The Great East Japan Earthquake and Current Status of Nuclear Power Stations
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1. Overview of Earthquake, Tsunami and Nuclear Accident
Tohoku Pacific Ocean Earthquake

- **Time:** 2:46 pm on Fri, March 11, 2011.
- **Place:** Offshore Sanriku coast (northern latitude of 38.062 degrees, east longitude of 142.516 degrees), 24km in depth, Magnitude 9.0
- **Intensity:** Level 7 at Kurihara in Miyagi prefecture
  - Upper 6 at Naraha, Tomioka, Okuma, and Futaba in Fukushima pref.
  - 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.

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**Seismic Acceleration at Fukushima Daiichi Unit 2**
- Horizontal: 550gal
- Vertical: 302gal

* gal: a unit of acceleration defined as cm/s².
Seismic Observed Data

## Comparison between Basic Earthquake Ground Motion and the record of intensity

<table>
<thead>
<tr>
<th>Observation Point (The lowest basement of reactor buildings)</th>
<th>Observed data</th>
<th></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></td>
<td>Horizontal (N-S)</td>
</tr>
<tr>
<td></td>
<td>Horizontal (N-S)</td>
<td>Horizontal (E-W)</td>
<td>Vertical</td>
</tr>
<tr>
<td><strong>Fukushima Daiichi</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit 1</td>
<td>460</td>
<td>447</td>
<td>258</td>
</tr>
<tr>
<td>Unit 2</td>
<td>348</td>
<td>550</td>
<td>302</td>
</tr>
<tr>
<td>Unit 3</td>
<td>322</td>
<td>507</td>
<td>231</td>
</tr>
<tr>
<td>Unit 4</td>
<td>281</td>
<td>319</td>
<td>200</td>
</tr>
<tr>
<td>Unit 5</td>
<td>311</td>
<td>548</td>
<td>256</td>
</tr>
<tr>
<td>Unit 6</td>
<td>298</td>
<td>444</td>
<td>244</td>
</tr>
<tr>
<td><strong>Fukushima Daini</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit 1</td>
<td>254</td>
<td>230</td>
<td>305</td>
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<tr>
<td>Unit 2</td>
<td>243</td>
<td>196</td>
<td>232</td>
</tr>
<tr>
<td>Unit 3</td>
<td>277</td>
<td>216</td>
<td>208</td>
</tr>
<tr>
<td>Unit 4</td>
<td>210</td>
<td>205</td>
<td>288</td>
</tr>
</tbody>
</table>
We assessed the impact of tsunami utilizing the latest bathymetry data, etc. in 2009, and took measures against tsunami, whose height is O.P. +6.1m at Fukushima Daiichi and O.P. +5.2m at Fukushima Daini.

Inundation height was approximately O.P. +15m at Fukushima Daiichi and approximately O.P. +7m at Fukushima Daini.

Accordingly, we have confirmed that the impact of Tsunami (water level and inundated area) was relatively larger in Fukushima Daiichi than Fukushima Daini.
Inundated and Inflowed Area at Fukushima Daiichi and Daini Site

Inflowed intensively

Inundated and Inflowed Area at Fukushima Daiichi and Daini Site

Inundated

Inflowed

Inflowed intensively
Fukushima Daiichi being struck by the tsunami (1)

Taken from near the south side of Unit 5, looking east

Breakwater was damaged

Taken from radwaste building 4th floor, looking north

Tank  Height about 5.5m
( height of ground : O.P. + 10m )

Submerged tank

O.P. : Onahama bay construction base level
Fukushima Daiichi being struck by the tsunami (2)

Unit 3 Sea Pump Area

Unit 5,6 Intake Screen Area
Impacts for Safety Function

- Nuclear fission chain reaction was stopped by automatic shutdown with all control rods inserted at the same time of the earthquake.
- Off-site power was lost due to the impact of the earthquake, etc. and emergency generator started up. However emergency power became unavailable due to flooding by the tsunami except for Unit 6.
- Finally the “Cooling” function for the reactors and spent fuel pools of Units 1 to 4 were lost due to the loss of AC power supply and seawater systems, etc. caused by the tsunami.
- "Containment" function was impaired with high level contaminated water found in turbine buildings.

