Demonstration Capabilities Area

Summary & Wrap Up

Piyush Sabharwall, Ph.D. | Technical Area Lead, DOE NE-MRP

MRP Microreactor Program

Demonstration Support Capabilities – *Activities & Milestones for FY 25*

- **SINGLE PRIMARY HEAT EXTRACTION AND REMOVAL EMULATOR (SPHERE)**
  - Development of a targeted Phenomena Ranking and Identification Framework to Pinpoint Critical Modeling, Simulation, and Engineering Needs for Heat Pipe Operation and Transient Studies (**04/01/2025**)
  - Perform vacuum boundary condition heat pipe analysis (**05/28/2025**)
  - Complete a well-defined boundary condition run of the high-performance refractory metal heatpipe from LANL **(07/31/2025)**
  - Utilizing Higher-Fidelity Models in Sockeye and Computational Fluid Dynamics for Studying Operational Transients in Heat Pipes With and Without Non-Condensable Gases and Validation Against Experimental Data (**08/28/2025**)
  - Complete limit testing on a high-performance heat pipe (**09/10/2025**)

- **MICROREACTOR AGILE NON-NUCLEAR EXPERIMENTAL TESTBED (MAGNET)**
  - Deliver PCU Shakedown Test Plan (**02/27/2025**)
  - Complete construction to integrate Power Conversion Unit (PCU) (**03/27/2025)**
  - Install and validate PCU Instrumentation and Control (**04/30/2025)**
  - Complete shakedown testing of PCU (**05/22/2025**)
  - Performance testing of LANL graphite core assembly(**08/28/2025**)

MRP Microreactor Program

SPHERE- Accomplishments from FY 24

Power Transient Testing

- Idaho National Laboratory has completed testing on power transients of a high-performance sodium filled heat pipe with a range of operating conditions. The resulting temperature profiles from this testing will be utilized to aid in the validation of the startup and shutdown portions of the heat pipe modeling code, Sockeye.

- Outcome: Provided data to Sockeye development team for model V&V for a series of power transients and heating profiles

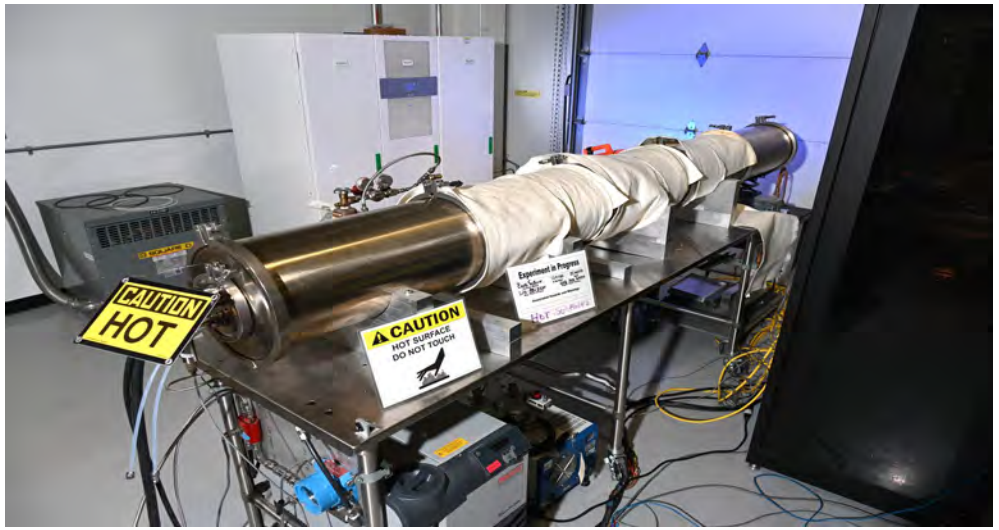


Fig. Sphere Test Bed

Fig. Instrumentation sodium filled heat pipe

Long Duration Testing

- Idaho National Laboratory has completed testing over a long duration of a high-performance sodium filled heat pipe while monitoring axial temperature profile, power supplied by the heaters, and heat removed by a gas-gap calorimeter

- Outcome: Provided data on heat pipe degradation over 1,000 hours to Sockeye team

