Decommissioning of the Fukushima Daiichi NPP
The Holistic Approach of Japan

FDR2019, May 24, 2019

Hajimu Yamana

President, Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF)
Professor Emeritus, Kyoto University
Ground of the decommissioning of the Fukushima Daiichi NPP

Nuclear power generation in Japan
- Current capacity: 38 commercial reactors operational; 38 GWe
- Re-started: 8 reactors in power generation
- Public’s mood: · Disinclined for nuclear power
  · Anxiety on radiation safety

D&D of Fukushima Daiichi Reactors
- Successful decommissioning of the four damaged units of Fukushima Daiichi is an indispensable prerequisite for Japanese energy policy
- Eliminating people’s anxiety on the NPP site is necessary for the revitalization of the suffered society
- Risk reduction of Fukushima Daiichi NPP, strongly required by regulatory authority

Air Dose Rate as of Nov. 2018
Data by NRA

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Where we are now, and what we are going to do

D&D process for accident nuclear facility generally understood (IAEA NW-T-2.7)

- Emergency response
- Stabilization
- Clean-up
- Safestore (Optional)
- Demolishing and remediation

Radioactive waste management

Fukushima Daiichi D&D

- Urgent stabilization of the damaged facilities (Core cooling, highly contaminated water removal, etc.)
- Contaminated water measures, ensuring cooling circulation, rubble removal, spent fuel removal, improvement of working environment
- Mid- and Long-term operations
  - Spent fuel removal (extended)
  - Fuel-debris retrieval
  - Waste storage and treatment
  - Ground water management (continued)
- Demolishing and waste disposal

Unit-3: March 2011

- Spent Fuel Removal
- Fuel-debris Retrieval
- Waste Management

Tanks for treated water

New incinerator

Frozen wall

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Organizational structure addressing 1F Decommissioning

NDF as a strategic supporter
- Legally authorized organization under jurisdiction of METI and MEXT
- Shareholder of TEPCO by majority of votes

Compensation facilitation
- Loan to TEPCO to facilitate compensation
- Business oversight to TEPCO

D&D facilitation
- Mid & long term Technical strategy for D&D
- Decommissioning Fund management
- Program and Project oversight
- R&D strategy and planning
- Public outreach

TEPCO • HD
(D&D operation delivery)
As a Licensee
As a Liability holder

Nuclear Emergency Response Headquarters
Government responsibility for disaster response

Whole of related Ministries

METI
- Strategic Proposal
- D&D policy (Roadmap)

NRA
- Safety regulation

IRID/JAEA/University
Technical support through R&D

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## Responsibility sharing for the 1F Decommissioning

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<td>Tokyo Electric Power Co. Ltd.</td>
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<td>Execution of R&amp;Ds</td>
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**METI**: Ministry of Economy, Trade and Industry  
**MEXT**: Ministry of Education, Culture, Science and Sports  
**NRA**: Nuclear Regulatory Authority  
**NDF**: Nuclear Damage Compensation and Decommissioning Facilitation Corporation  
**IRID**: International Research Institute for Decommissioning

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Risk reduction strategy


Data from Strategic Plan 2018 by NDF, 2017
Risk reduction as the basic strategy

Snapshot of the existing risk sources

- (Probability of exposure of the hazard)
- (Inventory of the potential hazard)

Envisioned risk-reduction trend

- (A) Crisis level
- (B) Hastily stabilized with urgent measures
- (C) Stabilized with strengthened control
- (D) Safe state achieved by D&D
- (E) Eternally safe state

Data from Strategic Plan 2018 by NDF, 2018
Contaminated water is successfully confined

Sea-side impermeable wall

Sea-side impermeable Wall

Land-side impermeable wall (Frozen soil)

Closed at Oct. 2015

Cs-137 concentration at the south part of the port

[Graph showing Cs-137 concentration (Bq/L) from 2011 to 2019, with a WHO drinking water guideline of 10 Bq/L marked.

Generation of ALPS-treated water

[Graph showing amount and rate of ALPS-treated water from 2014 to 2019.

Source: Modified from TEPCO website.

