Remote Technology for Decommissioning of Fukushima Daiichi Nuclear Power Station

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Agency for Natural Resources and Energy (ANRE) and TEPCO:
Council for the Decommissioning of TEPCO’s Fukushima Daiichi NPS, member
Nuclear Damage Compensation & Decommissioning Facilitation Corp. (NDF):
Fuel Debris Retrieval Expert Committee, member
Decommissioning R&D Partnership Council, member
International Research Institute for Nuclear Decommissioning (IRID), TC member
Japan Atomic Energy Agency (JAEA): Working Committee on Remote Control Equipment and Device Development Facility (Mock-up facility), Chair
Fukushima Innovation Coast Framework Promotion Committee, member
Accident of Fukushima Daiichi Nuclear Power Plant

- Earthquake (14:47)
- Loss of Power Supply
- Activation of Emergency Diesel Generator
- SCRAM  
  Stop Reactors
- Tsunami
- Damage of Fuel Tanks and Generators
- SBO (Situation Black Out) (15:39)
- Failure of Cooling System of Reactors and Fuel Storage Pool
- Loss of Cooling Water
- Melt down
- Hydrogen Explosion (Mar. 12-15, Unit 1, 3, 4)
Current Situation of 4 Units

- Fuel Debris (Melt-down Fuel)
- Spent Fuel and New Fuel in Spent Fuel Pool

55th meeting of Japanese Government and TEPCO: Council for the Decommissioning of TEPCO’s Fukushima Daiichi NPS
## Mid-and-long-Term Roadmap Summary (TEPCO)

### Present (Completion of Step 2)
- **Phase 1**
  - Period to the start of fuel removal from the spent fuel pool (Within 2 years)
  
  - Commence the removal of fuels from the spent fuel pools (Unit 4 in 2 years)
  
  - Reduce the radiation impact due to additional emissions from the whole site and radioactive waste generated after the accident (secondary waste materials via water processing and debris etc.) Thus maintain an effective radiation dose of less than 1 mSv/yr at the site boundaries caused by the aforementioned.
  
  - Maintain stable reactor cooling and accumulated water processing and improve their credibility.
  
  - Commence R&D and decontamination towards the removal of fuel debris
  
  - Commence R&D of radioactive waste processing and disposal

### Within 2 Years
- **Phase 2**
  - Period to the start of fuel debris removal (Within 10 years)
  
  - Complete the fuel removal from the spent fuel pools at all units
  
  - Complete preparations for the removal of fuel debris such as decontaminating the insides of the buildings, restoring the PCVs and filling the PCVs with water. Then commence the removal of fuel debris (Target: within 10 years)
  
  - Continue stable reactor cooling
  
  - Complete the processing of accumulated water
  
  - Continue R&D on radioactive waste processing and disposal, and commence R&D on the reactor facilities decommission

### Within 10 Years
- **Phase 3**
  - Period to the end of decommissioning (After 30-40 years)
  
  - Complete the fuel debris removal (in 20-25 years)
  
  - Complete the decommission (in 30-40 years)
  
  - Implement radioactive waste processing and disposal

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Actions towards systematic staff training and allocation, improving motivation, and securing worker safety will be continuously implemented.
Needs (Tasks) for Remote Technology

- Water injection
- Removal and transportation of rubbles, fuels (including fuel debris), and contaminated water, etc. (Cutting, suction, handling)
- Investigation, measurement, and mapping (images, radiation, etc.)
- Sampling (dust, contaminated water, concrete core, fuel debris, etc.)
- Decontamination and Shielding
- Fixing of contaminated water leakages
- Handling, transportation, removal, setup, and dismantling of devices, instruments, equipments, facilities, etc.
- Waste and contaminated water management
- Dismantling
Missions depending on phases

• Phase 1: Emergent Situation
  – Cooling down of reactors

• Phase 2: Stabilization
  – Containment, systems reconstruction, for aftershocks

• Phase 3: Decommission
  – Fuel removal

• Reduction of radiation exposure of workers
Phase 1
Procure off-the-shelf robots and equipment (for general purpose)
Phase 2
Remodel developed system and technology

Quince 1
Quince 2
Quince 3
Gamma-ray Measurement Robot
JAEA-3
Sakura
Rosemary
FRIGO-MA
Survey Runner
ROV
Quadruped Robot & Inspection Robot
ASTACO-SORA
MEISTeR
Inspection Robot Of upper part of S/C
Manipulator for Robot Set-up
Phase 3
New development
(for specific use)

- Robot for Decontamination
- Inspection robot for high location
- Water Surface Inspection Robot
- Inspection Robot for Lower part of S/C
- PCV Inspection Robot Scorpion Robot
- PCV Inspection Robot PMORPH
- PCV Inspection Robot Mini Mola Mola
Remotely controlled machines utilized for the response of accident of nuclear power plant (Foreign Machines)
Remotely controlled machines utilized for the response of accident of nuclear power plant (Domestic Machines)
What have achieved so far (Successful)

- Exploration, investigation & measurement
  - States, Spatial Radiation Dose (Level & Distribution), 3D data, etc.

