Recommendations for Fuel Debris Retrieval Policies
(Chapter 4 of Strategic Plan 2017)

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Nuclear Damage Compensation and Decommissioning Facilitation Corporation
(NDF)
Discussion Flow of Recommendations for FDR Policies

FDR : Fuel Debris Retrieval

1. Situation of each unit
   Fuel debris distribution, conditions of internal structures

2. Fuel debris characteristics and inherent risk
3. Feasibility of FDR methods
   Confinement of radioactive materials, criticality control, integrity of buildings and structures, worker exposures, establishing access routes etc.

4. Comprehensive evaluation for FDR policies
   Viewpoints of 5 guiding principles
   - safe, proven, efficient, timely, field-oriented -
Terms

- Spent Fuel Pool (SFP)
- Reactor Pressure Vessel (RPV)
- Primary Containment Vessel (PCV)
- Vent Pipe
- Pedestal
- Suppression Chamber (S/C)
- Reactor Building (R/B)

(Fuel debris)
Situation of each unit
Fuel debris distribution, conditions of internal structures
Inside of Unit 1

PCV internal investigation by robot

Sediments, which seem to have some weight, were found on the bottom of PCV and inside of pipes. (March 2017)

Machines and instruments were recognized in the drawing locations. No high-density materials (fuels) were observed in the core region. (May 2015)

Muon observation

(Courtesy of TEPCO)
Inside of Unit 2

**PCV internal investigation by robot**

Displacement of platform grating inside the pedestal and sediments were found. (February 2017)

**Muon observation**

A shadow of high-density materials deemed fuel debris were found on the bottom of RPV and its periphery. (July 2016)

(Courtesy of TEPCO)
Inside of Unit 3

PCV internal investigation by robot

Seemingly solidified molten materials, damaged structures, fallen objects, and sediments were found inside the pedestal. (July 2017)

No high-density materials were observed at the bottom of RPV. (July 2017)

(Courtesy of TEPCO)
Combination of severe accident analysis code, plant date analysis, muon observations, and internal investigation allows us to estimate the locations of fuel debris of each unit.

- Most fuel debris reside at the bottom of PCV
- Most fuel debris reside at the bottom of RPV
- Fuel debris reside at the bottoms of RPV and PCV
### Conditions of Internal Structures

#### Accessibility

<table>
<thead>
<tr>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessible from grating toward lower part of PCV (outside of pedestal)</td>
<td>Accessible from pedestal opening into inside pedestal</td>
<td>Accessible from pedestal opening into inside pedestal</td>
</tr>
</tbody>
</table>

#### Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No significant damages on the outer side of the pedestal wall (near grating)</td>
<td>No anomalies like cracks etc. on the inner side of the pedestal wall (near opening)</td>
</tr>
</tbody>
</table>
Fuel debris characteristics and inherent risk
**Radiation Risks Inherent in Fuel Debris**

- **Fuel debris** may change to release-prone morphology:
  - particulates
  - sludge
  - aerosol

- **Containment function** might deteriorate

- **Risk may increase with time.**

*Based on NDA developed SED index (a product of internal exposure impact through inhaling radiological materials and probabilities of the occurrence of the event) is evaluated the risk.

**Risk may effectively be reduced by**

- Retriving diffusive and movable fuel debris first to store them properly
- Focusing on PCV lower part, where MCCI may exist, with less containment-in-depth than RPV
- Considering NOT to induce excessive risk by generating particulates etc. during FDR
Feasibility of FDR methods
Confinement of radioactive materials, criticality control, integrity of buildings and structures, worker exposures, establishing access routes etc.
3 Basic Principles for Nuclear Power Plant Safety

😊 STOP
😊 COOL
😊 CONFINE
3 Prioritized FDR Methods

Key parameters for FDR methods – **PCV water level and access route** – suggest 3 feasible patterns below;

<table>
<thead>
<tr>
<th>Submersion (Top-Access)</th>
<th>Partial-Submersion (Top-Access)</th>
<th>Partial-Submersion (Side-Access)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access from the operation floor, submerge all fuel debris with water, and retrieve them from the operation floor</td>
<td>Access from the operation floor, retrieve fuel debris while showering water, and retrieve them from the operation floor</td>
<td>Access from the PCV side on 1st floor, retrieve fuel debris while showering water, and retrieve them from the PCV side</td>
</tr>
</tbody>
</table>

- potential location of fuel debris
- potential water level
- when vent pipe successfully sealed
Appearance of MARK-I Type PCV

Browns Ferry NPP Unit 1 of TVA (USA) under construction. In commercial operation on Dec. 20, 1973. PCV design for 1F units 1-5 is this MARK-I type.
Development of PCV Repair & Sealing Technology (1)
- Water sealing & Air in-leak prevention -

Dry Well penetration bellows

Sealing material spray nozzle

spray area

Shield block

Seal equipment hatch

Flange for equipment hatch

Weld head

Equipment hatch

(Generated based on IRID information)
Development of PCV Repair & Sealing Technology (2) - Tests -

Vent pipe seal test
- (1/2 scale test)

Inflating test
- (1/1 scale test)

Sealing test with real size simulator
(NARAHA Remote Technology Development Center)
- 1/8 sector

Potential repair location
- vent pipe
- seal balloon
- S/C
- down-comer
- quencher
- torus room
- test object