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Large-scale remote operation enabled the SF recovery (Unit-3)

- **2011**: Operating floor damaged by hydrogen explosion (appearance)
- **Sep 2011~Nov 2013**: Clearing up high dose rubbles
- **2011**: Operating floor damaged by hydrogen explosion (from the above)
- **2015**: Removal of large rubbles fallen down into the pool
- **2016**: Installation of radiation shielding
- **2018**: Installation of building cover and remote fuel handling system
## Schedule

### Unit-1
(Massive rubbles: being removed)

### Unit-2
(Operating floor: being investigated)

### Unit-3
(SF removal will start shortly)

<table>
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<tr>
<th>Phase-1</th>
<th>Phase-2</th>
<th>Phase-3</th>
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<td>2011</td>
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- **Spent fuel removal**
- **Fuel-debris retrieval**
- **Waste management**

**New milestones by the revised Mid and Long-term Roadmap**

- **Unit 3 removal**
- **Unit 1 removal start**
- **Unit 2 removal start**
- **Decision on the method for the 1st unit**
- **Fuel-debris retrieval for the 1st unit**
- **Prospect of processing & disposal**

Starting from small scale

Pics: https://photo.tepco.jp/en/index-e.html

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Fuel-debris distributed inside the reactor

Distribution of fuel-debris:
Estimated by severe accident simulation codes, muon-tomography, and heat balance analysis, as well as by referring to the result of TMI-2 accident. Inside RPV has yet to be observed.

Muon-tomography result

Types of fuel-materials

Data from Strategic Plan 2018 by NDF, 2018
Fuel-debris at Fukushima-Daiichi requires more investigation

1F-1,2,3

**Fuel-debris**
(U,Zr)O, (U,Zr,M)O,
(Fe, Cr, Ni),U, Zr),
(Fe, Cr, Ni),B,

**MCCI product**
(Zr, U, Ca)O,
Al-Ca-O
Fe-Si-(Zr,U)-Al

Fuel-debris of 1F-1,2,3, as its features;
- Consists of fuel (UO, PuO and Zircalloy) and control rods (B₄C and stainless steel)
- May have reacted with concrete to form MCCI product
- May have reacted with salt coming from sea water injected during accident
- Formed through unclear core disruption process with complicated dynamics of thermal and chemical conditions

TMI-2


Chernobyl-4

B. Burakov, V.G. Khlopina
Fuel-debris retrieval: a daunting challenge

**Associated difficulties**
- Uncertainty in the property of fuel-debris
- Uncertainty in the internal situation
- Uncertainty in the behavior of radioactive materials
- Difficult accessibility to the fuel materials
- Extremely severe internal environment
- Complexity in the water management
- Uncertainty in the long-term effect

**Technical Elements Needed**
- Internal inspection technique under extreme conditions inside PCV and RPV
  Instrumentation, remote manipulators, robotics, radiation-resistant electronics, etc.
- New techniques and devices for fuel-debris retrieval
  Retrieval machinery for fuel-debris, canister for retrieved fuel-debris, etc.
- Water management
  Processing of contaminated water, groundwater management, stoppage of leaks in reactor vessels, etc.
- Waste management
  Minimization, safe storage, treatment, disposal etc.
- Environmental control
  Reduction of atmospheric release, site remediation, etc.
- Safety/Risk assessment and safety control
  Risk analysis, safety case, probabilistic analysis, etc.
- Analysis of unknown materials
  Characterizing recovered fuel-debris and solid waste, non-destructive analysis, etc.
Fuel-debris retrieval strategy

Careful preparation is necessary for the fuel debris retrieval

1. Ensure confinement
2. Minimize exposure to workers
3. Safe retrieval of fuel debris

Partial-submersion plus side-entry method

**Requirements**
- Seismic integrity
- Workers safety
- Lower radiation dose
- Confinement of radioactive materials
- Confinement and access to the debris (Horizontal access)
- Fuel debris handling machine
- Prevention of re-criticality
- Water level control at PCVs and buildings

**Final selection of the fuel debris retrieval method**
- Partial-submersion
- Side-entry

**Rationales;**
- Too many penetrations at upper part of PCV
  - Technically difficult for water stoppage
  - causing too high dose to workers
- More information available on lower part of PCV through recent remote inspections
- Possible to work with SF removal in parallel
Remote inspection techniques adopted

**SA Analysis**

Estimation by MAAP/SAMPSON

- Shroud
- Pellets partially remain
- CR guide tubes partially remains
- Vessel bottom damaged
- Deposit of granular debris
- Fuel pins partially remain
- Part of FD solidified not causing MCCI?
- Damage of CR tube
- Dispersion of MCCI and FD

**Muon measurement**

- [Link](http://photo.tepco.co.jp/en/index-e.html)