- Rubble removal
  - On Site Field (Outdoor), Inside R/B, Inside Spent Fuel Pool, on Operation Floor

- Sampling
  - Dust, Contaminated Water, Core Samples
What have achieved so far (Insufficient or on-going)

- Decontamination
- Water Leakage Fixing
- Sampling
  - Fuel Debris
- Fuel Debris Removal and Transportation
Unrecoverable Robots
Factors of failures

- Direct factors
  - Communication failures
  - Misoperation
  - Malfunctions by radiation

- Indirect factors
  - Prototypes (not products)
  - Unknown environment
Measures for Direct Factors

- Communication failures
  - Combination of wired & wireless communication
  - Implementation of wireless com. infrastructure

- Misoperation
  - Training
  - Improvements of Human Interface (situation awareness)
Concept of Bird-eye view Display

- Production of Virtual bird-eye camera image by integrating Multiple Fish-eye cameras
- Obstacle detection by LRF
Outcome of the Project

Narrow Passage (Maze)  Bird-eye View Image
Application to Robot for Decommissioning of NPS

MHI Super Giraffe  MHI MEISTeR
Generation of robot view from arbitrary viewpoints
Measures for Direct Factors

- Communication failures
  - Combination of wired & wireless communication
  - Implementation of wireless com. infrastructure

- Misoperation
  - Training
  - Improvements of Human Interface (situation awareness)

- Malfunctions by radiation
  - Rad-hardened devices, mechanical systems (not use semiconductor)
  - Design of robust systems
  - Redundant and functionally degradable
Gamma irradiation experiment

- The gamma irradiation was conducted in the Technology Development Center of ATOX Co., Ltd.

![Experimental environment](image1.png)

**Camera model:** AXIS M3007-PV

![Experimental layout seen from above](image2.png)
Gamma irradiation experiment: Movie

- After 23 min irradiation

Bird's-eye view

Camera 1 (malfunction after 23 minutes)

Camera 2

Camera 3

Camera 4

Bird's-eye view generation corresponding to camera malfunction
Gamma irradiation experiment: Result(1)

- Camera 1 malfunctioned after 23 min irradiation (Integral dose: 192.1 Gy)
- Camera 2 malfunctioned after 54 min irradiation (Integral dose: 141.3 Gy)

Proposed method

Dept. of Precision Engineering
The University of Tokyo

2016/4/5
Gamma irradiation experiment: Result (2)

- Camera 4 malfunctioned after 82 min irradiation (Integral dose: 224.1 Gy)
- Camera 3 malfunctioned after 94 min irradiation (Integral dose: 162.9 Gy)
Measures for Other Factors

• Prototypes (not products)
  – Risk assessment for failures
  – Testing
Fukushima Innovation Coast Framework

R&D bases, organization for collaboration, human resource development in Fukushima prefecture

- Fukushima U.
- Aizu U.
- Nihon Univ., Col. Eng.
- Fukushima Tech. Center
- ふくしま国際医療科学センター (福島医大)
- 会津若松研究（福島医大）
- 産業技術再エネ研究拠点
- 環境創造センター
- 田沢湖

【アカデミアコンソーシアムふくしま】
- 県内19の高等教育機関の連携組織
- 独自の単位互換制度

Human Resource Development

- テクノアカデミー
  - 再エネ、医療など本県復興を担う人材を育成

- 福島県廃炉・除染ロボット技術研究会(ハイテクプラザ)
  - 各メーカーからの情報収集、情報共有化に関する産学ネットワークの構築(109)

- 関連産業協議会・研究会
  - 医療機器(258)・再エネ(501)・輸送用機械(376)・半導体(134)

- ハイテクプラザの取組実績
  - 技術相談…1,500社4,000件/年・機器開放…30000時間/年
  - 依頼試験…3,500件/年
  - 放射能測定…工業製品1000検体/年・加工食品2500検体/年

Collaboration with Industry
Mockup and instrumentation tools to be installed

Facilities

Demonstration test area for the technique to repair a water leakage at the PCV and development and demonstration test area for the remote controlled devices are prepared in Test building.