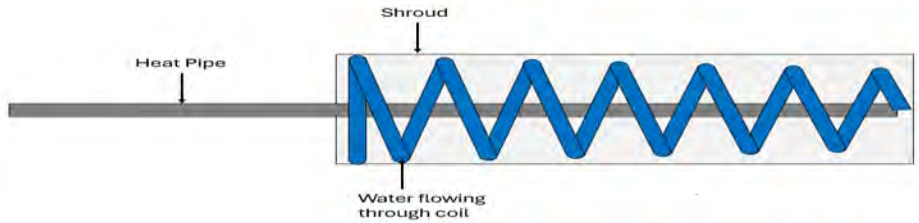


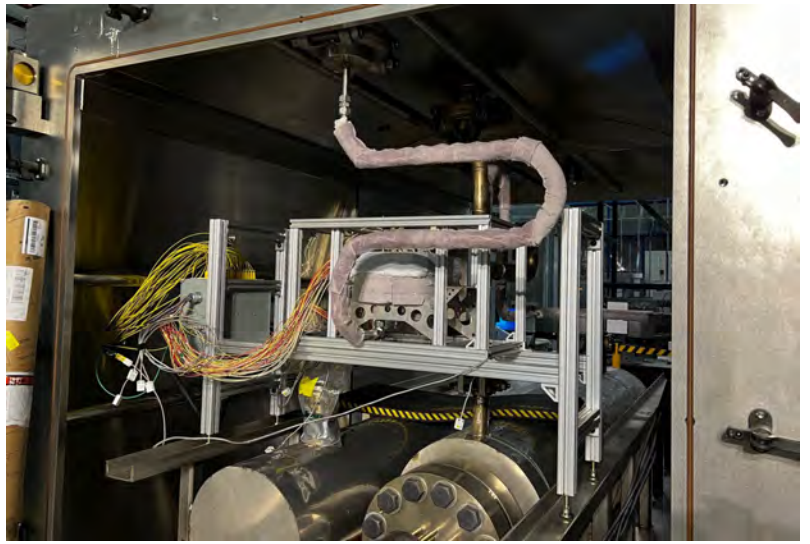
Fig. Calorimeter for heat removal

MRP Microreactor Program

MAGNET- Accomplishments from FY 24

Working with University of Wisconsin to support testing of Advanced Integration Heat Exchanger Technology for Micro-Reactors

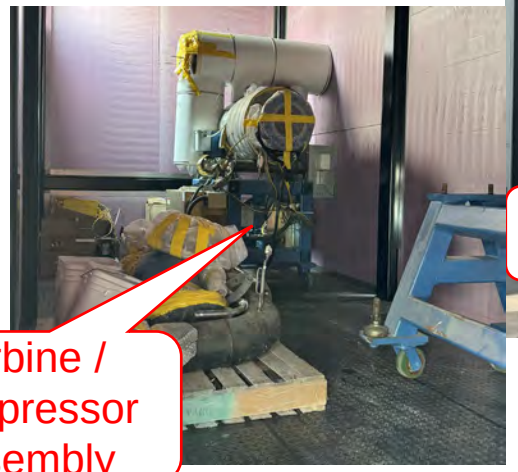
- Install U-W fabricated prototype in MAGNET
- Test prototype for approximately 30 hours
- N_2 temperature up to 650°C, pressure up to 600 kPa, and flow rate up to 100 g/s
- Phase II Testing Proposal for this NEUP submitted at the end of 2023



Installed HPIHX Prototype

Power Conversion Unit (PCU) Integration:

- Construction to integrate gas-Brayton-cycle PCU in progress
- Structural steel construction complete
- Piping installation in progress
- PCU assembly inside enclosure in progress



PCU Enclosure

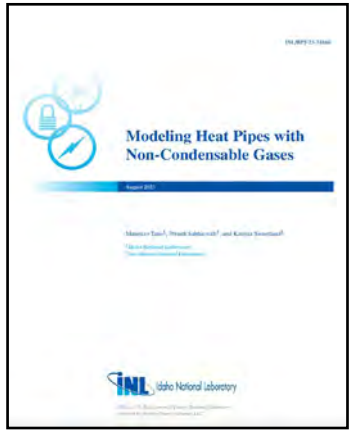
MRP Microreactor Program

Modeling Efforts

MRP Microreactor Program

Modeling Summary (From FY-23)

