Robot Technology for Nuclear Decommissioning of Fukushima Daiichi Nuclear Power Station

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*The contents of this presentation include the results of “Establishment of basic technology for decommissioning and safety of nuclear reactors for power generation in 2013 (technological study and research concerning forming an idea for processing and disposing of radioactive waste resulting from the accident)”, a project commissioned by the Ministry of Economy, Trade and Industry, and the 2013-2014 subsidiary for decommissioning and contaminated water measures (development of technologies for processing and disposing of waste resulting from the accident).

*Plant information included in this document is taken from TEPCO’s official website.
Outline of Today’s Talk

• About IRID
• Robots for the decontamination task
• Robots for the RPV inspection task
• Summary

I extend my sincere condolences for all the victims, and express my hearty sympathy to all the evacuees due to the Earthquake
About IRID

Research & Development Consortium for the decommissioning of the Fukushima Daiichi NPS

Founding Members (18)

- National Research Institutes(2):
  Japan Atomic Energy Agency (JAEA),
  National Institute of Advanced Industrial Science and Technology (AIST).

- Manufacturers(4):
  Toshiba Corporation, Hitachi-GE Nuclear Energy, Ltd.,
  Mitsubishi Heavy Industries, Ltd., ATOX (since May 29, 2014).

- Electric utilities etc. (12):
  Tokyo Electric Power Company (hereinafter called as EPC) (TEPCO),
  Hokkaido EPC, Tohoku EPC, Chubu EPC, Hokuriku EPC, Kansai EPC,
  Chugoku EPC, Shikoku EPC, Kyushu EPC, The Japan Atomic Power Company,
  J-POWER, Japan Nuclear Fuel Limited.
Scope of Business

IRID gathers knowledge and ideas from around the world for the purpose of R&D in the area of nuclear decommissioning under the integrated management system.

R&D projects:
- Investigation of damaged PCV and preparation of repair tools
- Preparation for fuel debris retrieval
- Treatment and disposal of radioactive waste

Over 700 researchers participate in IRID and engage in the R&D projects at their facilities.

R&D for Decommissioning
Promote collaboration for Decommissioning with Domestic and International Parties
Development of Human Resource for R&D

For more information >> http://www.irid.or.jp/en

15 projects (FY2015)
Relationship Diagram

METI: Ministry of Economy, Trade and Industry (http://www.meti.go.jp/)
NDF: Nuclear Damage Compensation and Decommissioning Facilitation Corporation (http://www.ndf.go.jp/)

NDF: Nuclear Damage Compensation and Decommissioning Facilitation Corporation (http://www.ndf.go.jp/)
TEPCO
IRID
METI
Decommissioning Policy
“Mid-and-long Term Roadmap”
Strategy Planning
R&D Planning & management
R&D Management
R&D Implementation
Fukushima Daiichi NPS
D&D Engineering
Specialization & Cooperation
Mid-and-Long-Term Roadmap was amended on June 12, 2015 and the target time frame (milestone) was specified.

**Fuel Debris Retrieval**
- Decision of principle plan for fuel debris retrieval of each Unit within 2 years
- Confirmation of fuel debris retrieval method for the first Unit by the first half of FY2018
- Commencement of fuel debris retrieval from the first Unit by December 2021
Fuel debris retrieval plan on Mid-and-Long-Term Roadmap (Unit 2)

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
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<tbody>
<tr>
<td>FY2012</td>
<td>FY2013</td>
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<td>FY2021</td>
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<td>FY2022</td>
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</table>

- **Decontamination of the inside of the R/B**
  - R&D of remote decontamination equipment (1F)
  - Upper floors
- **Repair the part between PCV and R/B**
  - R&D of the PCV inspection equipment
  - PCV repair (lower part) equipment
- **Water filling in the PCV**
  - PCV repair (upper part) equipment
- **Inspection of the PCV internals/in-core inspection/sampling**
  - Inspection of the lower part of the PCV
  - Repair / water filling
  - Inspection of the upper part of the PCV
- **R&D of fuel debris removing techniques**
- **Fuel debris removal work**
  - R&D of the method/device for fuel debris removal
- **Stable storage, processing/disposal of fuel debris after removal**
  - R&D of safety evaluation technique, technologies for loading, transportation and storage
  - R&D of mock-up processing/disposal technologies

**Technological Holding Point**

1. Defining the repair method of the lower part of the PCV (stop leakage)
2. Defining the method of inspecting the inside of the PCV
3. Defining the repair method of the upper part of the PCV (stop leakage)
4. Completion of water filling of the upper part of the PCV
5. Defining the method for inspecting inside of the core
6. Completion of the preparation of fuel debris storage cans etc.
7. Decision on fuel debris processing / disposal methods

