Efforts for the restoration at Fukushima Daiichi Nuclear Power Plants

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TOSHIBA CORPORATION

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13 Plants Struck by the Earthquake and Tsunami

East Japan (Tohoku region)

- Onagawa
  - Unit1: 1,100 MW
  - Unit2: 1,100 MW
  - Unit3: 1,100 MW

- Fukushima I
  - Unit1: 1,460 MW
  - Unit2: 1,784 MW
  - Unit3: 1,784 MW
  - Unit4: 1,784 MW
  - Unit5: 1,784 MW
  - Unit6: 1,100 MW

- Fukushima II
  - Unit1: 1,460 MW
  - Unit2: 1,784 MW
  - Unit3: 1,784 MW
  - Unit4: 1,784 MW
  - Unit5: 1,784 MW
  - Unit6: 1,100 MW

Plant status at time of earthquake:

- In operation:
  - Onagawa: Unit1: 524 MW, Unit2: 825 MW, Unit3: 825 MW
  - Fukushima II: Unit1: 460 MW, Unit2: 784 MW, Unit3: 784 MW, Unit4: 784 MW, Unit5: 784 MW, Unit6: 1,100 MW

- Out of operation (No fuel in RPV):
  - Onagawa: Unit3: Out of operation

- Out of operation:
  - Fukushima I: Unit6: Out of operation

- In operation:
  - Fukushima II: Unit1: 1,100 MW, Unit2: 1,100 MW, Unit3: 1,100 MW, Unit4: 1,100 MW

RPV: Reactor Pressure Vessel
## Plant Status at each site

### Onagawa Nuclear Power Station
- One of 5 off-site power line and 6 of 8 EDGs were available
- All plants achieved cold shutdown by using those electric power supply systems by March 12, 2011

### Fukushima Dai-Ni (2nd) Nuclear Power Station
- One of 4 off-site power lines and 6 of 12 EDGs were available
- Safety related motors and pumps were replaced
- Transformers were replaced from Kashiwazaki NPP
- All plants achieved cold shutdown by using tie-line of those power supply systems by March 14, 2011

### Fukushima Dai-Ichi (1st) Nuclear Power Station
- All of electric power supplies were lost on Units 1 to 4
- Only one EDG was available on Units 5 and 6

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<thead>
<tr>
<th>Reactor Scram Response</th>
<th>Loss of off-site Power due to Earthquake</th>
<th>Emergency DG startup</th>
<th>Reactor Cold Shutdown</th>
</tr>
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EDG: Emergency Diesel Generator
NPP: Nuclear Power Plant
Overview of Plant Status After Earthquake and Tsunami

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1. Emergency Response
(Initial actions after the accident)
# Overview of Emergency Response

## Emergency response

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 11, 14:46</td>
<td>Unit 1 Hydrogen explosion (March 12)</td>
</tr>
<tr>
<td></td>
<td>Unit 3 Hydrogen explosion (March 15)</td>
</tr>
<tr>
<td>Approx. 10 days</td>
<td></td>
</tr>
</tbody>
</table>

## Objective

<table>
<thead>
<tr>
<th>Objective</th>
<th>Activities taken by Toshiba</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery of electric power supply</td>
<td>• Supply and laying of cables&lt;br&gt;• Supply of car batteries for I&amp;C</td>
</tr>
<tr>
<td>Core cooling</td>
<td>• Supply and connection of hoses and cables for seawater injection&lt;br&gt;• Supply of 52 sets of submerged pump</td>
</tr>
<tr>
<td>Avoidance of hydrogen explosion</td>
<td>• Plan to drill holes on the R/B roof&lt;br&gt;• Mock up test</td>
</tr>
<tr>
<td>Cold shutdown of units 5 &amp; 6</td>
<td>• Utilize of the last D/G, cabling and panel installation&lt;br&gt;• Installation of pumps and piping</td>
</tr>
</tbody>
</table>

I&C: Instrumentation and Control  R/B: Reactor Building  D/G: Diesel Generator
Emergency Response

**Preparation of emergency measures**

- **Recovery of Electric Power Supply**
  - Car batteries for I&C power supply (2,000 units)
  - Installation of Cables
    - High-voltage cables: 2,000m
    - Low-voltage cables: 23,400m

- **Urgent core cooling by seawater injection**
  - Connection hose and cables
  - Submerged pumps (52 sets)

- **Avoidance of hydrogen Explosion**
  - Drill the roof of reactor building
    - (Water jet and core drill)
  - Mock up test before explosion of Unit 3

