Effect of Non-Condensable Gas On The Performance of Passive Containment Cooling System in VVER-1200 Design

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- Design Concept of PCCS - VVER1200
- Experiments for Validation
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Introduction

Status of the Nuclear Power Program

- Atomic energy in Vietnam started since 1976
- 1984: Operation of Dalat Research Reactor (RR)
- 2002-2009: Pre-Feasibility Study (Pre-FS) on construction of first NPPs
- 2008: Atomic Laws approved (to be changed)
- 2010: Contracts for the Ninh Thuan 1 (NT1) and Ninh Thuan 2 (NT2) NPPs Feasibility Studies (FS) and Dossiers for Site Approval (DSA) – E4 and JAPC
- December 2013: Completion of FS (NT1 and NT2)
- October of 2014: Revision of FS Report (NT1)
- Ninh Thuan 2 NPP: Technology selection is under consideration; Additional survey of site has been carried out by Japan Atomic Power Co. (JAPC)
- 2015: Review tasks (Focus on Ninh Thuan 1) → Formulation of tasks (Terms of References – TOR); Documents/dossier of requirements for selection of a foreign Consultant to perform Review
- March 07, 2016: BID for selection of Consultant …
- November 23, 2016: Decision of National Assembly – NPP Project Stopped
Introduction

Status of the Nuclear Power Program

- Pre-FS: 2002-2009
- Ninh Thuan 1 – NT1:
  - 2x1200 MWe + 2x1200 Mwe
    (Operation start: 2028/2029)
- Ninh Thuan 2 – NT2:
  - 2x1000 MWe + 2x1000 Mwe
    (Operation start: 2029/2030)
- Location:
  - 300 km from Ho Chi Minh City,
    140 km from Dalat
Introduction

Ninh Thuan 1&2 NPP Project

Possible NPP Technologies

Ninh Thuan 1

✓ AES-91 (Tianwan, China)
✓ AES-92 (Kudan-Kulam, India; Belene, Bulgaria)
✓ AES2006/V491 (Leningrad, Belarus, Kaliningrad-, Czech, Finland?) – [Active + Passive]
✓ AES2006/V392M (Novovoronhetz) – [Active + Passive]
✓ VVER-TOI (Turkey?) – [Active + Passive]

Ninh Thuan 2

✓ ABWR (Hitachi-GE, Toshiba)
✓ MPWR+/Tomari PWR (Mitsubishi)
✓ AP1000 (Westinghouse + Toshiba) – Passive Plant
✓ ATMEA1 (Mitsubishi + Areva)

Effective cooling ?
Reliability ?
Design Concept of PCCS - VVER1200/V491

- Containment Cooling Approaches

Standard PWR
Large Volume + Fan Cooler + Spray Cooling

AP1000
PCCS

International Conference on Topical Issues in Nuclear Installation Safety: Safety Demonstration of Advanced Water Cooled Nuclear Power Plant, Vienna, July 6-9th
Design Concept of PCCS - VVER1200/V491

PRHR/C

International Conference on Topical Issues in Nuclear Installation Safety: Safety Demonstration of Advanced Water Cooled Nuclear Power Plant, Vienna, July 6-9th
Experiments for Validation

