



Single Primary Heat Extraction and Removal Emulator (SPHERE)

SPHERE Testing and Validation

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Overview

- FY-25 SPHERE activities
 - Well-Defined Boundary Condition Testing
 - Phenomena Identification and Ranking Table (PIRT) for Heat Pipes
 - Capillary Limit Testing
 - Conclusions
- FY-26 Activities
 - BEPU
 - Vapor Flow Measurement Feasibility Assessment

SPHERE Purpose

- Provide a test bed to demonstrate heat pipe performance under various operating conditions, including steady-state, long-term, and transient scenarios, for improved understanding and validation
- Heat Pipe experiments for V&V
- Support MAGNET by providing testbed for preliminary activities to feed into larger experiments

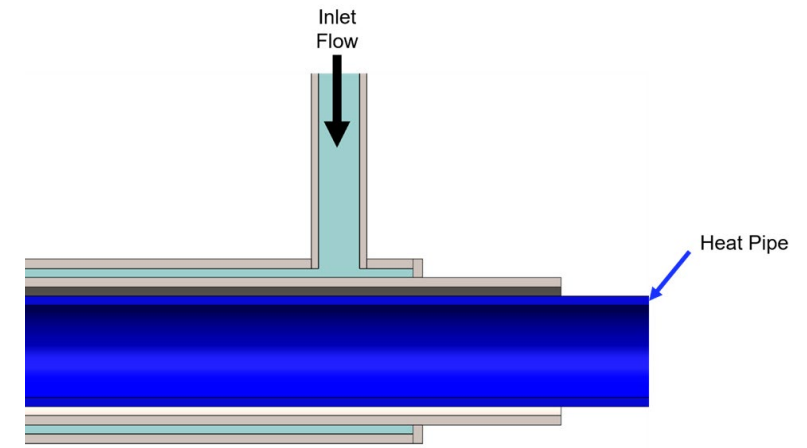


FY-25 Activities

- **Well-Defined Boundary Condition Testing**
- **Capillary Limit Testing**
- **Heat Pipe PIRT**

Gas-Gap Calorimetry

- Previous was unable to regulate heat pipe temperature at a specified power level, significantly limiting the heat pipe testing envelope
- Gas-gap calorimeters utilize He-Ar binary gas mixture to tune the thermal resistance between the heat pipe and the coolant
- This enables the efficient cooling of high-temperature heat pipes ($\sim 500\text{-}1000^\circ\text{C}$) using conventional fluids



