Analysis for Accident Progression with THALES2 Code

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JAEA has made efforts to evaluate accident progression and source terms for Fukushima Daiichi NPP accident by an integrated severe accident analysis code THALES2 developed at JAEA for level 2 PSA of light water reactors.

As a reference to the THALES2 code, additional analyses have been performed by MELCOR code (Ver.1.8.5).

Sensitivity studies for boundary conditions and physical modeling are presently underway.
Brief Description of THALES2 Code

- Fast running capability with simplified modeling for thermal-hydraulics and core melt progression
- Detailed modeling for fission product (FP) behavior

FP Behavior

- Gaseous form
  - Condensation/evaporation
  - Chemisorption
  - Gas/liquid partition

- Aerosol form
  - Aerosol growth by agglomeration and condensation
  - Aerosol deposition on wall and floor

- Removal by engineered safety features
  - Scrubbing in water pools
  - Spray and filter systems
### Nodalization for Unit 3

**Control volumes**

<table>
<thead>
<tr>
<th></th>
<th>TAHLES2</th>
<th>MELCOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor coolant system</td>
<td>7</td>
<td>20 (included 4 main steam lines and 8 SRV lines)</td>
</tr>
<tr>
<td>Containment system</td>
<td>4</td>
<td>6 (3 volumes for D/W)</td>
</tr>
<tr>
<td>Reactor building</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Assumptions of Analysis

◆ Operation of S/C and D/W sprays with flow rate of 50 t/h
◆ HPCI activation with reduced and constant flow rate assuming flow control with test line
◆ Consideration of dependence of water injection rate by fire engine (F/E) pump on RPV pressure
◆ Failure of SRV line and intermittent vapor leak to gas phase of containment vessel (CV) associated with the actuation of SRV
◆ No leak from CV to reactor building
# Conditions of Base and Sensitivity Cases

<table>
<thead>
<tr>
<th></th>
<th>HPCI flow rate(^1)</th>
<th>F/E flow rate(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case (BC)</td>
<td>3.5%</td>
<td>50%</td>
</tr>
<tr>
<td>Sensitivity case 1 (SC1)</td>
<td>3.5%</td>
<td>25%</td>
</tr>
<tr>
<td>Sensitivity case 2 (SC2)</td>
<td>3.0%</td>
<td>50%</td>
</tr>
</tbody>
</table>

\(^1\) Fraction to nominal flow rate  
\(^2\) Fraction to TEPCO’s open information (taking pressure dependence into account)

TEPCO’s open information for water injection

[Diagram showing flow rate vs. RPV pressure with points at 100%, 50%, and 25% flow rates and corresponding pressures]
Water Injection into RPV

**Mass flow rate (BC)**

- RCIC (nominal)
- THALES2
- HPCI
- S/C & D/W (3.5%)
- Spray (50t/h)
- F/E Flow

**Total mass injected by F/E pump**

- BC
- SC1
- SC2
- TEPCO’s data

**Total mass of F/E injection at 15–35% of TEPCO’s data**

<table>
<thead>
<tr>
<th>HPCI flow</th>
<th>F/E flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC : 3.5%</td>
<td>50%</td>
</tr>
<tr>
<td>SC1: 3.5%</td>
<td>25%</td>
</tr>
<tr>
<td>SC2: 3.0%</td>
<td>50%</td>
</tr>
</tbody>
</table>
Good agreement of analysis with measurement for RPV pressure
Similar tendency for RPV mixture level between two codes before core melt

Core melt start (~45 hours)
D/W Pressure and H₂ Generation (BC)

Direct vapor leak to gas phase of CV

- Overestimation

H₂ generation in RPV

- Comparable trend of D/W pressure between analyses and measurement
- H₂ generation corresponding to 30–35% oxidation of Zr
FP Release to Environment (BC)

- Xe: $>0.8$, CsI and CsOH: $<10^{-2}$
- Other species: $<10^{-4}$

![Graph showing release fraction over time for various species.](chart.png)
Comparison of Base and Sensitivity Cases
(1) Sequence of Major Events

<table>
<thead>
<tr>
<th>Events</th>
<th>THALES2</th>
<th></th>
<th>MELCOR</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BC</td>
<td>SC1</td>
<td>SC2</td>
<td>BC</td>
</tr>
<tr>
<td>Gap release*1</td>
<td>44.2</td>
<td>44.2</td>
<td>40.9</td>
<td>43.2</td>
</tr>
<tr>
<td>Core melt*2</td>
<td>46.1</td>
<td>46.1</td>
<td>45.2</td>
<td>44.3</td>
</tr>
<tr>
<td>Lower core support failure</td>
<td>47.3</td>
<td>47.5</td>
<td>46.8</td>
<td>45.3</td>
</tr>
<tr>
<td>Lower head failure</td>
<td>-</td>
<td>59.6</td>
<td>61.7</td>
<td>-</td>
</tr>
</tbody>
</table>

