OSU Thermal Hydraulic Loops

Xiaodong Sun

Nuclear Engineering Program
Department of Mechanical and Aerospace Engineering
The Ohio State University

October 5, 2016
Acknowledgements

• This research is being performed using funding received from the DOE Office of Nuclear Energy's Nuclear Energy University Programs

• Collaborators:
  – Thomas Blue (OSU-emeritus)
  – Richard Christensen (OSU-emeritus)
  – Srinivas Garimella (Georgia Tech)
  – David Holcomb (ORNL)
  – Qiuping Lv (OSU, now at ANL)
  – Farzad Rahnema (Georgia Tech)
  – Piyush Sabharwall (INL)
  – Dane Wilson (ORNL)
  – Grady Yoder (ORNL)
Outline

• Status of Thermal Hydraulic Loops for DRACS Testing
  – Low-temperature DRACS test facility (LTDF)
  – High-temperature DRACS test facility (HTDF)

• Additional Test Loops/Facilities
  – Component testing
  – Heat exchanger testing
  – Corrosion screening testing: SS 316H in FLiNaK
  – Reduced-scale tritium removal testing
Direct Reactor Auxiliary Cooling System (DRACS)

Under normal operation

NDHX

DHX

Under accident

Holcomb et al. (2009)
Low-Temperature DRACS Test Facility (LTDF)

- To understand coupling and interactions of three natural circulation/convection loops
- To provide experience for construction and operation of a high-temperature salt test facility
- Construction and testing: Completed
  - DRACS startup test
  - Pump trip tests without/with IHX

<table>
<thead>
<tr>
<th></th>
<th>Primary water (1.0 MPa)</th>
<th>Secondary water (0.1 MPa)</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{hot}}$ (°C)</td>
<td>76.5</td>
<td>65.2</td>
<td>40</td>
</tr>
<tr>
<td>$T_{\text{cold}}$ (°C)</td>
<td>63.7</td>
<td>34.8</td>
<td>20</td>
</tr>
<tr>
<td>$\dot{m}$ (kg/s)</td>
<td>0.038</td>
<td>0.016</td>
<td>0.102</td>
</tr>
<tr>
<td>Loop Height (m)</td>
<td>1.71</td>
<td>0.42</td>
<td>3.43</td>
</tr>
</tbody>
</table>
LTDF (Cont’d)
High-Temperature DRACS Test Facility (HTDF)

- Primary and secondary salts: FLiNaK
- Core: Simulated by seven cartridge heaters with special sheath to match fuel heat conduction time (Max.: 70 kW)
- Pump: 5-hp cantilever sump pump from Nagle
- Fluidic diode: Vortex diode
- Fully instrumented: Clamp-on ultrasonic flow meters (Flexim); N-type thermocouples (Omega); level measurement (Delta Controls); in-house solution for the differential pressure measurement
- Construction completed, salt being prepared

<table>
<thead>
<tr>
<th></th>
<th>Primary Fluid (FLiNaK)</th>
<th>Secondary Fluid (KF and ZrF₄)</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{hot}}$ (°C)</td>
<td>722</td>
<td>666</td>
<td>110</td>
</tr>
<tr>
<td>$T_{\text{cold}}$ (°C)</td>
<td>678</td>
<td>590</td>
<td>40</td>
</tr>
<tr>
<td>$\dot{m}$ (kg/s)</td>
<td>0.120</td>
<td>0.127</td>
<td>0.142</td>
</tr>
<tr>
<td>Loop Height (m)</td>
<td>1.14</td>
<td>1.08</td>
<td>3.43</td>
</tr>
</tbody>
</table>
HTDF (Cont’d)
HTDF (Cont’d)
LTDF and HTDF Models in RELAP5

• RELAP5/SCDAPSIM/MOD 4.0
  – Selected for thermal hydraulic system-level code V&V
  – Salt property implementation

• RELAP5 models of LTDF and HTDF
  – Working fluid in LTDF: water, water, and air
  – Working fluid in HTDF: FLiNaK, KF-ZrF$_4$, and air

• Heat loss considered: Piping, flanges, and insulation

Comparison of with and without heat loss model
LTDF Benchmark Study

- RELAP5 simulation results against LTDF experimental data
  - DRACS startup scenario
  - Pump trip scenario
HTDF Simulation Results

- Thermodynamic and transport properties of molten salts (FLiBe, FLiNaK, and KF-ZrF$_4$) have been implemented into RELAP5
- RELAP5 transient analyses
  - DRACS startup scenario
  - Pump trip scenario
- Benchmark study to be performed when experimental data become available
Salt Processing

- **Preparing salt mixture**
  - Further dehydrate the constituent salts at a controlled temperature (~150 to 200 °C)
  - Weigh and mix the salts in a controlled environment (glove box)

- **FLiNaK melting point measurement**
  - A flat-temperature stage corresponding to salt freezing
  - Melting point of 458.7 °C (average over 4500 - 5500 s)
Salt Purification and Component Testing

- Filtering molten salt
- Testing valves
- Benchmarking ultrasonic flow meters under high-temperature liquid salt conditions
- Calibrating level sensors
- Testing differential pressure measurement method
Heat Exchanger Testing

- Additional components are being added to the HTDF to facilitate HX testing under salt-salt and salt-air conditions.
Corrosion Screening Testing

Operating Condition:
• Salt: FLiNaK
• Cover gas: Ar
• Temperature: 722 °C
• Time: 103 hrs
• Test specimen: SS 316H
Corrosion Screening Testing (Cont’d)

Ultrasonic cleaner

Cleaning
• \(\text{Al(NO}_3\text{)}_3\): 1 mol/L
• Distilled water

Corrosion Rate
A: 3.12 mg/cm\(^2\)-d   B: 3.07 mg/cm\(^2\)-d
C: 2.87 mg/cm\(^2\)-d   D: 2.88 mg/cm\(^2\)-d
Reduced-scale Tritium Removal Testing

Back to main loop

From main loop

H₂ addition facility

H₂ outlet

Purging gas outlet

H₂ removal facility

H₂ inlet

Purging gas inlet

Flowmeter
Reduced-scale Tritium Removal Testing (Cont’d)

H₂ addition gas line

H₂ removal gas line

Sampling & venting
Reduced-Scale Tritium Removal Testing (Cont’d)