Gas-Gap Calorimeter Sizing and Rating Tools for Experiment Design

- Newly developed Excel and MATLAB tools
 - Option 1: Determine heat pipe temperature given geometry, input power, He-Ar composition
 - Option 2: Determine He-Ar composition given geometry, input power, and condenser temperature
- Development of this capability improves SPHERE testing by:
 - Reducing procedural uncertainties by predicting experimental conditions
 - Enabling safer operation by prior estimates of surface temperatures
 - Allowing more accurate calorimetry and better characterization of heat losses
 - Explores future testing approaches such as gas coolant loops

```
1 =====  
2                      Results  
3 =====  
4  
5 Using Option 2: Solve for Mole Fraction  
6  
7 Using Sub-Option 2: Static Gas  
8  
9 Heat pipe condenser wall temperature = 1000.0°C  
10 Shell average wall temperature = 109.3°C  
11 Cooling power due to radiation = 233.2 W (%4.7)  
12 Cooling power due to conduction = 4766.8 W (%95.3)  
13 Coolant mean temperature = 53.9°C  
14 Gas compositions: He = 0.943, Ar = 0.057
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Option to solve for He-Ar fractions, given power (5 kW) and temperature (1000 K)

He-Ar gas composition required to achieve the input condition

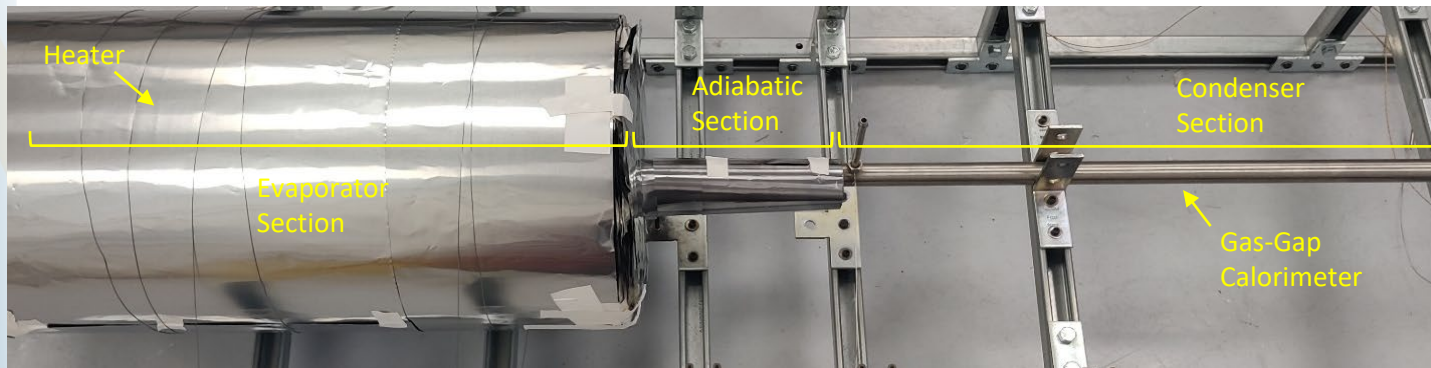


Startup Procedure Development with Gas-Gap Calorimetry

- Use coupling curves to
 - Determine operating envelop for the configuration
 - Develop calculation-guided experimental procedures
 - Safely ramp heat pipe temperatures from ambient conditions
 - Prevent rapid temperature spikes
- He-Ar composition is controlled by newly acquired pressure controllers

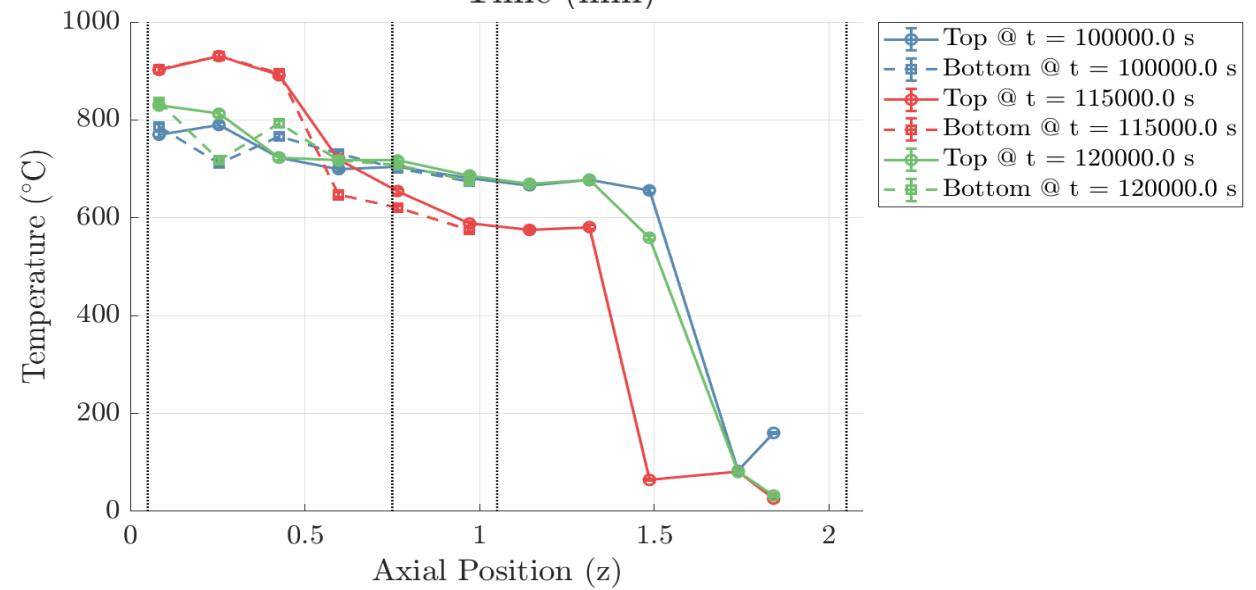
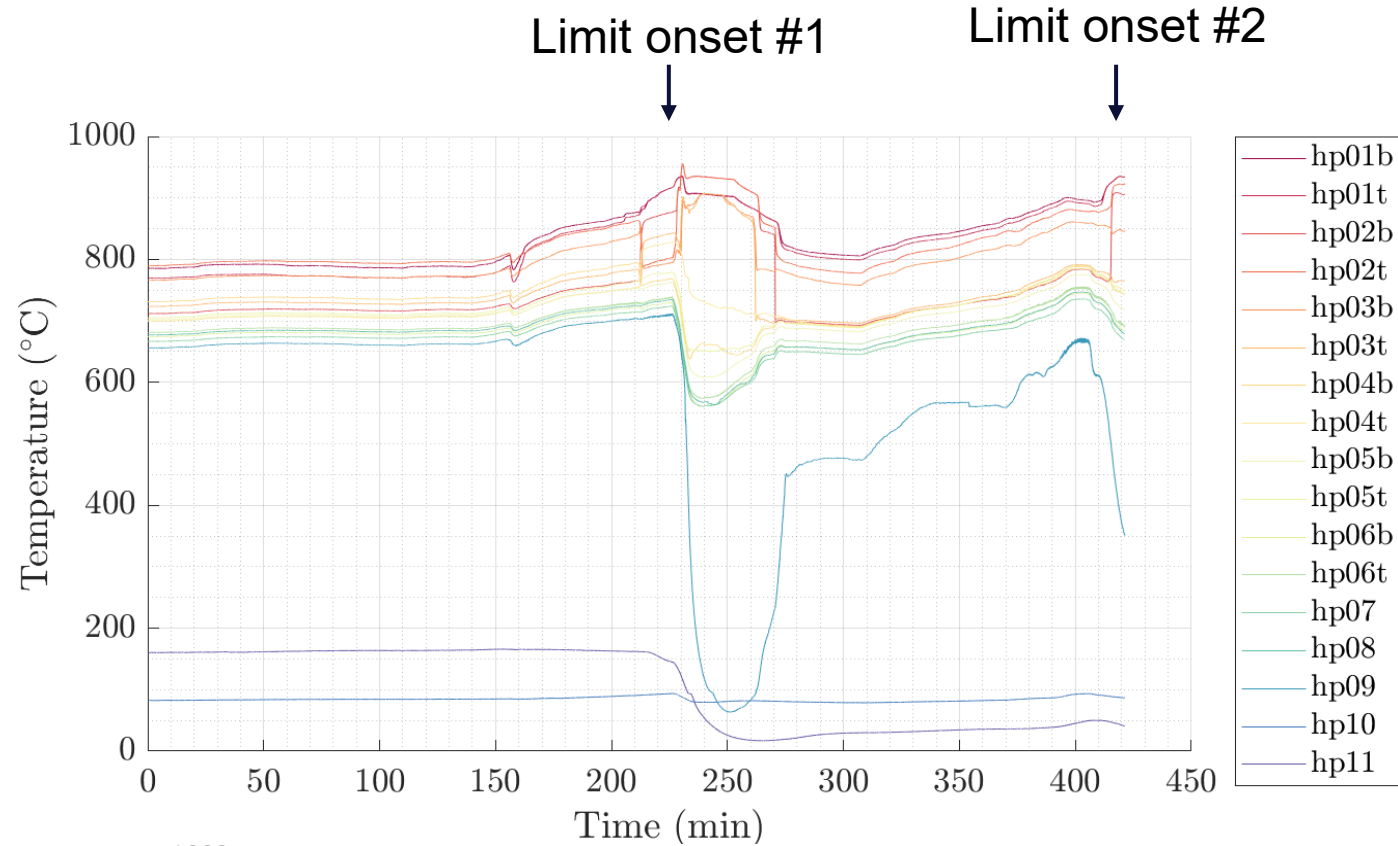
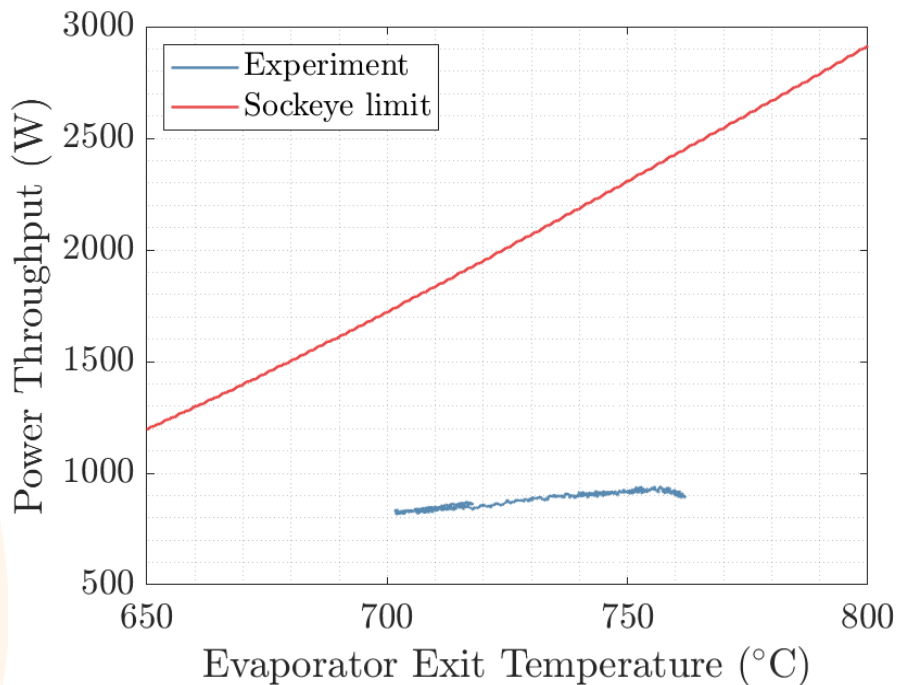
Capillary Limit Test Setup

- LANL Sodium-filled heat pipe, 76.5" long
 - Evaporator: 24"
 - Adiabatic: 11.5"
 - Condenser: 40"
- LANL Calorimeter



Onset of Capillary Limit

- Sharp rise in evaporator temperatures and drop in adiabatic/condenser temperatures.
- Two limit onsets at ~230 min and ~420 min, at ~900 W
- Axial temperature drop prior to onset (~150°C) indicates degraded performance prior to test



PIRT Graphical Abstract

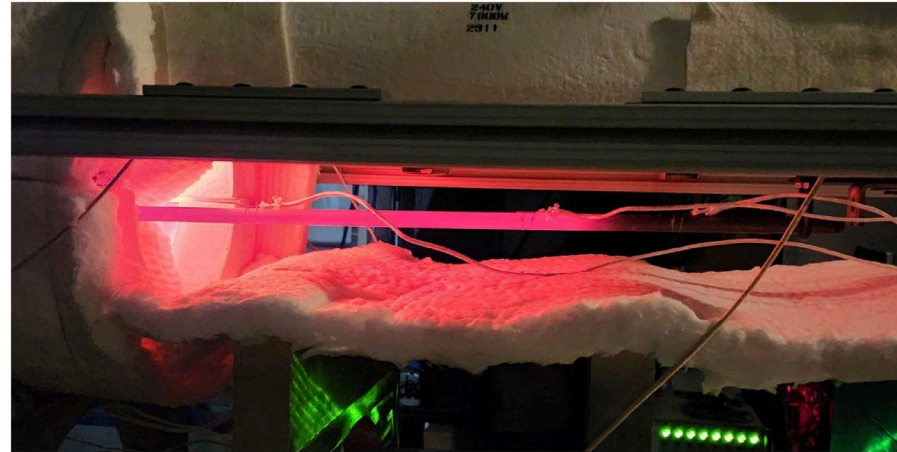


High Importance Phenomena	
Low M&S Knowledge	Low E&I Knowledge
<i>Wick De-Wetting</i>	<i>Liquid Flow & Pressure Drops</i>
<i>Wettability</i>	<i>Vapor Pressure Drops</i>
<i>Critical Heat Flux</i>	<i>Evaporation/ Condensation</i>
