Validation of Thermal-hydraulic codes for boron dilution transients in the context of the OECD/SETH and OECD/PKL Projects
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Introduction

OECD SETH project:

- PKL – AREVA - Boron dilution
  - SB-LOCA (3 tests : E2.1, E2.2, E2.3)
  - Loss of RHR at Mid-loop with 1 SG available for cooling, 1 SG full but isolated, and 2 empty SG. Closed primary system. (1 test : E3.1) => BENCHMARK

- PANDA – PSI (CH) - CFD code assessment
Introduction

OECD PKL project:

F1 series:
- SB-LOCA with 56K/h SG cooldown,
- SET Circulation/deborication a different inventories, 12 bars

F2 series: (Sensitivity test on E3.1)
- F2.1 - 3 runs: hot pressurizer, low inventory, UH bypass 2%
- F2.2 - 2 runs: 1 SG available, 2 SG available

F3 series – open primary

F4 series – …..
## Introduction

<table>
<thead>
<tr>
<th></th>
<th>SETH</th>
<th></th>
<th>PKL</th>
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<tbody>
<tr>
<td><strong>Test Run</strong></td>
<td><strong>E3.1</strong></td>
<td><strong>F2.1 Run 1</strong></td>
<td><strong>F2.1 Run 2</strong></td>
<td><strong>F2.1 Run 3</strong></td>
</tr>
<tr>
<td><strong>Secondary</strong></td>
<td>2 SGs filled with water :</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>• 1 ready, regulated at 2 bar</td>
<td></td>
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<tr>
<td></td>
<td>• 1 isolated</td>
<td></td>
<td></td>
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<tr>
<td><strong>Upper Head Bypass (%)</strong></td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>LV&lt;sub&gt;HL&lt;/sub&gt;</strong></td>
<td>¾ loop</td>
<td>¾ loop</td>
<td>Lower edge</td>
<td>¾ loop</td>
</tr>
<tr>
<td><strong>T&lt;sub&gt;PRZ&lt;/sub&gt; (°C)</strong></td>
<td>50</td>
<td>160</td>
<td>50</td>
<td>50</td>
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**Notes:**
- SETH: Sølund Experimental Test Holding
- PKL: Preparatory Knowledge Laboratory
Boron Dilution Problematic

Mid-loop operation – closed primary – at least 1 SG for cooling

Deboration Phenomena

- reflux-condenser mode => unplugging of U-tubes / Overspilling
  => Formation of deborated slugs in loop seal
- Condensation in outer vessel => Formation of deborated slugs in downcomer

Main safety issue:

Will the deborated slug cause return to criticality?
PKL Facility

1 Reactor pressure vessel
2 Downcomer
3 Steam generator
4 Reactor coolant pump
5 Pressurizer

Volume, power: 1 : 145
Elevations: 1 : 1
Max. pressure: 45 bar
Max. power: 2.5 MW (10%)
Test E3.1

● Initial conditions:
  – Closed Primary, Mid-Loop operation, Nitogen present, RHR system. SG 1 full and ready. SG 2 full (cold PRZ), SG 3 and 4 empty

● Event : Loss of RHR

● Main Transient :
  – **Phase A** : Pressurization, SG 1 regulated at 2 bar. Unstable Reflux-condenser mode
  – **Event** : Nitrogen Unplugging U-tube/s of SG 1—Condensed slug overspill
  – **Phase B** : Continuous overspilling at top U-tubes of SG 1 : constant - deboration in Loop seal 1
Benchmark - Generic

Participants

- AVN (Belgium) - CATHARE2 v1.5b mod 5.1
- VTT (Finland) - APROS v5.06
- UPVLC (Spain) - RELAP5 mod3.3
- JNES (Japan) - RELAP5 mod3.3
- PSI (Switzerland) - TRACE v4.160
- UNIPI (Italy) - RELAP5 mod3.3

UPM (Spain), GRS (Germany) – not submitted
Benchmark – Deck Qualification

Lumping

Loops: Generally all 4 separately (AVN 3)
Downcomer Annular and Pipes: 1D/2D and 1/2
SG1 U-tubes: Generally 3 groups: 11,11,6 (VTT 1,5,20,2)
Remaining SGs: Same as SG1 (AVN, PSI 1 U-tube group)

Meshing

Group 1: 550 meshes (delivered nod.)
Group 2: others 800-950
Benchmark – Deck Qualification

Volume Error
Primary circuit: 0.17% (0.005m$^3$) - 1.26% (0.042m$^3$).
Secondary circuit: 0.58% (0.034m$^3$) to 8.65%(0.516m$^3$).

