Passive System Performance and Reliability Assessment using the APSRA Methodology

Vikas Jain, A.K. Nayak

Reactor Engineering Division
Bhabha Atomic Research Centre
Mumbai, India
Outline of the Presentation

- Progress made since last meeting
  - Performance assessment of ICS of reactor like SBWR
    - Issues in Application of APSRA methodology
  - RELAP Nodalisation of NC facility L2 (in Italy)
    - Issues in RELAP5 simulation

- Critical issues pertaining to the reliability assessment of passive systems

- An assessment of BE Code RELAP5/Mod3.2 to simulate NC phenomena in test facilities at BARC

- Work Plan for next year
Performance assessment of ICS of reactor like SBWR

- A document ‘Methodology for the evaluation of the reliability of the passive systems’ was received.

- The system considered for analysis has the features of isolation condenser system, a part of SBWR design.

- System has been analyzed using BE Code RELAP5/Mod3.2.

- Nodalization scheme for the system has been used as provided in the document. Because, this scheme has been used for thermohydraulics study and PSA.

- System initial and boundary conditions are used as provided in the document.
Performance assessment of ICS of a SBWR like reactor

• First, the system performance is evaluated for departure from nominal design parameters like:
  — RPV pressure
  — RPV Level
  — Pool Level
  — Pool Temperature
  Design parameters are varied over the range provided.

• Subsequently, the system performance is evaluated for effect of critical parameters :
  — Noncondensable in RPV
  — Noncondensable in inlet line of IC
  — Pipe inclination, Heat loss through piping, Initial Liquid Level in IC

• Performance is evaluated in terms of failure criteria –
  derived parameters in in terms of thermal power exchanged across the IC and mass flow rate at the IC inlet.
## Performance assessment of ICS of– Design Parameters and Failure Criteria

### Nominal Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPV pressure</td>
<td>70 bar</td>
</tr>
<tr>
<td>RPV collapsed level</td>
<td>8.7 m</td>
</tr>
<tr>
<td>Pool level</td>
<td>4.3 m</td>
</tr>
<tr>
<td>Pool initial temp</td>
<td>368 K</td>
</tr>
</tbody>
</table>

### Discrete value considered for deviation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPV pressure</td>
<td>2, 10, 30, 50 &amp; 90 bar</td>
</tr>
<tr>
<td>RPV collapsed level</td>
<td>5 &amp; 12 m</td>
</tr>
<tr>
<td>Pool level</td>
<td>2 &amp; 5 m</td>
</tr>
<tr>
<td>Pool initial temp</td>
<td>280 &amp; 303 K</td>
</tr>
</tbody>
</table>

### Failure Criteria

- \( \frac{(Z-Z_{\text{ref}})}{Z_{\text{ref}}} < (-0.2) \) continuously valid for a time interval greater than 100s
- \( Z \) may be either thermal power exchanged across the IC or mass flow rate at the IC inlet
Performance assessment of ICS– Sample Results

Behaviour at RPV Pressure: 2 bar
Performance assessment of ICS– Sample Results

![Graph 1](https://via.placeholder.com/150)

- thermal power exchanged across IC

![Graph 2](https://via.placeholder.com/150)

- IC Inlet Mflow

Behaviour at RPV Pressure: 10 bar
Performance assessment of ICS of reactor like SBWR – Sample Results

Behaviour at RPV Pressure: 90 bar
Performance assessment of ICS– Sample Results

Behaviour at RPV Level: 5 m
Performance assessment of ICS – Sample Results

Behaviour at RPV Level: 12 m
Effect of Critical Parameters – Sample Results

Heat losses pipings 5kW

- Thermal Power exchange across the IC
- Mass flow rate at the IC inlet

Liquid level L2(0) 100

- Thermal Power exchange across the IC
- Mass flow rate at the IC inlet
Issues in Application of APSRA Methodology

- Identification of the key parameters affecting the system performance –
  - Key parameters should be independent:
  RPV Pressure and RPV Collapsed Level – treatment as independent parameters may not be appropriate – as pressure, void fraction and inventory are correlated. Their independence is questionable.

- Effect of Non-condensable:
  Presence of Non-condensable has significant effect on the performance. However, treatment of non-condensable separately at different locations like in vessel and piping does not appear appropriate, as the non-condensable will flow in the system and may accumulate at the top. The location of Non-condensable should be rather related to its source.

- Range of parameters: Range of parameters considered should be consistent with the operational state of reactor and function of safety system.
  - For example, RPV pressure is considered to vary from 2 bar to 90 bar; does it mean that other system like control system, regulation system and safety systems are not credited.
Issues in Application of APSRA Methodology

• For nuclear system with stringent QA – the geometrical configuration is not supposed to deviate significantly to affect the performance of passive systems. In view of this, is it justified to treat parameters like heat loss through pipe segments, pipe inclination as critical parameters. Initial level in IC also has no effect. The analysis also confirms the same.

• Identification of Failure Criteria –
  • Failure criteria proposed is a derived parameter in terms of heat exchanged through IC and mass flow rate entering IC
    • Instead, it is desirable to define the failure criteria in more explicit manner – it should be rather correlated with the state of reactor in terms of pressure or clad temperature etc.

• Identification of causes of deviation –
  • Root diagnosis is required to trace the sources of deviation – need of information regarding controllers / control valves / source of NC etc.
A document ‘Single-Phase Natural Circulation Loops: Effects of geometry and heat sink temperature on dynamic behaviour and stability’ was received.

The system considered was L2 - a NC test facility in Italy.