<i>Nucleate Boiling</i>	<i>Critical Heat Flux</i>
<i>Pressure Dynamics</i>	<i>Nucleate Boiling</i>
	<i>Wettability</i>
	<i>Pressure Dynamics</i>
	<i>Creep</i>
	<i>Fluid Contamination</i>
	<i>Wick Degradation</i>

ADVANCED REACTORS

The current status of heat pipe R&D

Fri, Oct 10, 2025, 3:42PM | Nuclear News | Ilyas Yilgor, Mauricio Tano, Katrina Sweetland, Joshua Hansel, and Piyush Sabharwall



NuclearNewswire

<https://www.ans.org/news/article-7390/the-current-status-of-heat-pipe-rd/>




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Phenomena Identification and Ranking Table (PIRT) for heat pipes

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Phenomena Identification and Ranking Table (PIRT) for Heat Pipes

INL/RPT-25-84171
Revision 0

Microreactor Program

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<https://gain.inl.gov/content/uploads/4/2025/05/2025-Document-INL-RPT-25-84171.pdf>



MRP Microreactor Program

FY-25 Conclusions

- Facility and methodology upgrades enabled well-defined boundary condition testing
 - Vacuum and He-Ar binary gas mixture control in chamber
 - Gas-gap calorimeter sizing and rating tools
 - Operational experience on chamber operation
- PIRT
 - 50 phenomena identified
 - Future research directions established based on importance and knowledge