**Remote survey**

- Unit 3 Underwater ROV
- Unit 1 Underwater view

Photographic images inside the pedestal of Unit-2

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Internal inspection of Unit-2 PCV (Jan. 2018)

(1) At an upward angle to the lower part of RPV (CRD housings)
Internal inspection of Unit-2 PCV (Jan. 2018)

(2) At a downward angle in PCV; inside Pedestal
Internal inspection of Unit-2 PCV (Jan. 2018)

(3) Bottom of PCV; inside Pedestal

Data from TEPCO
Newest observation by remote inspection (Unit-2) [Data from TEPCO, Feb. 13/2019]

- Shielding wall
- Isolation valve
- Guide pipe
- Telescopic pipe
- Biological shield
- PCV drywell
- Platform
- CRD housing
- Pedestal
- Remotely operated observation device

Deposit before touching
Deposit being touched
Approaching to bottom

Pictures: tepco.co.jp/decommissioning.information/newsrelease/reference/pdf/2019/1h/RF_20190213_1.pdf
Newest observation by remote inspection (Unit-2)

Data from TEPCO, Feb. 13/2019

Unit 2 internal investigation
Planned internal inspection using an advanced remote arm

(1) Access to PCV through an existing penetration

Courtesy of IRID
Solid waste management approaches

Features of 1F Solid Waste
To date, ca. 400 kt accumulated
- Huge volume
- High radiation
- A variety of nuclide compositions and concentration
- Lack of experience in managing and disposing of secondary waste generated from water treatment in Japan
- Characterisation needed along with progress of 1F D&D

Rubbles (metal, concrete)/Woods & leaves/Soils/Incinerables/Adsorbers and sludge from water treatment /Waste from fuel-debris retrieval operation/Waste from dismantling

Policy for Solid Waste Management
- Focus on characterisation, treatment, packaging and storage until determination of disposal approach

Increasing storage capacity for radioactive wastes

Today’s Challenges and R&D
- To avoid generation of contaminated waste
- Volume reduction of solid Waste
- Quick waste characterization
- Determination future disposal method based on provisional waste form
- Pursuit of sustainable waste management scheme
- Reduction of workers dose

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R&D activities for solid waste management

Waste Generation

Characterization

Safe Storage

Treatment Solidification

Disposal

Ongoing studies along with the lifecycle of the waste

Characterization and analysis:
- Sampling from stored waste and reactors
- Analytical study to characterize wastes and contaminated materials
- Correlation study for nuclide composition
- Technique to streamline complicated analysis

Improvement of the storage integrity and efficiency:
- Countermeasure for hydrogen generation
- Projection of the wastes pertaining to the fuel-debris retrieval operation
- Waste segregation by determination of the contamination

Comparative study of solidification technique:
- High temperature process
  - CCIM, In Can Melting, GeoMelt
- Low temperature process
  - Geopolymer, Improved Cement

International survey on disposal:
- Disposal concept options
- Performance assessment
- Experienced regulatory requirements
Organizational structure for R&Ds

Core Entities for Decommissioning Implementation

- METI
  - Strategic Support to Gov.
  - R&D Coordination
- NDF
  - Strategic Support to Gov.
  - Fund Management
  - Project Oversight
- MEXT
  - Subsidy for Basic Research and Human Resource Development
- NRA
  - Decommissioning Policy (RM)
  - Safety Regulation
  - Contract-based consigned developments
- TEPCO implementation
  - Contract-based implementation
- Vendors (Domestic and Foreign)*
  - Technical Contribution
- JAEA
  - Research Fund
- Universities

*: A consortium is founded by some Japanese organizations; IRID (International Research Institute for Nuclear Decommissioning)
In line with the holistic approach of Japan, the decommissioning of the Fukushima Daiichi NPP is progressing. The followings are the highlights.

- The situation of the site has been stabilized to date by adopting various best available techniques and knowledge.
- Institutional and organizational system to underpin the Fukushima Daiichi decommissioning has been solidified, and it is working.
- Risk reduction is recognized as the base of the long-term decommissioning challenge, and the result of the risk assessment shows the strategic direction.
- Difficult spent fuel recovery is progressing by using remote operations.
- Preliminary engineering and developments are ongoing for the fuel-debris retrieval which will start from sampling and small-scale operation using a remote arm.
- Inspection inside PCV is going forward, giving valuable information to unveil the unclear status of three units.
- Research and development for the waste management is continuing in line with the provisional approach.
- Research and development is underpinned by the cooperation of relevant organizations.