**Timeline**

- FY2021
- FY2019
- FY2017
- FY2015
- FY2013

- R&D of remote decontamination equipment (1F)
- Upper floors
- Defining the repair method of the lower part of the PCV (stop leakage)
- Defining the method of inspecting the inside of the PCV
- Defining the repair method of the upper part of the PCV (stop leakage)
- Completion of water filling of the upper part of the PCV
- Defining the method for inspecting inside of the core
- Completion of the preparation of fuel debris storage cans etc.
- Decision on fuel debris processing / disposal methods
- Installation of fuel debris removal equipment
- In-core inspection/sampling
- Fuel debris removal

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Fuel debris retrieval procedure

Current

- Removal of fuel from Spent fuel pool
- Decontamination of work area and walkway
- Investigation of RPV interior
  - Location and configuration of fuel debris
  - Damage of structural material
- Investigation of PCV interior
  - Location and configuration of fuel debris
  - Damage of Pedestal and PCV
- Investigation and stop of water leakage from PCV

Technology R&D

Fuel Debris Retrieval from 2021

- Submersion method
- In-air method

- Most favorable approach for minimizing the radioactive exposure of workers
- Stop whole water leakage on the PCV
- Retrieve the fuel debris at 35m distance
- Ensure boundaries
- Operate and maintain the equipment in the PCV boundary

Dose rate
- *PCV 100 Gy/h
- *RPV 1k Gy/h
- *Requirement level for equipment R&D

Current Technology R&D

Investigation of RPV interior
- Location and configuration of fuel debris
- Damage of structural material

Investigation of PCV interior
- Location and configuration of fuel debris
- Damage of Pedestal and PCV

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Research and Development for the decontamination task

Decontamination of work area and walkway
## Dose rate goal for decontamination equipment

- **Development goal of the decontamination equipment**
  - (the needs for PCV leakage investigation repairing work, and overall dose reduction scenario)
  - 3 mSv/h for work area
  - 5 mSv/h for access route

<table>
<thead>
<tr>
<th>Needs for dose reduction* and the dose rate</th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building conditions</td>
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<tr>
<td>The dose rates are low in whole; about 1 to 10 mSv/h</td>
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<tr>
<td>The rates have been high in south area, some parts in southeast area measures 5,000 mSv/h</td>
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<tr>
<td>Used to be 2<del>60 mSv/h (In 2014 Oct, the rates were about 5</del>10 mSv/h because of decontamination in lower/middle parts and shielding)</td>
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<tr>
<td>The dose rates are high in whole; about 20~100 mSv/h</td>
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</tbody>
</table>

* mapping results of the dose rates at planned operation area (with needs of dose reduction) derived from PCV investigation and repair project

- : 3 mSv/h to 10 mSv/h
- : 10 mSv/h to 20 mSv/h
- : 20 mSv/h to 50 mSv/h
- : more than 50 mSv/h
- : out of study due to the lack of data
Overall Plan (Developed decontamination equipment and development status)

Upper floors

- FY2013: design
- FY2014-2015: production, verification test, applicability study of actual device

Underground floor

- FY2014: Study of technical challenges, development planning

High places

- FY2013: design, production
- FY2014-2015: improvement, verification test, applicability study of actual device

Low places <Development completed>

- FY2011-2012: design, production, test in 2F
- FY2013: improvement, verification test (factory, 1F)

Types of decontamination equipment:

- Dry ice blast
- High pressure water jet
- Suction/blasting
Development of technology for remotely operated decontamination in reactor buildings

- Contamination condition is the combination of loose material and fixing material.
- Dose comes from low place, high place, side wall, and hot spot.

**For Low Places**
- Suction/blast
- High pressure water jet
- Dry ice blast

**For Upper Floors**
- Compressor Unit
- Decontamination Unit
- Work Unit

Each unit is lifted up to the upper floor with the Lifter in continuity.

**For High Places**
- Expand
- Swing arm

Ground floor of Reactor Building
Research and Development for the RPV inspection task

Investigation of PCV interior
  • Location and configuration of fuel debris
  • Damage of Pedestal and PCV
Development plan for investigation method and device

Set the development plan based on estimated condition of RPV and PCV of Unit 1 to Unit 3 (*1)

Unit 1

- Almost all of melted fuel have been fallen down to the bottom of RPV plenum and little fuel have left in RPV.

Unit 2

- While some part of melted fuels has fallen down to the bottom of RPV lower plenum and PCV pedestal, the other part may have been left inside RPV.
  - Presumed that more fuel than having estimated may have fallen down to PCV in Unit 3.

Unit 3

- As the possibility that fuel debris spread outsides the pedestal is lower compare with Unit 1, investigation inside the pedestal should be developed as priority.
  - As in Unit 3, the water level inside the PCV is high, penetration which will be used in Unit 1 and 2 must be submerged, other methods should be examined.