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**Emergency response**

- (≈10 days)
- July, 2011
- December, 2011

**H₂ explosion**

**Drill the Holes**

**Submerged pump • hose**

I&C: Instrumentation and Control

HVAC: Heating Ventilation and Air Conditioning and Cooling System

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Activities for Reactor cooling of Unit 5

**Prediction of core damage risk of Unit 5**

- Observed and understood the plant condition and predict future trend considering current plant condition
- Predicted the risk of core and spent fuel damage
- Designed and installed components, piping and cables

With the installed system operation, temperature began to fall on the first day


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**Graph**

- RPV Temp.
- SFP Temp.


- Prediction and warning

- In-service

- 9 days

- 1 day

**Diagram**

- RHRS Pump and Motor
- RHR System
- RHR Heat Exchanger
- Flooded by Tsunami
- Temporary submerged water Pump
- Damaged by Tsunami
- From DG of Unit 6 (Temporary Cables)

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2. Reducing Radioactive Release

- H₂ explosion
- (~10 days)
- July, 2011
- December, 2011

- Emergency response
- Reducing radioactive release
- Achieving cold shutdown
- Mid- & long-term countermeasures
Reduction of Overflow Risk

- Risk prediction, proposal, and urgent on-site work
  - Evaluated overflow risk
  - Installed water level gauge in T/B pit
  - Proposed water treatment facility based on the risk evaluation
  - Poured concrete by civil team to avoid excess release of contaminated water to sea
Establish the water treatment system

Highly contaminated water accumulated in T/B

- Nearly 70,000 tons of contaminated water as of April 19, 2011
- Urgent water transfer is required to Rw/B
- Established recirculation loop for water treatment system
- Huge volume of construction

Transfer piping installation 4,100m with 3,000 welding points
Installation of 1st Water Treatment System

- **International collaboration**
  - KURION & AREVA systems was integrated by Toshiba site work
  - 24-hrs-a-day work to meet schedule
- **Just two months for delivery**
  - Designed started on April 11, and delivered on June 17

![Diagram showing water level changes over time](chart.png)
Installation of 2\textsuperscript{nd} Water Treatment System

\textbf{Simplified Active water Retrieve and Recovery System}

- Increase the stability and redundancy
- Ready for operation within only 2.5 months from proposal under severe conditions
- Major role among water treatment systems since October, 2011

\textbf{Major Characteristics}

- Reduction of media changes
- Shielding design for workers
- Improvement of DF
- Stable operation

DF: Decontamination Factor
System performance comparison

- System performance is better in each respect

<table>
<thead>
<tr>
<th></th>
<th>SARRY</th>
<th>KURION</th>
<th>AREVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cesium Removal DF</td>
<td>$1 \times 10^6$</td>
<td>$1 \times 10^{2\sim5}$</td>
<td>$1 \times 10^3$</td>
</tr>
<tr>
<td>Treated Water/Vessel</td>
<td>5,568 m$^3$/vessel</td>
<td>425 m$^3$/vessel</td>
<td>-</td>
</tr>
<tr>
<td>Max Radiation Exposure*</td>
<td>&lt;1mSv/h</td>
<td>30mSv/h</td>
<td>-</td>
</tr>
</tbody>
</table>

* surface

![Graph showing accumulated amount of treated water and number of vessels for waste storage over time.](image)
3. Achieving Cold Shutdown
Achieve Cold Shutdown

- **Improve reliability for core cooling**
  - Installed another injection line using Core Spray line to enhance redundancy and to make direct cooling possible

- **Install temporary SFP cooling system**
  - Installed within a week in the severe dose rate area in Unit 2
  - Remarkable temperature reduction from approx. 70 °C to 40 °C on the first day

- **Improve reliability of N2 gas injection**
  - Installed three additional N2 injection facilities to reduce the risk of further hydrogen explosions
Continuous Monitoring of Plant Parameters

- **Improve reliability of RPV temperature monitoring**
  - Existing thermocouples of RPV have been broken in Unit 2
  - Installed alternate thermocouple under severe radiation conditions

- **Direct observation of PCV inside**
  - Industrial endoscope
  - Performed 1st and 2nd entry into PCV of Unit 2
  - Evaluated water level within the PCV

Photo of PCV inside in Unit 2

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**Photo of PCV inside in Unit 2**

- **N-10 Nozzle**
- **X-51 Penetration**
- **13 meters, 5 bends of piping**
- **Grating**
- **Inside wall of PCV**

