Licensing Analysis of RPV and BOP Blowdown for the Event of FWLB with RELAP5-3D/K for Lungmen ABWR Containment Design

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Introduction

- Conventionally, the limiting break for BWR containment design is the recirculation line break.
- In the ABWR design, the jet pumps driven by the recirculation loops are replaced by the reactor internal pumps (RIPs).
- As a result, the limiting break for ABWR containment design shifts to the Feedwater Line Break (FWLB).
Introduction

Engineering Simulator
Introduction

Essential Processes to be calculated

(1) Critical flow at the break ends or the internals, such as FW sparger and venturi;
(2) Flashing of RPV inventory and FW near the break;
(3) Run out and coast down of the FW pumps;
(4) Steam extractions to FW heaters and FWP turbines;
(5) Flashing of saturated water initially stored inside the FW heater shell sides and MSR drain tanks;
(6) Energy release from saturated water and system metal,
(7) Cold water transportation from the main condenser to the break; and
(8) ECC injections and associated level variations.
System Modeling with RELAP5-3D

-Modeling Scope-
Modeling of RPV and Steam Lines

-123 hydraulic nodes
-137 junctions
-123 heat slabs
System Modeling with RELAP5-3D

Modeling of Main Steam & Turbine Systems

- 141 hydraulic nodes
- 126 junctions

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System Modeling with RELAP5-3D

Modeling of Condensate & Feedwater Systems

- 158 nodes
- 151 junctions
- 133 slabs
System Modeling with RELAP5-3D

Modeling of FW pump-shaft-turbine module

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Modeling of Inboard & Outboard Breaks

Inboard Break Node

Feedwater Line A
(To RPV) (Inboard Check Valve) (Outboard Check Valve) (Venturi)

Feedwater Line B

Feeder Line Header

Outboard Break Node

Primary Containment Wall
Assumptions

Initial Conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial Value (INER)</th>
<th>Initial Value (GE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Thermal Power [MWt]</td>
<td>4005.0 (102 %)</td>
<td>4005.0 (102%)</td>
</tr>
<tr>
<td>RPV Dome Pressure [MPa]</td>
<td>7.31 (102 %)</td>
<td>7.31 (102%)</td>
</tr>
<tr>
<td>RPV Core Flow [kg/s]</td>
<td>16,107 (111.1 %)</td>
<td>16,110 (111.1%)</td>
</tr>
<tr>
<td>RPV Narrow Range Water Level [cm]</td>
<td>426.0</td>
<td>427.0</td>
</tr>
<tr>
<td>Steam and Feedwater Flow [kg/s]</td>
<td>2177.8 (102 %)</td>
<td>2174.0 (102%)</td>
</tr>
<tr>
<td>Feedwater Temperature [°C]</td>
<td>216.9 (102 %)</td>
<td>216.9 (102%)</td>
</tr>
</tbody>
</table>
Sensitivity Studies

RPV modeling: (1) initial core flow

Effect of Core Flow on the Initial RPV Inventory

Effect of Initial Core Flow on the Accumulated RPV Blowdown Mass
Assumptions

Plant Operations

- Extraction steam continues to enter the feedwater heater and the feedwater pump turbines until steam inventory is depleted or blocked by the non-return valves designed to protect main turbines;

- Non-safety systems and components are assumed to fail in ways that maximize the amount of water mass and energy blowdown;

- Feedwater flow to the vessel through the unbroken line continues intermittently through the event, depending on the feedwater line and RPV pressures.

- MSIVs will be fully closed within 3.0-4.5 seconds [3-4], and 3.0 seconds is conservatively assumed for inboard break (RPV and BOP blowdown);

- After 30 minutes after break for long term blowdown calculation, HPCF and RCIC injections will be terminated and LPFL injection will be regulated to maintain water level between L-2 and L-8.
Assumptions

Modeling Assumptions

- Homogeneous Moody model is applied to calculate blowdown flow rate;
- The effects of internal choking at Venturi of FW system and Spargers inside RPV are considered;
- The pump curves of flow run out are used to model the FWPs;
- Flashing of water depressurized below its saturation point and the associated effect of flashing on steam supply are considered;
- The effect of stored heat from metal and saturated water stored in feedwater heater shell sides on the feedwater heating are considered;
Results

