1FL</td>
</tr>
<tr>
<td></td>
<td>× Related equipment Water damage</td>
<td>× Related equipment Water damage</td>
</tr>
<tr>
<td>DG DG 5B</td>
<td>T/B B1FL</td>
<td>DG 6B DG building 1FL ○</td>
</tr>
<tr>
<td></td>
<td>× Related equipment Water damage</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Related equipment Water damage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(M/C) M/C 5C</td>
<td>T/B B1FL</td>
<td>M/C 6C R/B B2FL ○</td>
</tr>
<tr>
<td></td>
<td>× Submerged</td>
<td></td>
</tr>
<tr>
<td>(M/C) M/C 5D</td>
<td>T/B B1FL</td>
<td>M/C 6D R/B B1FL ○</td>
</tr>
<tr>
<td></td>
<td>× Submerged</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>HPCSD/G R/B B1FL ×</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Related equipment Water damage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>HPCSD DG M/C R/B 1FL ○</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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)

Air-cooled DG (3)
Unit 2 (B), Unit 4 (B), Unit 6(B)

[Fukushima Daini: DG System Outline]

Sea water-cooled DG (12)
Unit 1 to Unit 4(A)(B)(H)

All function was lost after the tsunami
Power was secured in Unit 6 (B) only
Power was secured in Unit 3 (B)(H) and Unit 4 (H) only
## Power Access/Restoration Status Immediately after 1F-1,2 Shutdown

<table>
<thead>
<tr>
<th>Date</th>
<th>Operation and Restoration Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 11</td>
<td>Temporary MCR lighting on (Temporary small engine generator)</td>
</tr>
<tr>
<td>March 12</td>
<td>Power source for Unit 1 Instrument restored (Temporary small engine generator)</td>
</tr>
<tr>
<td></td>
<td>Power source for Unit 1 Instrument restored (power source cart)</td>
</tr>
<tr>
<td></td>
<td>Temporary small engine generator destroyed by H2 explosion</td>
</tr>
<tr>
<td></td>
<td>Temporary MCR lighting on (another temporary small engine generator)</td>
</tr>
<tr>
<td>March 19</td>
<td>Backup transformer ~ Unit 1 &amp; 2 temporary M/C (A) cable laid</td>
</tr>
<tr>
<td>March 20</td>
<td><strong>Off-site power restored</strong> (P/C2C power received)</td>
</tr>
</tbody>
</table>
## Power Access/Restoration Status Immediately after 1F-3,4 Shutdown

<table>
<thead>
<tr>
<th>Date</th>
<th>Operation and Restoration Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 11</td>
<td>Temporary MCR lighting on (Temporary small engine generator)</td>
</tr>
<tr>
<td>March 13</td>
<td>P/C 4D restored (power source cart)</td>
</tr>
<tr>
<td>March 14</td>
<td>Yonomori Line 1L step-down transformer cart (66/6.9kW) connected to the Shin-Fukushima Substation</td>
</tr>
<tr>
<td></td>
<td>Yonomori Line 1L ~ Okuma Line 3L connected</td>
</tr>
<tr>
<td></td>
<td>Power source for Unit 1 Instrument restored (power source cart)</td>
</tr>
<tr>
<td></td>
<td>The power source cart destroyed by H2 explosion</td>
</tr>
<tr>
<td>March 18</td>
<td>Unit 3 &amp; 4 MC, Switch installation location</td>
</tr>
<tr>
<td>March 22</td>
<td><strong>Off-site power restored</strong> (P/C4D power received)</td>
</tr>
</tbody>
</table>
**Power Access/Restoration Status Immediately after 1F-6 Shutdown**

<table>
<thead>
<tr>
<th>Date</th>
<th>Operation and Restoration Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 11</td>
<td>DG6B startup (6A and 6H were shut down by the tsunami, 6B is an air-cooled type)</td>
</tr>
<tr>
<td></td>
<td>SGTS(B) startup, DC125V/250V (B system) restoration</td>
</tr>
<tr>
<td>March 12</td>
<td>DC125V/250V (A system) restoration</td>
</tr>
<tr>
<td>March 13</td>
<td>MUWC(B) startup</td>
</tr>
<tr>
<td>March 19</td>
<td>RHR 6B startup, temporary RHRS alternative pump startup (power source cart)</td>
</tr>
<tr>
<td></td>
<td>DG6A startup (March 21 shutdown)</td>
</tr>
<tr>
<td>March 20</td>
<td>Cold shutdown condition</td>
</tr>
<tr>
<td>March 22</td>
<td>Off-site power restored (M/C6C, 6D power received)</td>
</tr>
<tr>
<td>March 23</td>
<td>Temporary RHRS alternative pump switched to off-site power</td>
</tr>
<tr>
<td>Date</td>
<td>Operation and Restoration Status</td>
</tr>
<tr>
<td>------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>March 12</td>
<td>DC125V/250 restoration</td>
</tr>
<tr>
<td>March 13</td>
<td>MUWC(A), SGTS(A) startup</td>
</tr>
<tr>
<td>March 18</td>
<td>Temporary RHRS alternative pump startup (power source cart)</td>
</tr>
<tr>
<td>March 19</td>
<td>RHR 5C startup</td>
</tr>
<tr>
<td>March 20</td>
<td>Cold shutdown condition</td>
</tr>
<tr>
<td>March 22</td>
<td>Off-site power restored (M/C6C, 6D power received)</td>
</tr>
<tr>
<td>March 23</td>
<td>Temporary RHRS alternative pump switched to off-site power</td>
</tr>
</tbody>
</table>
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
<table>
<thead>
<tr>
<th>Parameter/unit</th>
<th>1F1</th>
<th>1F2</th>
<th>1F3</th>
<th>1F4</th>
<th>1F5</th>
<th>1F6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor water level</td>
<td>A:◎ B:△</td>
<td>A:△ B:△</td>
<td>A:△ B:△</td>
<td>N/A</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Reactor pressure</td>
<td>A:◎</td>
<td>A:○</td>
<td>A:△ B:△</td>
<td>N/A</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Reactor water temp.</td>
<td>Not sampled</td>
<td>Not sampled</td>
<td>Not sampled</td>
<td>N/A</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Temperatur e around RPV</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>D/W pressure</td>
<td>◎</td>
<td>△</td>
<td>○</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S/C pressure</td>
<td>○</td>
<td>×</td>
<td>○</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>CAMS rad monitor</td>
<td>D/W: ×  S/C:○</td>
<td>D/W:○ S/C:○</td>
<td>D/W:○ S/C:○</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S/C temperature</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