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- **Shutdown**: Stop nuclear fission reaction by inserting all control rods that absorb neutrons.
- **Cooling**: Cool down reactor coolant & SFP water, and keep its temperature low.
- **Containment**: Contain radioactive materials inside the Reactor Building by five walls.

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**Diagram**:
- Reactor Pressure Vessel (RPV)
- Spent Fuel Pool (SFP)
- Primary Containment Vessel (PCV)
- Reactor Building

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**Overview**
- Improvised water injection via fire engines
Progress towards Cold Shutdown Status in each Unit (Outline)

The Great East Japan Earthquake around 14:46, Mar. 11th

Reactor SCRAM due to the Earthquake (Emergency Shutdown)

Loss of External Power, D/G Start-up

Handling following the SCRAM

Tsunami struck Fukushima-Daiichi & Fukushima-Daini NPPs around 15:20~, Mar. 11th

Units 1~3

Fukushima-Daiichi

[Power] No AC power, No D/G
[Seawater system] Not available

Water injection & heat removal via HP system

Water injection via LP system (Freshwater & Seawater)

No route secured for heat removal, response for stabilization

Cold Shutdown Condition (Dec. 16)

Units 5, 6

Fukushima-Daiichi

[Power] D/G6B start-up
[Seawater system] Not available

Power supply from Unit 6 to Unit 5

Heat removal secured by temporary power source & seawater pump

Cold Shutdown (Mar. 20)

Fukushima-Daini 1~4

[Power] AC Power available
[Seawater system] Unit 3 available*2

Water injection via HP (Steam-driven) & LP systems

Water injection via LP system

Heat removal secured by temporary power source & motor replacement etc.

Cold Shutdown (Mar. 15)*3

*1 D/G Emergency Diesel Generator

*2 RHR Seawater System

*3 Fukushima-Daini Emergency State was Lifted on Dec. 26th
On-site testimony:

“When the power source failed, we felt completely helpless.”

“Heated discussion broke out among the operators regarding whether it was important to remain in the control room without power and lights.”

“I bowed to ask them to remain here and somehow they agreed.”
On-site testimony:
“As the tremendous aftershocks occurred, with our full face masks still on, we frantically headed off to the upper ground.”

“While laying down cables at night, entailing the search of penetrations and terminal treatment work, we were terrified that we might be electrocuted due to the outside water puddles.”
Measure to Decrease Pressure of PCV (Ventilation)

- Implemented ventilation to reduce the pressure of Primary Containment Vessel (PCV) in Units 1-3 to prevent PCV from getting over pressured.

Worker’s testimony:
“When I climbed on top of the torus to reach for the high positioned valve, the soles of my boots quickly melted away.”
Radiation Control

- 6 TEPCO employees were exposed to more than 250 mSv radiation dosage during restoration work after the accident. Maximum exposure was approximately 670 mSv.
- 167 workers including TEPCO employees and partner companies’ workers were exposed to more than 100 mSv radiation dosage.
- No health problem due to acute radiation injury has been observed.

(The radiation limit for emergency workers was increased to 250mSv on March 14, 2011 due to the accident, but it is now returned to 100mSv with some exceptions.)

Screening for workers

Screening Drilling
Radiation Dose

ʢ mSvʣ

(Note) The amount of natural radiation is including the effect of inhalation of Radon.
(source) UNSCEAR 2000 Report, "Sources and Effects of Ionizing Radiation" etc.