Structures
Primary circuit (expt AVN): 5.2% (929 kg) to 8.1% (1450 kg)
Secondary circuit (expt AVN): 2.72% (803 kg) to 16.9% (4992 kg)
Benchmark – Deck Qualification

Steady State Qualification

Pressure Losses: still problems from some participants
Heat Losses: very good
SG heat exchange area: very good
Benchmark – Main Results

Initial Conditions

Primary:
- Pressure at edges of range
- Inventory close to 1300Kg
- Temperatures ok.
- Big Nitrogen inventory/distribution differences

Secondary
- ok
Benchmark – Main Results

Figure 02.01: Pressurizer Pressure

Figure 03.01: Pressurizer Level
Benchmark – Main Results

Figure 02.02: Steam Generator 1 Dome Pressure

Figure 02.03: Steam Generator 2 Dome Pressure
Benchmark – Main Results

Figure 03.02: Vessel Internal Level

Figure 03.03: Vessel External Level
Benchmark – Main Results

Figure 03.04: Loop 1 Seal (SG Side) Level

Figure 03.05: Loop 1 Seal (Pump Side) Level
Benchmark – Main Results

Figure 03.11: SG 1 - U tube group 1 - Riser Level

Figure 03.12: SG 1 - U tube group 1 - Downcomer Level
Benchmark – Main Results

Figure 04.02: Liquid temperature in the middle of downcomer pipe 1

Figure 05.01: Boron Concentration at the top of downcomer pipe 1
Benchmark – Main Results

Figure 04.07 : Liquid temperature at Core inlet

Figure 05.05 : Boron Concentration at Core Inlet
Benchmark – Main Results

Figure 04.10: Liquid temperature 1 m from bottom of Loop Seal 1 (SG side)

Figure 05.07: Boron Concentration at COMBO location in loop seal
Benchmark – Main Results

Figure 04.16: Liquid temperature 2m from the bottom of the Pressurizer

Figure 04.23: Liquid temperature at level P/A in SG 1 Riser (10.31m)
Benchmark – Main Results

Figure 05.10: Boron Concentration in horizontal part of loop seal 2

Figure 05.12: Boron Concentration in loop seal 3 (Pump side)
Benchmark – Main Results

Figure 06.01: Integral of liquid flow at the top of all the U tubes of SG 1

Figure 07.01: Feedwater flow in SG 1

Figure 07.02: Steam flow out of SG 1
Benchmark – Main Results

Figure 08.01: Vessel Internal - Nitrogen Mass

Figure 08.02: Vessel External - Nitrogen Mass
Benchmark – Main Results

Figure 09.01: SG 1 - Total Exchanged Power

Figure 09.02: SG 2 - Total Exchanged Power
Benchmark – Conclusions

**OK**: Main T-H parameters (P,T,L): good/average

**NOK**: SG1 U-tube boron behaviour (unplugging/overspilling) assessment
  - liquid distribution in the pressurizer => nitrogen => levels => difficulty in assessment of boron capabilities

**NOK**: downcomer pipe behaviour (both T-H, Boron)

**OK**: Boron distillation trends (condensation) were seen in the loop seals of SG 2 and 3

**OK/NOK**: boron evolution in core (phase A ok)
Benchmark – Conclusions

- PKL F-series tests => necessary to simulate the steam generator U-tubes singularly in order to correctly see the unplugging/overspilling phenomenon seen in the experiment => long computing times

- Diminish computing times by assessing codes on a similar test (separate effect test) using only one isolated loop (w/o pressurizer) and very precise knowledge of the initial N₂ content

- Today boron predictions seem to be possible => more assessment has to be performed