- Capillary limit testing
 - Temperature response at the onset of capillary limit characterized

FY-25 Ongoing Activities

- Test article for LANL refractory heat pipe test—delayed due to limited resources.
 - Expected to be complete for individual heat pipe measurement after MAGNET completes graphite core block test
 - Estimated Complete Q2 FY26



FY26 Activities

- **BEPU**
- **Vapor Flow Measurements Feasibility**

BEPU Methodology for Heat Pipe Design

Best-Estimate Plus Uncertainty (BEPU) workflows to support risk-informed design decisions

Why BEPU for heat pipes?

- Quantify how uncertainties in geometry, materials, and fluid properties propagate to performance limits.
- Provide defensible design margins by targeting reliability goals (coverage + confidence) instead of ad-hoc safety factors.
- Identify dominant contributors via sensitivity indices to prioritize experiments, QA, and model improvements.
- Enable rapid trade studies across temperature, fill state, and geometry for early design space screening.

Design metric (example)

We evaluate limiting heat transport rates and aggregate them into an overall allowable power.

$$Q_{lim} = \min(Q_{cap}, Q_{sonic}, Q_{entr}, Q_{visc})$$

Typical contributors:

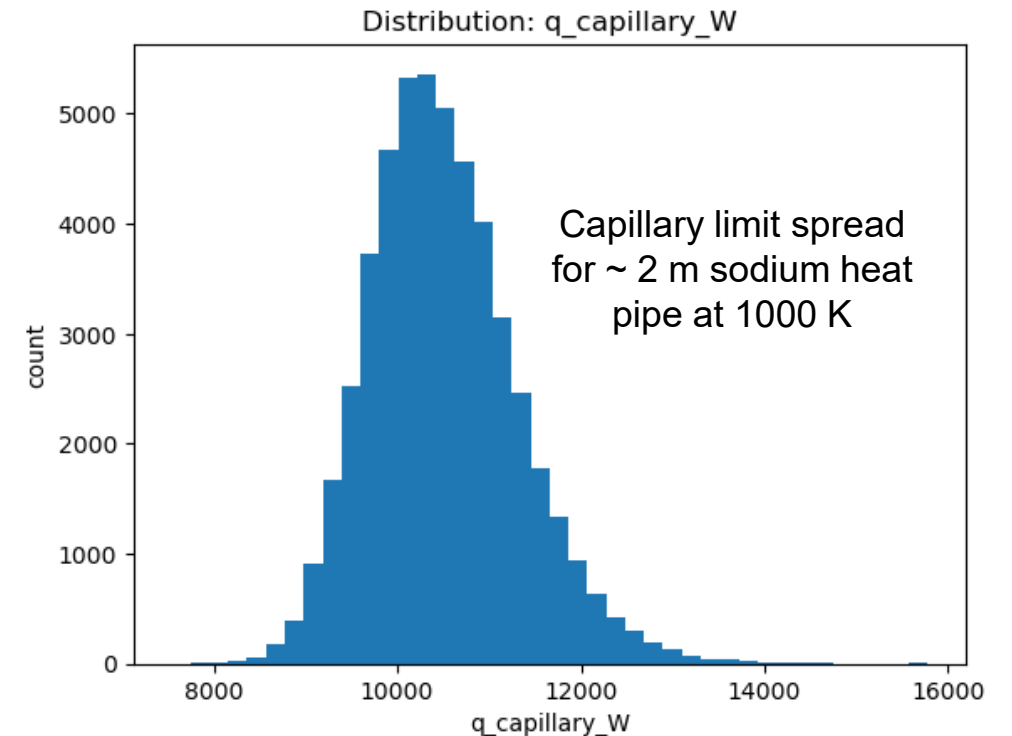
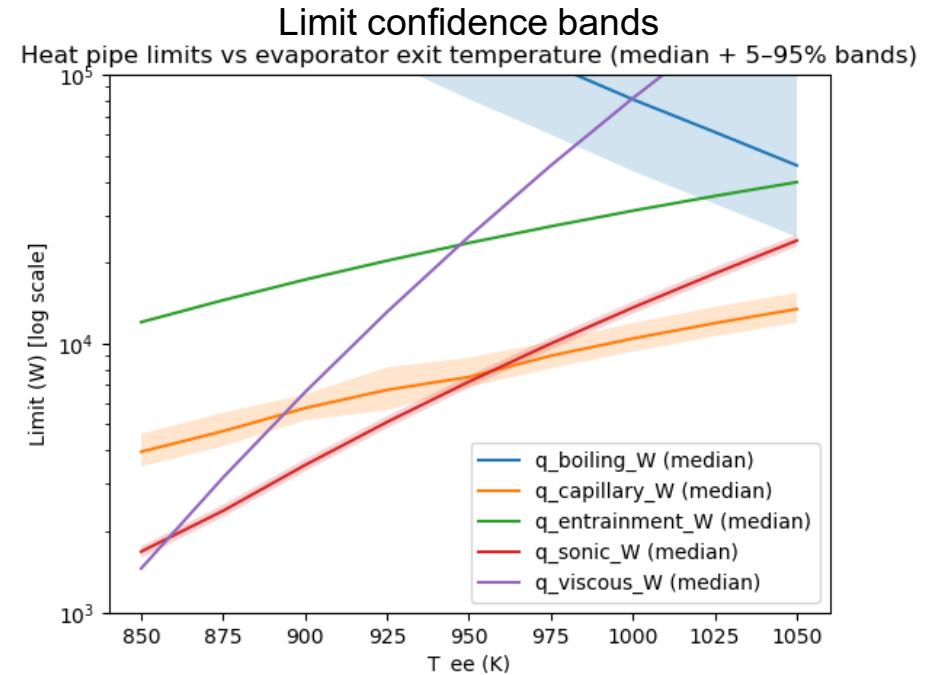
- Capillary limit
- Sonic / choking limit
- Entrainment limit
- Viscous limit
- ...(extendable as models mature)

BEPU output: distributions, tolerance bounds, and sensitivities on Q_{lim} and sub-limits.

BEPU Progress

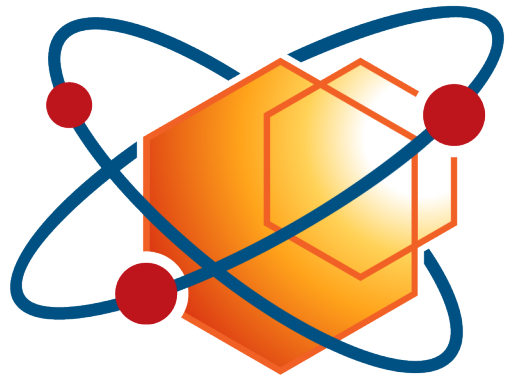
- Test cases across regime transitions establishes
- Uncertain parameters and distributions identified
- UQ and heat pipe modeling framework established
- Preliminary calculations conducted using HTPPIPE models

Operating points of interest



Vapor Flow Measurements Feasibility Study

- Evaluating the feasibility of advanced diagnostic techniques for measuring internal pressure, velocity, and temperature within alkali metal heat pipes
 - These measurements are essential for characterizing two-phase flow dynamics and ensuring system stability, but are difficult to obtain
- Estimated Timeline:
 - Literature review and technology assessment (05/2026)
 - Conduct fluid-to-fluid scaled system feasibility study (06/2026)
 - Develop conceptual design (07/2026)
 - Conduct feasibility analysis (08/2026)
 - Determine technical approach and prepare documentation (09/2026)



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