- Advance modeling of heat pipes with and without non-condensable gases
  - Two distinct models were compared:
    - Conduction model in Sockeye (NEAMS tool)
    - Two-phase Euler-Euler Computational Fluid Dynamics developed with STAR-CCM+
  - Both models were tested against Katrina Sweetland's Ph.D. experiments for copper-water heat pipes with a single condenser
  - Advantages and disadvantages of both models are driven from experiment comparison and runtime assessments

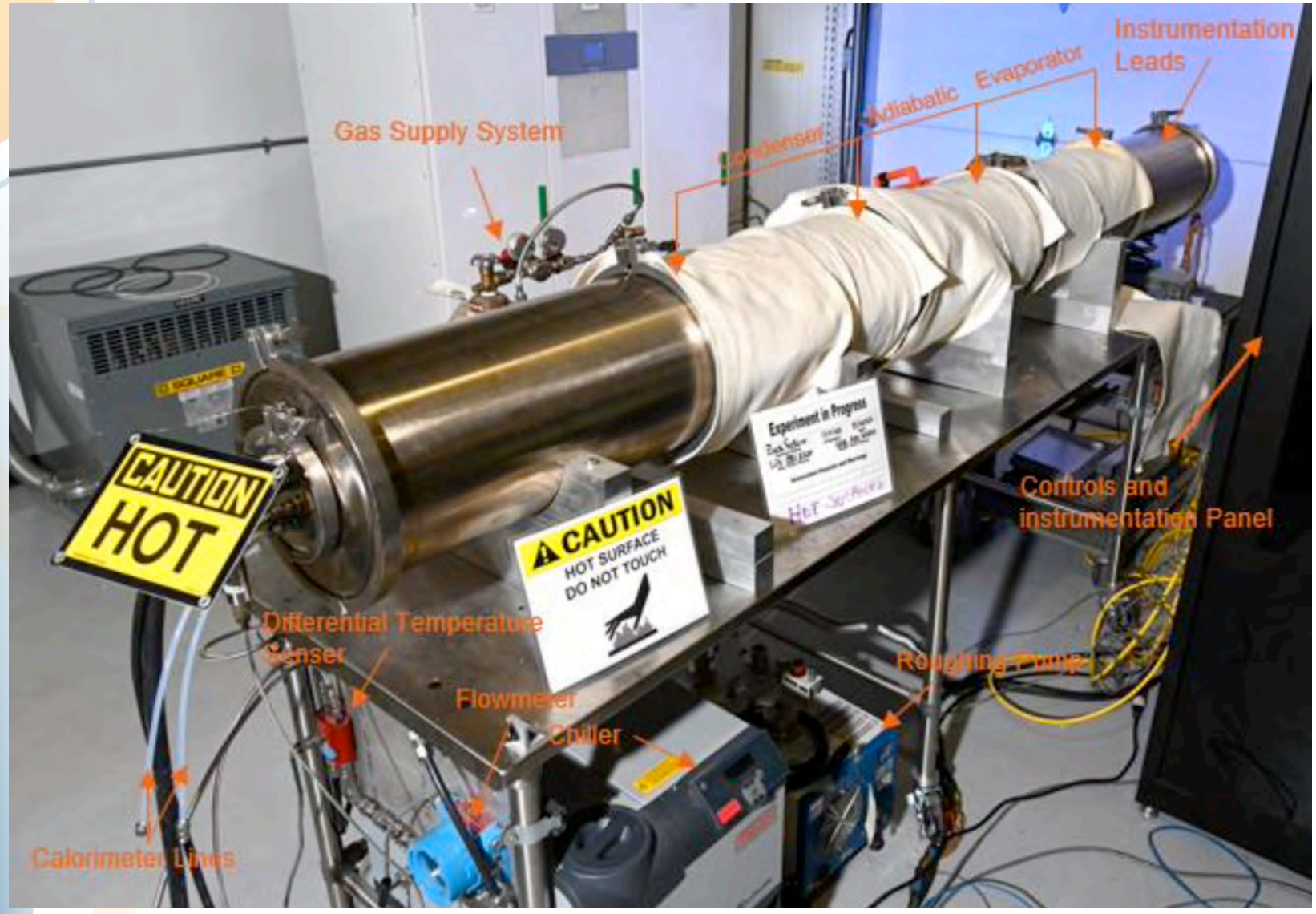


Credit: Mauricio Tano Retamales (INL)