◎: calibrated, ○: assumed to be intact, △: under continuous observation, ×: failure
Unit 1 Isolation Condenser

Function of the Isolation condenser

- Depressurization of the reactor by steam condensation during reactor Isolation (MSIV closure condition)
- Redundancy design (2 systems)

① Initiating system by opening the valve

② Reactor steam is cooled by Isolation condenser coolant tank

③ Heated water in the tank released to the open air

④ Condensate water return back to RPV driven by natural convection force
The automatic isolation interlock of the IC was actuated due to the loss of power caused by the tsunami and then lost its function. Afterwards, the reactor water level decreased in a short period of time and the core was exposed (Dropped to TAF), leading to the core damage. During this time, it was difficult to understand plant status due to the loss of power.

Based on the analysis results, it is evaluated that the core would have been damaged regardless of the continuation of the operation of the IC after 18:18.

When the water level gauge was temporarily restored using a temporary power source after 21:00 on March 11, a reading was obtained showing that the reactor water level was above TAF. However at this point, there was not enough information to comprehensively determine that this reading was erroneous. At the Emergency Response Headquarters on the site and the Head Office, it was not deemed at this point that the IC had stopped. The possibility of the core damage was recognized due to the increase in dose rate in front of the double doors of the reactor building at around 23:00 on March 11 and the unusually high reading for the dry well pressure that was obtained for the first time at around 0:00 on March 12.
On March 12 at around 3:00, the reactor pressure decreased, although reactor depressurization operation was not conducted. This implies that damage to the reactor cooling water pressure boundary had occurred due to core damage. This implies that core damage might have progressed to a considerable extent in a short period of time.

Based on the results using the accident analysis codes, it took about 3 hours to drop to TAF after the earthquake and about 4 hours until core damage began, which indicates the rapid event progress to the core damage. This result is consistent with the events actually observed.
1F Unit 2 Schematic System Diagram (After Tsunami)

- Stack
- D/W vent valve
- S/C vent valve
- CS
- RHRS
- Sea
- CST
- Filtrated Water Tank
- Gen
- Condenser
- H/W
- Condenser
- Sea
- CST
- RCIC
- MD-RFP
- TD-RFP
- LPCP
- CWP
- D/W vent valve
- Operable
- Inoperative due to power loss
- Inoperative

From CST & H/W

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Summary of the Plant Behavior in Unit 2

- As the RCIC of Unit 2 functioned for a relatively long period of time, the core decay heat was lower than immediately after shutdown. However as the high-pressure systems (RCIC) lost its function, decrease in the reactor water level started.

- About 1 hour and 20 minutes later after the RCIC shutdown, the fire engine’s pump was started up and preparations for low-pressure water injection were ready. However the SRV did not immediately operate during reactor depressurization.

- It is considered that core damage occurred because low-pressure water injection did not function immediately after the SRV was activated and reactor depressurization was achieved. Because of the rapid decrease in the retained water due to the outflow of steam to the S/C associated with reactor depressurization, cooling function degraded furthermore.

- According to the analysis by using the MAAP code, it is evaluated that core damage started due to the decrease in reactor water level followed by degradation of the function of the RCIC.
1F Unit 3 Schematic System Diagram (After Tsunami)

Stack

D/W vent valve

S/C vent valve

SLC

CRD

RPV

SRV

HPCP

HPCI

RCIC

MUWC

DD FP

D/W vent valve

RHR

CST

Filtrated Water Tank

Sea

Condenser

H/W

Gen

CWP

Sea

:Operable

:Inoperative due to power loss

:Inoperative
Summary of the Plant Behavior in Unit 3

- In Unit 3, preparations for low-pressure water injection were performed by activating the diesel-driven fire pump. However, because the reactor pressure was higher than the water injection pressure, switching to low-pressure water injection was not immediately successful after shutdown of the high-pressure systems (HPCI). This caused degradation of cooling and thus leading to core damage.

- S/C venting was conducted and repeated several times. The monitoring car reading near the main gate increased temporarily. However no large increase in the background level was observed.

- In addition, the hydrogen that was generated following the core damage was not completely retained in the PCV and leaked into the reactor building, and is considered to have caused the explosion of the reactor building.