- Test building (W60m×D80m×H40m)
- Research management building
- Virtual Reality System
- Test assembly (1/8 cut) : IRID
- Water pool
- Motion capture camera
- Mock-up staircase
- Robot Simulator
Measures for Other Factors

• Prototypes (not products)
  – Risk assessment for failures
  – Testing

• Unknown environment
  – Advance investigation
  – Assumption of various situation
For Fuel Debris Retrieval and Decommissioning

- Development of diverse technology (Portfolio)
  - Devices and robots for specific and general use
  - Cutting devices, manipulators, handling devices
    (Sampling, leakage fixing, contaminated water processing, retrieval of fuel debris)
  - Endoscope-type Robot
# Summary of Technology Diversity (Portfolio)

<table>
<thead>
<tr>
<th>Needs</th>
<th>Basic Function</th>
<th>Environment/Objects</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access</td>
<td>Mobility</td>
<td><strong>Basic Environment type</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground</td>
<td>Move by crawlers, wheels(normal, magnet), endscope</td>
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<tr>
<td></td>
<td></td>
<td>Aerial</td>
<td>Move by multi-copter, balloon, blimp, suspension-type, telescopic</td>
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<tr>
<td></td>
<td></td>
<td>Water, Underwater</td>
<td>Move by boat(ROV, USV), submarine(ROV, UAV)</td>
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<tr>
<td></td>
<td></td>
<td>Others</td>
<td>Combination, specialized</td>
</tr>
<tr>
<td></td>
<td>Environment conditions</td>
<td>Obstacles</td>
<td>Avoiding, pushing, clearing, climbing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Narrow space, Pipes</td>
<td>Passing through (active/passive)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High radiation</td>
<td>Radiation-tollerant</td>
</tr>
<tr>
<td>Information acquisition</td>
<td>Sensing</td>
<td><strong>Basic Environment type</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground, aerial, underwater</td>
<td>Camera, gamma camera, dosimeter, laser range sensors, endoscope</td>
</tr>
<tr>
<td></td>
<td>Environment conditions</td>
<td>Obstacles</td>
<td>Image processing (counter-occlusion)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turbidity</td>
<td>Soner</td>
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<tr>
<td></td>
<td></td>
<td>Water drop</td>
<td>Image processing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High radiation</td>
<td>Radiation-tollerant</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Work</th>
<th>Objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>(debris removal, decontamination, set-up)</td>
<td>Manipulation, handling, vacuuming</td>
</tr>
<tr>
<td></td>
<td>Material(Rubbles, debris, shielding blocks, walls/floors)</td>
</tr>
<tr>
<td></td>
<td>Arm, gripper, vacuumer, water injection</td>
</tr>
<tr>
<td>(sampling)</td>
<td>Cutting, scabbling</td>
</tr>
<tr>
<td></td>
<td>Material(Rubbles, debris, shielding blocks, walls/floors)</td>
</tr>
<tr>
<td></td>
<td>Machining tools, laser cutting devices, waterjet</td>
</tr>
<tr>
<td></td>
<td>Vacuuming, cutting, manipulation, handling</td>
</tr>
<tr>
<td></td>
<td>Material(fuel debris, concrete-core), air, dust, sand, water</td>
</tr>
<tr>
<td></td>
<td>Vacuumer, machining tools, waterjet, arm, gripper</td>
</tr>
</tbody>
</table>
For Fuel Debris Retrieval and Decommissioning

• Development of diverse technology (Portfolio)
  – Devices and robots for specific and general use
  – Cutting devices, manipulators, handling devices
    (Sampling, leakage fixing, contaminated water processing, retrieval of fuel debris)
  – Endoscope-type Robot

• Water proof devices
• Radiation-tolerant devices
• Autonomy and intelligence of remotely controlled systems
• 3D reconstruction from movies
  – Structure from Motion
Inspection inside PCV in Unit 3
(operated by IRID/Toshiba and TEPCO)
July 19-22, 2017

- Structures
- Melt
- Deposits
3D Reconstruction of Unit 3 Pedestal

- 3D Reconstruction by Structure from Motion

3D reconstruction using multiple images

Univ. of Tokyo

IRID, Toshiba
Coming soon

• Removal of spent fuel of unit 3
• Dismantling of exhaust pipe of unit 1-2
• Investigation inside PCV of unit 1
• Retrieval of fuel debris of unit 2
Removal of spent fuel of unit 3
(2018.11-)

(Toshiba, IRID)
Dismantling of exhaust stack of unit 1-2
(2018.12-)

(TEPCO, ABLE)
Investigation inside PCV of unit 1 (2019-) (HGNE, IRID)
Retrieval of fuel debris of unit 2 (2019-)

(MHI, IRID)
For Future Development

• Make use of the failure experience
• Utilization of available technology
  – SLAM, SfM, Drones, AI (Deep Learning), IoT, etc.
• Efficiency: Systematic and drastic design for repeating use
• Common platform
  – From specific system development to standardized components
Summary

  - System integration
  - Derivation of solutions
  - Intelligent (not just mounting AI)
- Needs to concentrate the wisdom of the world
  - Nuclear accidents do not happen often
  - International cooperation in knowledge sharing and technology transfer
- Dissemination of the developed technology to other sites and applications
- Develop young human resources
IFAC World Congress 2023
(International Federation of Automatic Control)

**Venue:**
PACIFICO Yokohama (All-in-One Venue)

**Dates (tentative):**
July 9th (Sun) – 14th (Fri), 2023

**Vision:**
Wa: Harmony of Traditional Culture and Innovative Technology

Control for Solving Societal Problems and Creating Social Values
Thank you for your attention!

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