MRP Microreactor Program

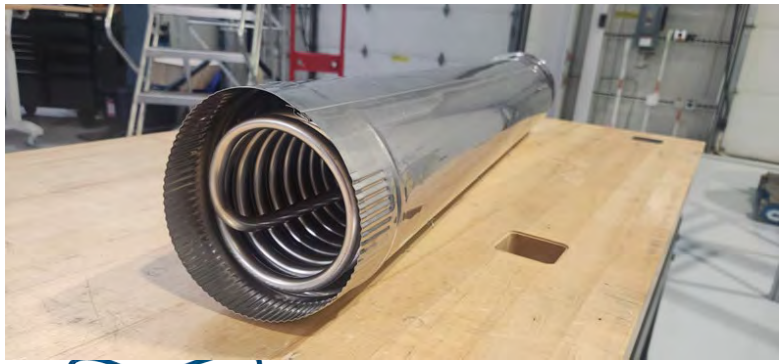
Tano, M., P. Sabharwall and K. Sweetland, *Modeling Heat Pipes with Non-Condensable Gases*, INL/RPT-23-74866, August 2023.

SPHERE (2024 Long-Duration) – Setup



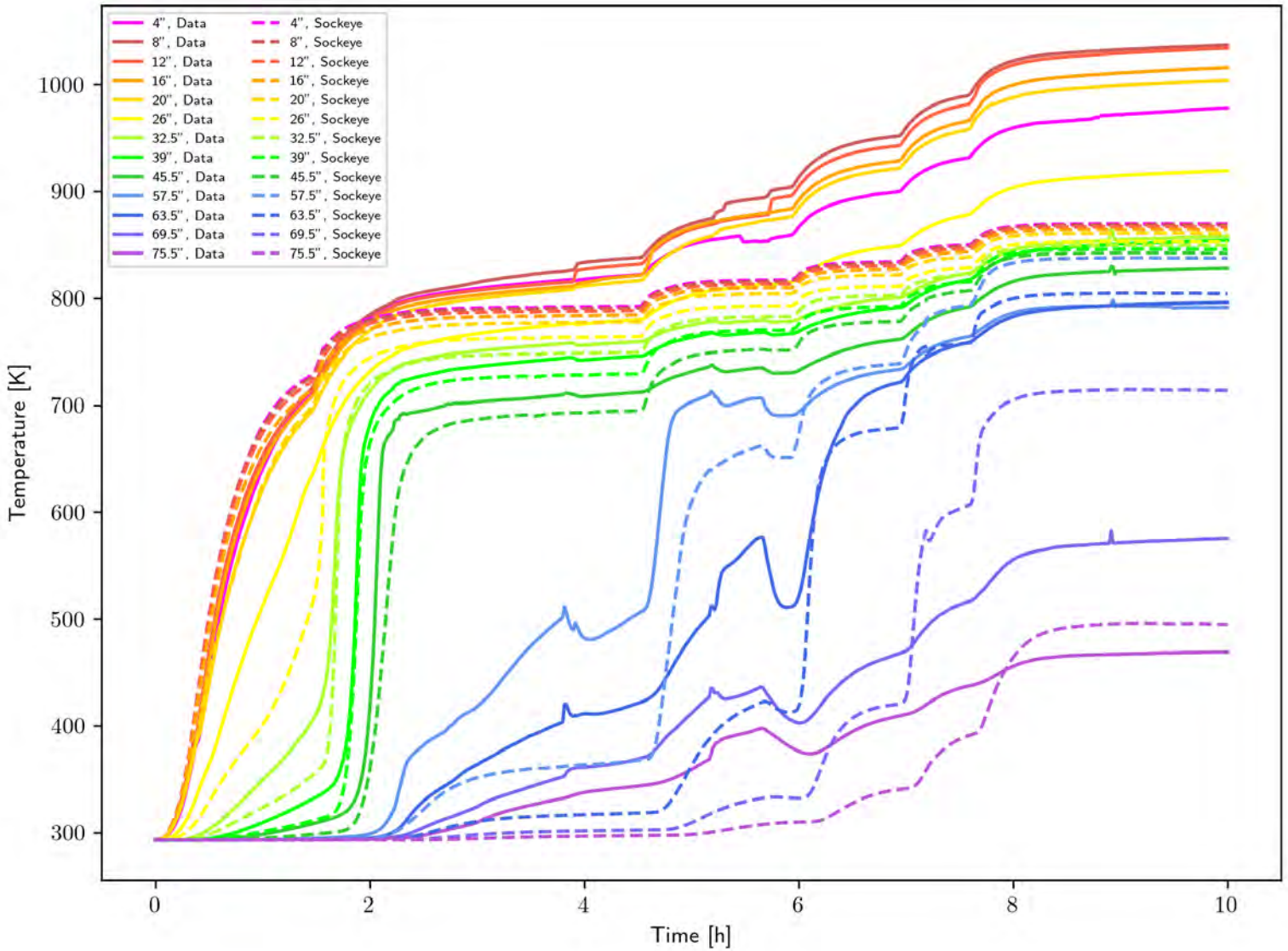
Heater (half):