*1: Cladding temperature at 1173 K
*2: Cladding temperature at 2098 K

Unit in hours

In HPCI 3.5% cases, almost same

HPCI 3% case

Almost same with time at lower core support failure

◆ No failure of lower head in BC
Comparison of Base and Sensitivity Cases
(2) Fraction of Core in RPV

- Major slump of molten core into Pedestal area between 50 and 80 hours in SC1 and SC2

### Comparison of Base and Sensitivity Cases

- **BC**: 3.5%, 50%
- **SC1**: 3.5%, 25%
- **SC2**: 3.0%, 50%

**MELCOR**

**THALES2**
Comparison of Base and Sensitivity Cases (3) I and Cs Release to Environment by THALES2

◆ Larger release of CsI and CsOH in SC1 and SC2 by ex-vessel release of FPs after RPV failure

CsI

CsOH

Release Fraction [-] (for initial core inventory)

BC
SC1
SC2

Time after scram [h]

100
60
80
40
20
0

10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}

HPCI flow    F/E flow
BC: 3.5%, 50%
SC1: 3.5%, 25%
SC2: 3.0%, 50%
Sensitivity studies have been performed for Fukushima Daiichi NPP accident by THALES2 and MELCOR codes to examine influence of HPCI and F/E pump flow rates on accident progression and source terms.

We continue sensitivity studies to clarify key parameters for future uncertainty analysis.
Thank you for your attention
## Calculated Condition

<table>
<thead>
<tr>
<th></th>
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<th>MELCOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decay heat</td>
<td></td>
<td>1979 ANS standard</td>
</tr>
<tr>
<td>Zr/water reaction</td>
<td>Urbanic–Heidrick</td>
<td>Baker–Just</td>
</tr>
<tr>
<td>FPs release</td>
<td></td>
<td>CORSOR–M</td>
</tr>
<tr>
<td>Pool scrubbing</td>
<td>SPARC model</td>
<td>For aerosol</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kaneko’s Experimental model</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For vapor FPs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Theoretical models</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Initial condensation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Diffusion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Gas/liquid partition</td>
</tr>
</tbody>
</table>
## Grouping of Radionuclides

<table>
<thead>
<tr>
<th></th>
<th>MELCOR</th>
<th>THALES2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Xe</td>
<td>Xe</td>
</tr>
<tr>
<td>2.</td>
<td>CsI</td>
<td>CsI</td>
</tr>
<tr>
<td>3.</td>
<td>CsOH</td>
<td>CsOH</td>
</tr>
<tr>
<td>4.</td>
<td>Te</td>
<td>Te</td>
</tr>
<tr>
<td>5.</td>
<td>Ba</td>
<td>Sr</td>
</tr>
<tr>
<td>6.</td>
<td>Ru</td>
<td>Ru</td>
</tr>
<tr>
<td>7.</td>
<td>Ce</td>
<td>Ce</td>
</tr>
<tr>
<td>8.</td>
<td>La</td>
<td>Other aerosol*</td>
</tr>
<tr>
<td>9.</td>
<td>Mo</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>U</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Sn</td>
<td></td>
</tr>
</tbody>
</table>

* Aerosol materials other than representative element are classified into ‘Other aerosol’ group in THALES2.
Influence on the Accident Progression by the difference in HPCI flow rate

HPCI Flow Condition (2 cases): 3 and 3.5%
- The results of accident progression on two codes all almost same.
- The pressure drop can be simulated by HPCI flow control using test line.

The difference in HPCI flow rate effects on the RPV mixture level
- HPCI flow at 3% is around TAF during HPCI operation.
- The trend of mixture level just after reactor depressurization can be simulated at 3.5%.
**THALES2**

### RPV Pressure

- **RCIC**
- **HPCI**
- **RPV depressurization**

### D/W Pressure

- **RPV depressurization**
- **Spray (S/C,D/W)**
- **Vent**

### HPCI

- **3.5%**
- **3%**

### F/E flow

- **50%**
- **25%**

### H2 generation in RPV

- **Core support plate failure**
- **RPV failure (SC1 and SC2)**

### Time after scram [h]