*1: [Reference] TEPCO’s webpage Dec. 13, 2013 “The first progress report related to estimated state of reactor core and RPV of Fukushima Daiichi NPS Unit 1, 2 and 3, and unsolved issues”
Development of technology for investigation inside the PCV

Investigation methods and remotely operated devices have been developed to identify conditions inside the PCV and determine the situation regarding fuel debris.

Shape-changing crawler (Unit 1)
- Moving within pipes
- Shape changing
- Moving along flat surfaces
- Camera & Light
- Thermometer
- Crawler

Small size crawler (Unit 2)
- Coming in the inside of the pedestal via CRD rail
- Camera & Light

【Unit 1】X-100B penetration (φ115mm)

【Unit 2】X-6 penetration
Development Steps (for Unit 1)

Investigated area:  
- Outside the pedestal on the basement floor  
- Near the access entrance of RPV pedestal

(1) Investigations from the X-100B penetration (FY2015): B1 (Completed), B2  
 CURRENTLY, DOSE RATE NEAR THE X-6 PENETRATION IS VERY HIGH.

(2) Investigation from X-6 (FY2016 ~ FY2017): B3  
(After decontamination near X-6 penetration)  
Investigation to obtain information using debris shape measurement apparatus outside the pedestal on the basement Fl.

B1. Investigation outside the pedestal on the first Fl (grating).  
Completed in April, 2015

B2. Investigation outside the pedestal on the basement Fl.

B3. Investigation outside the pedestal on the basement Fl.  
And workers entrance

Depending on result of B2 investigation, B3 may be conducted.

Investigation inside the pedestal may be conducted depending on the investigation of Unit 2.
B1 investigation completed in April, 2015

(1) Overview of equipment
- Shape-changing crawler equipment
- Inserted from the narrow access entrance (X-100B penetration: φ100mm)
- Travel on grating stably.

(2) Image of investigation route
### Achievement of B1 investigation

<table>
<thead>
<tr>
<th>item</th>
<th>Observed result</th>
</tr>
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<tbody>
<tr>
<td>Opening on grating to the lower floor</td>
<td><strong>&lt;Potential access path&gt;</strong> to the lower floor during next B2 investigation&lt;br&gt;&lt;br&gt;<strong>No interference around the opening</strong></td>
</tr>
<tr>
<td>CRD rail</td>
<td><strong>&lt;Potential access path&gt;</strong> to the inside of pedestal&lt;br&gt;&lt;br&gt;<strong>Could not be observed well</strong>&lt;br&gt;(difficult access due to narrow access route)</td>
</tr>
<tr>
<td>General observation</td>
<td><strong>&lt;Existing components&gt;</strong> No serious damage&lt;br&gt;(PLR pump &amp; piping, pedestal wall, HVH, etc..)&lt;br&gt;&lt;br&gt;<strong>&lt;measurement results at 12 locations&gt;</strong>&lt;br&gt;Temperature 17.8<del>21.1 ℃&lt;br&gt;Dose rate 4.7</del>9.7 Sv/hr</td>
</tr>
</tbody>
</table>
Development Steps (for Unit 2)

[Investigated area] : - On the platform (Upper surface of platform, CRD housing)
   - Basement floor

(1) Investigation from X-6 penetration (Φ115mm) (FY2015) : A2
(2) Investigation from X-6 (Enlarge hole) (FY2016～2017) : A3, A4
   • Insert debris visualization system, investigate inside pedestal.

Step to use X-6 penetration
• Remove shield in front of penetration
• Pierce a hole to penetration hatch
• Remove inclusions inside penetration

Based on the result of internal investigation from A2 to A4, investigation outside pedestal may be conducted.
Lessons learned and future issues

IRID is responsible for Researching and Developing technology that is indispensable for the decommissioning of the Fukushima Daiich Nuclear Power Station

< Lessons Learned >
- Robot Technology is indispensable for the decommissioning tasks
- But, there are lots of difficulties;
  - Luck of TRUE specification
  - Requirement of high reliability in short term project
  - Based on Man-Machine systems

< Future Issues >
- System complexity
- interdisciplinary knowledge
- Risk reduction vs. cost and efficiency

Call for challengers in the field of Robotics and Automation.
Implementing Technology in Society
For Your Information

• **TEPCO homepage** “Decommissioning Plan of Fukushima Daiichi Nuclear Power”
  http://www.tepco.co.jp/en/decommission/index-e.html

• **METI homepage** “Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4”
  http://www.meti.go.jp/english/earthquake/nuclear/decommissioning/

• **TEPCO VIDEO** “Use of robots for reactor stabilization and decommissioning at Fukushima Daiichi Nuclear Power Station” (2015.02.15)

• **IRID Homepage**
  http://www.irid.or.jp/en/
For Your Information

Overview of IRID

http://www.irid.or.jp/_pdf/pamphlet2014_eng.pdf

Annual Report

http://www.irid.or.jp/_pdf/pamphleth26_eng.pdf