Initial Testing of the Stainless Steel NaK-Cooled Circuit (SNaKC)

Abstract. An actively pumped alkali metal flow circuit, designed and fabricated at the NASA Marshall Space Flight Center, is currently undergoing testing in the Early Flight Fission Test Facility (EFF-TF). Sodium potassium (NaK) was selected as the primary coolant. Basic circuit components include: simulated reactor core, NaK to gas heat exchanger, electromagnetic liquid metal pump, liquid metal flowmeter, load/drain reservoir, expansion reservoir, test section, and instrumentation. Operation of the circuit is based around the 37-pin partial-array core (pin and flow path dimensions are the same as those in a full core), designed to operate at 33 kWt. This presentation addresses the construction, fill and initial testing of the Stainless Steel NaK-Cooled Circuit (SNaKC).
Initial Testing of the Stainless Steel NaK-Cooled Circuit (SNaKC)

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Early Flight Fission – Test Facility (EFF-TF)
Presentation Summary

- Early Flight Fission Test Facility (EFF-TF)
- Test Objectives
- Test Configuration
- Instrumentation
- Initial Fill and Test
- Test Results
- Summary
Realistic Non-Nuclear Testing of Nuclear Systems:
From Paper to Reality

The Early Flight Fission Test Facility (EFF-TF) is the only operating facility in the U.S. capable of performing realistic thermal hydraulic testing of nuclear systems using non-nuclear (electrical) heat sources.

Development of a similar test bed for General Purpose Heat Sources (GPHS) builds on success of the EFF-TF and ESTF.
History
Early Flight Fission Test Facility

Working closely with customer to help devise/design useful facilities and perform tests to help customer turn ideas from paper to reality.
Test Objectives

- A reactor concept shall be filled with liquid metal (NaK) and thermal hydraulically tested. This testing will:
  - Provide the EFF-TF team with hands-on liquid metal systems experience.
  - Assist in the design of the Fission Surface Power Primary Test Circuit (FSP-PTC) and its subsystems.

- Specific objectives:
  - Inclusion of a “test section” to evaluate components.
  - Preliminary flow analysis using simulation.
  - Experimental data will flow into second-generation circuit design.
  - Personnel trained in the handling of NaK.
  - Procurement and integration of a liquid metal cleaning system to enhance operation.
Test Configuration

Stainless steel NaK-cooled circuit (SNaKC)
Test Configuration

- 1/3 partial core from 100 kWt LANL design study
- 37-pin assembly divided into 4 zones
- Zones allow 44 kW to be applied to thermal simulators (in total)
- 12 zones allowable at maximum (giving 180 kW input power)
- NaK can be brought up to 1000°F (537°C) maximum

Power Zones & Thermal Simulators

Zone 1 - 7 Heater Elements
Zone 2 - 12 Heater Elements
Zone 3 - 12 Heater Elements
Zone 4 - 6 Heater Elements
Test Configuration

- **NaK-to-GN\(_2\)** heat exchanger
  - Inlet pressure and temperature can reach 185 psia and ~400°C
- **Liquid metal pump** provided by CEI
  - No moving parts; operates on F=JxB principle
  - Capable of generating ~1.5 kg/s mass flow rate
  - GN\(_2\) flows through housing for pump cooling
Test Configuration

- Test section can be used for:
  - Single channel element testing
  - Liquid metal flowmeter evaluation
  - Insertion of other components into circuit (e.g. pumps)
Instrumentation

- Test article instrumentation:
  - ~75 type-K thermocouples
  - 8 pressure measurements
  - 9 level sensors (6 on LR, 3 on UR)
  - Liquid metal flowmeter
- Pressure, temperature, flow measurements for GN2 system
- LabVIEW used for data acquisition and control
Initial Fill and Test

- Lower reservoir was filled to a height of 4.5” above the bottom of the reservoir
- Corresponds to ~15.3 L (~29.3 lbs) of NaK
- First Test
  - Applied a maximum of 13.7 kW to the core
  - Reached a temperature of 431°C (~700 K)
  - Reached a maximum NaK flow rate of 12.8 GPM (0.66 kg/sec)
  - Heat exchanger was not used
## Pump Performance Test Matrix

<table>
<thead>
<tr>
<th>NaK Flow Temp</th>
<th>EM Pump Voltage</th>
<th>100V</th>
<th>140V</th>
<th>200V</th>
<th>max V</th>
</tr>
</thead>
<tbody>
<tr>
<td>350°C</td>
<td></td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>375°C</td>
<td></td>
<td>3</td>
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<td>4</td>
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</tr>
<tr>
<td>400°C</td>
<td></td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>4</td>
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<tr>
<td>425°C</td>
<td></td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>3</td>
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<tr>
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<td>4</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
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<tr>
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<tr>
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<td>4</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>577°C</td>
<td></td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

- Pump is reportedly inefficient at temperatures less than ~800°F (427°C)
- Pump behavior for NaK-56 at 1060°F (571°C) provided by pump manufacturer
- Test a variety of pump power settings over a range of temperatures
- Tested ranges may be varied as needed
Test Results

Pump Performance

Liquid metal pump functions at approx. X% efficiency at temperatures greater than 427°C (800°F)

Representative Curves

Flow Rate (kg/sec)

Developed Pressure (psi)
Test Results

Average Component Temp vs. Time
NaK Flow Rate vs. Time

- Core
- HX
- Tube 1
- Tube 3
- Tube 4
- NaK Flow Rate
Test Results

Power Added, Removed vs. Time
NaK Flow Rate vs. Time

Mass Flow Rate (kg/s)

Power (kW)

Time from Start of Test (H:M:S)
Summary

- Test article has been filled and NaK can be moved to and from the lower reservoir
- All components and instrumentation are functioning well
- Test article has been brought up to a maximum of 430°C (700 K)
- Flow rates of 12.8 GPM have been reached
- Liquid metal pump operates at X% efficiency above 427°C (800°F)
- Personnel have been trained to properly handle NaK
- Many lessons learned regarding the filling and draining of the circuit, NaK flow, changing out of components, and use of instrumentation
References


Acknowledgments

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BACKUP CHARTS
Simulation

Pump Input = 140 V
NaK Flow Rate = 1.07 kg/s
Nitrogen Flow Rate = 0.16 kg/s
Total System Pressure Drop = 5.14 psi
Core Inlet Temperature = 422 °C
Core Outlet Temperature = 457 °C
NaK Handling Training

- Training sessions conducted by Creative Engineers, Inc.: at MSFC and at CEI facility in York, PA (CEI performed clean-up at Y-12)

- Activities:
  - Observing NaK in argon gas and in air
  - Stirring exposed NaK
  - Wiping up small spills
  - Cleaning pipe fittings
  - Burning NaK in air
  - Exposing NaK to large quantities of water

- ER24 has previous alkali metal experience (sodium purification, filling of sodium heat pipes, SAFE-30, SAFE-100A)