The objective of L2 facility was to study the effect of cooler temperature on the stability of the loop. Additional parameter investigated was loop inclination.

Two working fluids were used in L2 facility – water and FC43.

Heat rejection in L2 facility is through a secondary coolant that is a mixture of 50% water and 50% glycol. Coolant flow is maintained such that temperature difference <1K is maintained between inlet and outlet of secondary.

For the purpose of analysis, tests with water as working fluid were considered and heat sink is approximated using a boundary condition of high heat transfer coefficient (~500 -600 W/m²K).
Analysis of NC facility L2 – Nodalization

- Nodalization has been setup for RELAP5/Mod3.2 simulation:

Assumptions:

- The cooler and heater is modeled slightly eccentric.
- Modeling of Cooler:
  - It is mentioned that the temperature rise in the secondary side flow is less than 1°C.
  - Hence, a high heat transfer coefficient is used as the b.c. at the cooler side along with the heat sink temperature as the B.C.
- Modeling of Expansion Tank:
  - Tank with ID 100 mm and connecting lines of 200mm length are modeled.
• Sample Results are qualitatively in good agreement with test data.
• More details are required – expansion tank and lines, secondary side details.
• Detailed test matrix required along with instability thresholds.
Critical Issues pertaining to reliability assessment of passive systems

- Probabilistic treatment of parameters:
  - variability of geometrical parameters and material properties may be treated with pdf
  - but the treatment of variability of process parameters like system pressure using pdf is questionable
  - experience in test facilities suggest otherwise

Probability density data of variation of pressure during single-phase NC

Probability density data of variation of pressure during boiling NC
Critical Issues pertaining to reliability assessment of passive systems

- Mission Time vis-à-vis Variability in time domain:
  - failure frequencies of active components are based on generic data
  - and active components are considered to have binary states like valve could be fully closed / open
  - however, depending on mission time a partial closed / open valve can serve the desired function
  - in view of this, multiple states of active components need to be considered in reliability assessment

Probability density data for variation of cooling water temperature in November

Probability density data for variation of cooling water temperature in July-December
Assessment of BE Code RELAP5 to simulate NC

- Applicability of BE codes like RELAP5/Mod3.2 to simulate the NC behavior is not well established. This is important in context of evaluating reliability of passive systems using NC with application of BE codes.

- An exercise was carried out in this regard: two NC test facilities at BARC, India were chosen namely: High-Pressure Natural Circulation Loop (HPNCL) and Parallel Channel Loop (PCL).

- Nodalization sensitivity study was carried out and experimental data were compared with RELAP predictions.

Range of experimental parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>1 – 70 bar</td>
</tr>
<tr>
<td>Working fluid</td>
<td>Water</td>
</tr>
<tr>
<td>Power</td>
<td>0 to 70 kW</td>
</tr>
<tr>
<td>Level</td>
<td>85 % of full SD level</td>
</tr>
</tbody>
</table>
Assessment of BE Code RELAP5 to simulate NC

**Legend**
- Time Dependent Volume
- Junction
- Single Volume
- Time Dependent Junction
- Heat Structure

---

**Graphs**

1. **Graph 1**
   - Pressure = 4 bar
   - SD Level = 85%
   - Power = 2-58 kW
   - Graph showing Pressure Drop (mm of WC) vs. Time (s)

2. **Graph 2**
   - Pressure = 35 bar
   - SD Level = 85%
   - Power = 2-70 kW
   - Graph showing Pressure Drop (mm of WC) vs. Time (s)

---

3rd IAEA RCM, Vienna, April 26-28, 2011 (VJ)
Assessment of BE Code RELAP5 to simulate NC

Comparison of experimental data with RELAP predictions
Assessment of BE Code RELAP5 to simulate NC

- Single phase well predicted by all three nodalization scheme.
- During Two phase flow experimental results show oscillatory flow throughout power raising.
- Base nodalization shows oscillatory flow at intermediate range of power.
- Fine nodalization shows oscillatory flow at initial range of power.
- Coarse nodalization shows completely stable flow.

Nodalization Sensitivity Study
Assessment of BE Code RELAP5 to simulate NC

Range of experimental parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>1 – 10 bar</td>
</tr>
<tr>
<td>Working fluid</td>
<td>Water</td>
</tr>
<tr>
<td>Power to each channel</td>
<td>0 to 15 kW</td>
</tr>
<tr>
<td>Level</td>
<td>70 % of full SD level</td>
</tr>
</tbody>
</table>

Schematic of Steam Drum

PCL

3rd IAEA RCM, Vienna, April 26-28, 2011 (VJ)
Assessment of BE Code RELAP5 to simulate NC
Assessment of BE Code RELAP5 to simulate NC
Assessment of BE Code RELAP5 to simulate NC

• In summary, predictions of flow instability using RELAP5 code are very sensitive to the nodalization scheme adopted. Even then the code may be successful in predicting the characteristic of oscillations for one operating condition / one geometry, but it may not be successful if there is change in operating conditions / geometry.

• In addition, it can be noted that, even with most appropriate nodalization scheme, the flow predictions are somewhat different from the experimental data. To some extent, this can be attributed to the constitutive relation used in RELAP5 which are semi-empirical in nature. The validity of these correlations for experimental conditions in the test facility is questionable as correlations are mostly valid for forced circulation flows, whereas, flow in such test facilities is by natural circulation.
Future Work Plan

• Reliability Assessment of ICS of SBWR will be carried out

• L2 facility will be analyzed for the test matrix

• PCCS of IRIS will be analyzed (if data are obtained)
Thank You