Relationship between Health and Radiation Dose

Effective dose equivalent
(mSv)

10000

1000

100

10

1

0.1

Maximum permitted for staff working in emergency cases (only Fukushima Daiichi case) 250

Maximum permitted for staff working in emergency cases (ordinary) 100

Maximum permitted for radiation workers in one year 50

Chest X-Ray computed tomography (one time) 6.9

Regular public space (except medical area) 1.0

Abdominal X-Ray for health check up (one time) 0.6

The target figure around Nuclear Power Plant area (per year) 0.05

Natural Radiation at Guarapari Beach, Brazil (per year) 10

Natural Radiation per person (per year, world average) 2.4

Tokyo – New York flight (round trip) 0.19 (radiation varies depending on the flight altitude)

(Whole body exposure) 99% mortality 7,000〜10,000

(Whole body exposure) 50% mortality 3,000〜5,000

(Whole body exposure) decrease of lymphocyte 500

50% mortality 3,000〜5,000

99% mortality 7,000〜10,000

(Note) The amount of natural radiation is including the effect of inhalation of Radon.
(source) UNSCEAR 2000 Report, "Sources and Effects of Ionizing Radiation" etc.
INES (International Nuclear Event Scale) Evaluation

On April 12, Nuclear and Industrial Safety Agency released as below:
- Tentatively assigned Level 7 on INES for the accident at Fukushima Daiichi Nuclear Power Station.
- In this regard however, the amount of released radioactive materials is one-tenth as much as the accident at Chernobyl.

We are wrestling with hurdles such as cooling the reactors or reducing the diffusion of radioactive materials in order to resolve the situation as soon as possible. We will commit in full force to resolve this situation along with close coordination and cooperation with the national and local governments.

### Criteria (highest level represents the evaluation result for the event)

<table>
<thead>
<tr>
<th>Level</th>
<th>Criteria 1: External impact</th>
<th>Criteria 2: Internal impact</th>
<th>Criteria 3: Defense in depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 7: Major accident</td>
<td>Major release of radioactive materials (more than several hundred of thousand TBq (equivalent of I-131))</td>
<td></td>
<td>Soviet Union : Chernobyl (1986)</td>
</tr>
<tr>
<td>Level 6: Serious accident</td>
<td>Serious release of radioactive materials (from several thousand to several ten of thousand TBq (equivalent of I-131))</td>
<td>Severe damage to reactor core</td>
<td>USA : Three Mile Island (1979)</td>
</tr>
<tr>
<td>Level 5: Accident with wider consequences</td>
<td>Limited release of radioactive materials (from several hundred to several thousand TBq (equivalent of I-131))</td>
<td></td>
<td>JCO criticality accident (1999)</td>
</tr>
<tr>
<td>Level 4: Accident with local consequences</td>
<td>Minor release of radioactive materials (radiation exposure of several mSv for the public)</td>
<td>Significant damage to reactor core / fatal radiation exposure of workers</td>
<td></td>
</tr>
<tr>
<td>Level 3: Serious Incident</td>
<td>Extremely minor release of radioactive materials (radiation exposure of several tenth mSv for the public)</td>
<td>Major contamination within site / acute radiation injury of workers</td>
<td>Loss of defense in depth</td>
</tr>
<tr>
<td>Level 2: Incident</td>
<td></td>
<td>Significant contamination within site / radiation exposure of workers beyond the annual dose limit</td>
<td>Deterioration of defense in depth</td>
</tr>
<tr>
<td>Level 1: Anomaly</td>
<td></td>
<td>Deviation from limiting conditions of operation</td>
<td>Monju sodium leakage (1995)</td>
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<tr>
<td>Level 0: Deviation</td>
<td>No safety significance</td>
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</table>

*S1 : Becquerel (Bq) : unit for amount of radioactive materials (T = 10^{12})
*S2 : Sievert (Sv) : unit for radiation influence on human body (m = 1/1000)

Source: March 18, 2011 Press release by Nuclear and Industrial Safety Agency
Nuclear fuels continue to generate decay heat even after stop of fission by control rod insertion.

In order to remove decay heat, “Residual Heat Removal System (RHR)” is installed. RHR pumps circulate reactor coolant and remove heat by sea water through heat exchanger in “Residual Heat Removal Sea water System”.

This will enable fuels in reactors to be kept in stabilized cooling state (under 65 °C).

*note Diagram above depicts RHR system in Units 2~5 schematically, however actual system equips multiple pumps and heat exchangers.