(from 2017 IRID symposium)
Severe dose environment lags investigation of repair positions
- Numerous subject-to-repair penetrations exit
- Needed remote technology yet to be established
- Enormous worker exposures anticipated

Considerable efforts required to realize ‘Submersion’
How to Set PCV Water Level

Current PCV water level is different from unit to unit, and depending on the situation of each unit, the PCV water level to be set may differ. Below are points to be noted.

a. Advantages to handle fuel debris under water
b. Possibility of reversal of water level between ground water and the torus room water
c. Technical feasibility of water sealing
d. Technical feasibility of water level control

<table>
<thead>
<tr>
<th>Unit</th>
<th>Current water level (m)</th>
<th>Water level control to achieve max level*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

* When setting max level at the torus room ceiling
Primary Confinement System for Partial-Submersion Method (Side-Access) EXAMPLE

Under NORMAL and OFF-NORMAL conditions, each predefined safety level for radiation exposure must be observed

(Generated based on IRID information)
Container and cell preventing dispersion of radioactive materials are installed on the operation floor. Reactor internals and fuel debris inside RPV are retrieved from the upper side.
Fuel debris retrieval cell is installed on the 1st floor of R/B. PCV bottom internals and fuel debris at the bottom of PCV are retrieved from the side.
Comprehensive evaluation for FDR policies

Viewpoints of 5 guiding principles
- safe, proven, efficient, timely, field-oriented -
6 Recommendations for FDR Policies

- Judge feasibility
- Basic concepts considered most probable at present
- Engineering work
- Update

Analyze the progress whatsoever small to scale-up gradually in uncertain conditions (Step-by-Step)

① execute
② reflect timely

Internal investigation
In harmony
FDR

Unyielding Baseline
Recommendation #1

➢ To aim at a comprehensive plan for FDR covering preparatory to retrieval work, transport/treatment/storing and cleaning up in harmony with other tasks being conducted on-site.

1F on-site
(unit-wise, 3-units-wise, site-wise)
To proceed with the specified FDR method in a flexible step-by-step approach utilizing the acquired information

- Reflect results of PCV and RPV investigation to FDR method review
- Start from small-scale retrieval, conduct confirmation and updates based on the newly acquired data, and then gradually scale up to the large-scale retrieval operations

Investigation (PCV internal investigation, detailed investigation)

Preparation for FDR (Design/manufacturing/installation/mock up etc.)

Exploit acquired data to proceed step-by-step

FDR (Gradual scale-up)
To work on the premise that combination of various methods is necessary for accomplishing FDR

- Efficient FDR for PCV bottom and RPV inside by the sole method would not be realistic. Side-entry for PCV bottom and top-entry for RPV inside need to be combined.
- Progress of R&D and ideas gathered from domestic and international societies must flexibly be fed back to search for optimum FDR methods.
To proceed with focus on Partial-Submersion method toward preliminary engineering, R&D, etc.

- Submersion method poses tough technical challenges at present. However, its merits (radiation shielding and dust dispersion prevention) would necessitate future discussion on this method anticipating advancement of technologies.
Recommendation #5

➢ To focus initially on FDR from the bottom of PCV and continue review based on the knowledge and experience gained in the operations.

◆ Internal investigation experience and related technical development rationalize the first approach to the fuel debris in PCV bottom from the viewpoints of 5 guiding principles.
◆ Information and knowledge obtained during ensued investigation and FDR work helps understand the situation in the RPV and contributes to the comprehensive study of FDR.

Situation of PCV bottom (Unit 3)
To proceed with the study of the side access method to approach the fuel debris at the bottom of PCV

- Hurdles to be cleared in realizing the side access method are;
  - Reduction of radiation on work area
  - Establishment of water level control technology
  - Establishment of cell connection technology and securing of area
Initiatives after the FDR Policy Decision

Toward the decision of the first unit of FDR and its method, and for the acceleration of construction planning, the following initiatives should be taken.

Preliminary engineering

On-site applicability of R&D results be studied for defining FDR process. The FDR method may be subject to revision as required based on the results of preliminary engineering.

Technical development/practical application through selection & focus of R&D

- Implementation of detailed PCV internal investigation
- Implementation of RPV internal investigation
- Judge feasibility of alpha nuclides control system to realize Partial-Submersion method
- Accelerate R&D to realize side-access method/Study the significance of mock-up facility
- Accelerate R&Ds for collection, transport, and storage of fuel debris, and management of generated waste during FDR

Considerations for project implementation

① Sustainability of project ② Optimization of site-wise D&D work ③ Communication with locals and the society, domestic regulatory body, and international communities like IAEA
Initiatives after the FDR Policy Decision (Image)

1. Decide FDR policies
2. Decide FDR method for initial unit
3. Safeguards implementation (SG strategy)
4. Safety considerations
5. Preliminary eng.
6. Investigation (PCV internal investigation, detailed investigation)
7. Reflect preliminary engineering results
8. Preparation for FDR (Design/manufacturing/installation/mock up etc.)
9. FDR (Gradual scale-up)
10. Investigation
11. Continue licensing work if necessary
12. Reflect to SG strategy
13. Safeguards implementation
14. Reflect to licensing
15. Safety evaluation/Licensing
16. Design & manufacturing of fuel debris canister
17. Fuel debris collect/transport/store
Thank you for your attention!