**Experimental Loops: KMS & SMK (PRHR/C)**

<table>
<thead>
<tr>
<th></th>
<th>NPP-2006</th>
<th>KMS</th>
<th>Scale</th>
<th>SMK</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height of containment shell, m</strong></td>
<td>67</td>
<td>28,9</td>
<td>1:2,3</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td><strong>Inside diameter of containment shell, m</strong></td>
<td>44</td>
<td>12,0</td>
<td>1:3,7</td>
<td>12</td>
<td>1:3,7</td>
</tr>
<tr>
<td><strong>Total volume, ( V_Σ ), m³</strong></td>
<td>76700</td>
<td>1838</td>
<td>1:41</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Volume above the angular gap, ( V_{\text{above a.g.}} ), m³</strong></td>
<td>48622</td>
<td>769</td>
<td>1:63</td>
<td>1130</td>
<td>1:43</td>
</tr>
<tr>
<td><strong>Lower volume, ( V_{\text{lv}} ), m³</strong></td>
<td>28078</td>
<td>1069</td>
<td>1:26</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Surface of heat exchange, ( F_{\text{HE}} ), m²</strong></td>
<td>1200*</td>
<td>32,6*</td>
<td>1:21,8*</td>
<td>176*</td>
<td>1:6,82*</td>
</tr>
<tr>
<td>( V_{\text{above a.g.}} / F_{\text{HE}} )</td>
<td>40,5</td>
<td>23,6</td>
<td>1:1,72</td>
<td>6,42</td>
<td>1:6,3</td>
</tr>
<tr>
<td><strong>Distance from annular gap to heat exchanger, m</strong></td>
<td>22,8</td>
<td>4</td>
<td>1:5,7</td>
<td>≈5</td>
<td>1:4,6</td>
</tr>
<tr>
<td><strong>Height of heat-exchanger, m</strong></td>
<td>5,0</td>
<td>1,70</td>
<td>1:2,94</td>
<td>2,5</td>
<td>1:2</td>
</tr>
<tr>
<td><strong>Power of the system, MW</strong></td>
<td>22,4</td>
<td>0,570</td>
<td>≈1:40</td>
<td>0,14</td>
<td>1:160</td>
</tr>
</tbody>
</table>
Experiments for Validation

- Experimental Loops

  - Cooling loop: Full-scale

  - Test facility in OKBM, Nizhniy Novgorod

  - Routing of the test facility cooling circuit fully corresponds to the standard arrangement of the containment PHRS pipelines

  - Steam release to the atmosphere

  - Evaporator tank

  - Supports

  - Containment model

  - Gas system

  - Removal pipeline

  - Supply pipeline

  - Aftercooler

  - Condensate collector

  - Electric steam generator

  - Heating steam system

(Bakmetev et al., 2009)
Steam Condensation Model

.Mode of Heterogeneous Nucleation

- Film-wise Condensation
  - Latent Heat, Released on Condensation, Conducted through the Film
- Drop-wise Condensation
  - Condensate Forms in Drops which do not Wet the Solid Surface well.
Steam Condensation Model

Film-wise Condensation inside a Vertical Tube

Presence of Non-condensable gas

RELAP5 Model

Collier (1994)
Numerical Simulation of PHRS/C

RELAP5 Nodalization

122 HX tubes
Numerical Simulation of PHRS/C

- **Test cases**
  - Experimental test cases with different gas (air) content in the modeling tank and total power of the electricity generators ranging from 0.5 to 1.8 MW (controlled by electrical heater inside steam generator)
  - The gas content is setup by partial pressure in the modeling tank prior to discharging steam from steam generator to the modeling tank with following cases: 0, 150, 200, 250 and 300 kPa.
  - For each test case, steam is discharged into the modeling tank with total power of the electricity generator 1.8 MW. Then the power of the electricity generator is lowered to 1.5, 1.0, and 0.5 MW and the parameters is allowed to stabilized over a time of 1 hour at each power level.
Results and Discussion

Pressure

![Pressure Graphs]

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Results and Discussion

- Natural Circulation: Mass Flow Rate
Results and Discussion

- Temperature in Cooling Loop
Conclusions

- The capability of the RELAP5/MOD3.2 code to investigate the performance of cooling loop of PCCS in VVER-1200 V491 design with an elevated concentration of non-condensable gases was assessed in this study.

- Overall, the RELAP5/MOD3.2 captured quite well the effect of the initial air pressure inside the containment to the performance of the PCCS.

- However, the current RELAP5/MOD3.2 code strongly underestimated the condensation heat transfer coefficient which lead to a strong overestimation of the pressure level.