## RPV Short-Term Inboard Break

Sequence of Events of FWLB Inboard Break

<table>
<thead>
<tr>
<th>Time [s]</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>Feedwater line break.</td>
</tr>
<tr>
<td>0.310</td>
<td>L-4 and 10 RIPs Runback (L-4 + 0.0s, not apply).</td>
</tr>
<tr>
<td>5.000</td>
<td>Reactor scram by drywell high pressure (Assumption).</td>
</tr>
<tr>
<td>5.393</td>
<td>L-3, Trip of 4 RIPs without MG set (L-3 + 0.0s).</td>
</tr>
<tr>
<td>12.629</td>
<td>L-8, Turbine trip (L-8 + 0.0s, not apply), and Feedwater pump turbine trip (L-8 + 0.0s, not apply).</td>
</tr>
<tr>
<td>19.268</td>
<td>MSIVs closure by main steam line low pressure.</td>
</tr>
<tr>
<td>26.742</td>
<td>L-2, Trip of 3 RIPs with MG set (L-2 + 0.0s).</td>
</tr>
<tr>
<td>31.000</td>
<td>HPCF startup complete (Drywell high pressure + 26.0s).</td>
</tr>
<tr>
<td>32.742</td>
<td>Trip of other RIPs with MG set (L-2 + 6.0s).</td>
</tr>
<tr>
<td>34.000</td>
<td>RCIC startup complete (Drywell high pressure + 29.0s).</td>
</tr>
<tr>
<td>41.000</td>
<td>LPFL startup complete (Drywell high pressure + 36.0s).</td>
</tr>
</tbody>
</table>
Results

RPV Short-Term Inboard Break

Break Flow from RPV Side

Break Flow Enthalpy from RPV Side
Results

- **RPV Short-Term Inboard Break**

  **Reactor Water Levels**

  **ECC Injection Flows**

  Engineering Simulator
Results

RPV Short-Term Inboard Break

Pressure Responses before and after MSIV

Flows through both the Intact and Broken FW Lines

Engineering Simulator
Results

**BOP Short-Term Inboard Break**

Feedwater Pump Run out Speed

BOP Blowdown Flow Rate
Results

**BOP Short-Term Inboard Break**

- Local voids near the BOP Break End
- Comparison of the Local Saturation Temperature against the Coming Water Temperature
Results

- **BOP Short-Term Inboard Break**

Extraction Steam Flow from Low Pressure Turbine

Feewater Heater Shell Side Pressures

Engineering Simulator
Results

BOP Short-Term Inboard Break

BOP Blowdown Enthalpy

Comparison BOP Blowdown Enthalpy against PSAR Curve
Results

- **BOP Short-Term Inboard Break**

Comparison of the Blowdown Flow against PSAR Curve

Comparison of the Accumulated Blowdown Energy against PSAR

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Conclusions

- The blowdown licensing analysis of FWLB have been successfully analyzed by the advanced RELAP5-3D/K, which include:
  - Inboard & Outboard break
  - RPV & BOP blowdown
  - Short term & long term

- All essential processes involved can be adequately simulated by RELAP5-3D/K:
  1. critical flow at the break ends or the internals,
  2. flashing of RPV inventory and FW near the break,
  3. run out and coast down of the FW pumps;
  4. steam extractions to FW heaters and FWP turbines;
  5. flashing of saturated water initially stored inside systems;
  6. energy release from saturated water and system metal,
  7. cold water transportation from condenser to the break; and
  8. ECC injections and associated level variations.
Conclusions

- Through comparisons against the PSAR curves for the inboard break, it was observed that
  - The revised accumulated blowdown mass can be bounded in the first 180 seconds,
  - The revised accumulated blowdown energy can only be bounded in the first 120 seconds.
What is the LPFL Injection Bypass?

- A two-phase mixture water column with cold ECC water above might exist in the DCM during a FWLB event.
- The effective hydraulic head of this mixture water is not enough to bring the DCM water into the core core.
- Once DCM water level ascends to the FW rings, all the LPFL injection water will be directly driven to the break without entering the core shroud.
Special Issue of LPFL Injection Bypass

Graphs showing suppression pool liquid temperature and void fraction over time.
Special Issue of LPFL Injection Bypass

RPV Water Level Responses

Balance of RPV Boundary Flows

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