RPV: Reactor Pressure Vessel
PCV: Pressure Containment Vessel
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Restoration Activities for Fukushima NPP

Mid- and long-term Countermeasure

International Cooperation

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Major Activity Areas of Mid- and Long-term

Three major areas of activities

- New additional water treatment system to reduce the risk of stored treated water further
- Spent fuel removal from SFP
- Core debris removal from PCV

H₂ explosion

(~10days)

Emergency response

Reducing radioactive release

Achieving cold shutdown

Mid- & long-term countermeasures

SFP: Spent Fuel Pool
PCV: Pressure Containment Vessel
New Accumulated Water Treatment System

**MRRS (Multi Radionuclide Removal System)**
- Increase of accumulated amount of treated water
- Expect further risk reduction of stored water

- **Oil separator**
- **KURION**
- **AREVA**

Desalination unit (RO apparatus)

**Multi-radionuclide removal system**

Tank

Emergency response

Reducing radioactive release

Achieving cold shutdown

Mid- & long-term countermeasures

H₂ explosion

(~10 days)

July, 2011

December, 2011

RO: Reverse Osmosis

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Outline of MRRS System

- **MRRS (Multi Radionuclide Removal System)**
  - Conceptual design by EnergySolutions
  - Detailed design and manufacturing by Toshiba

- **Performance**
  - Remove all residual radioactivity to below non-detectable level (less than about 1Bq/L depending on nuclide)
  - Strontium was identified as the major nuclide
  - With MRRS, the radioactivity level will become lower by two order of magnitude.
Overview of MRRS

The system has already been installed at the Fukushima site, and is now waiting for approval by NRA

As of September, 2012
Cited from TEPCO release

TEPCO: Tokyo Electric Power Company
NRA: Nuclear Regulatory Authority
Development of fuel removal system

- Collaborate with U.S. team, e.g., Westinghouse and U.S. vendors
- Develop remote control fuel handling machines, crane and transfer vessel
- Radiation condition: over 800 mSv/h at a maximum
- Removal work to be started from the end of 2014

<table>
<thead>
<tr>
<th>Item</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
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<tr>
<td>System Design</td>
<td></td>
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<tr>
<td>Basic Design</td>
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<tr>
<td>Detail Design</td>
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<tr>
<td>Fabrication</td>
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<tr>
<td>Installation and Test</td>
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<tr>
<td>Spent Fuel Removal</td>
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</table>

Schedule for Fuel Removal

Fuel Removal System of Unit 3
Leakage inspection for PCV Vent Pipe

- **Develop Quadruped robot with compact inspection vehicle**

Image of vent pipe inspection by Quadruped Robot for Unit 2

Reference: TEPCO HP
URL: http://photo.tepco.co.jp/date/2012/201212-j/121211-01j.html
Inspection results for PCV Vent Pipe

- Quadruped robot performed leakage inspection
  - Inspected vent pipe of PCV in Unit 2 on December 11, 2012
  - No leakage was found
  - Seven other vent pipes will be inspected in the near future

Reference: TEPCO HP
URL: http://photo.tepco.co.jp/en/date/2012/201212-e/121211-02e.html
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International Cooperation

Toshiba’s international partners

- Mt. Fuji-team: Toshiba, Westinghouse, B&W, Shaw, and Exelon
  - Issued “Total Management Plan” reflecting TMI experiences with an eye toward 10-year restoration in April and in May, 2011
  - Promoted SAMG with Exelon to improve plant safety

- Install equipment for inspection and restoration
  - T-HAWK (US: Westinghouse and Honeywell)
  - Simplified Active water Retrieve and Recovery System (US: Shaw, etc)
  - Multi Radionuclide Removal System (US: EnergySolution)
  - Spent Fuel Removal System on Unit 3 (US: Westinghouse)

- Toshiba is investigating available technologies with Russia, Germany, UK, and Kazakhstan on waste management and core debris removal

TMI: Three Mile Island Nuclear Power Station
SAMG: Severe Accident Management Guideline
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Conclusion

Since March 11, 2011, Toshiba has taken a key vital role of restoration at all steps, such as:

- Prediction and evaluation of the plant,
- Planning of various recovery plan,
- Design, engineering and manufacturing,
- Site execution

Toshiba will continue its activities at the Fukushima site in cooperation with the Japanese government and TEPCO.

In addition, Toshiba greatly appreciates international support for these challenges.
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