Calorimeter:

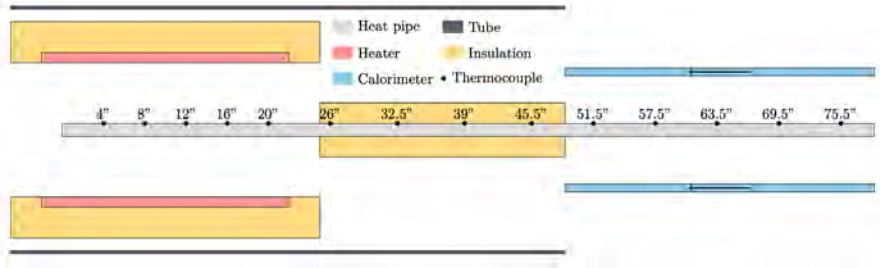


MRP Microreactor Program

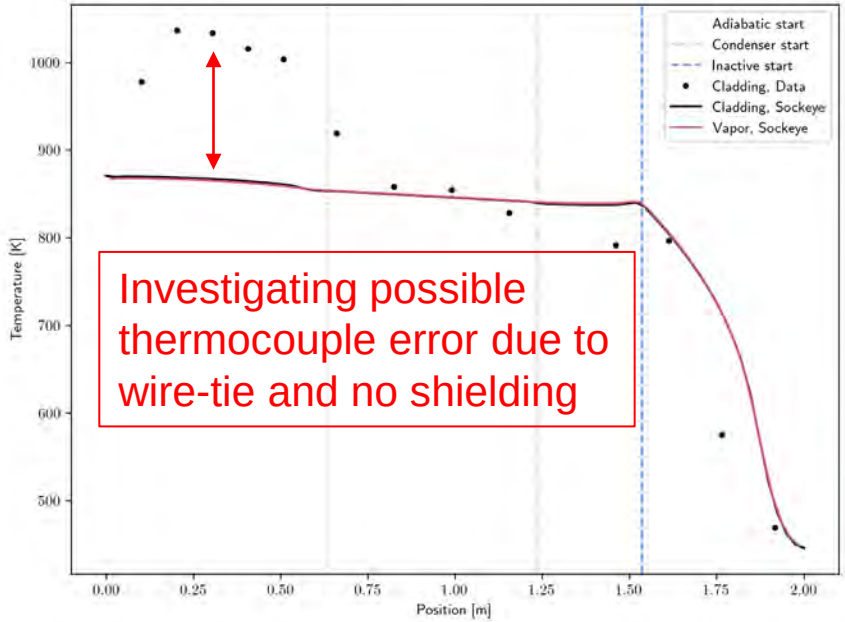
SPHERE (2024, Long-Duration) – Ongoing



Model diagram:



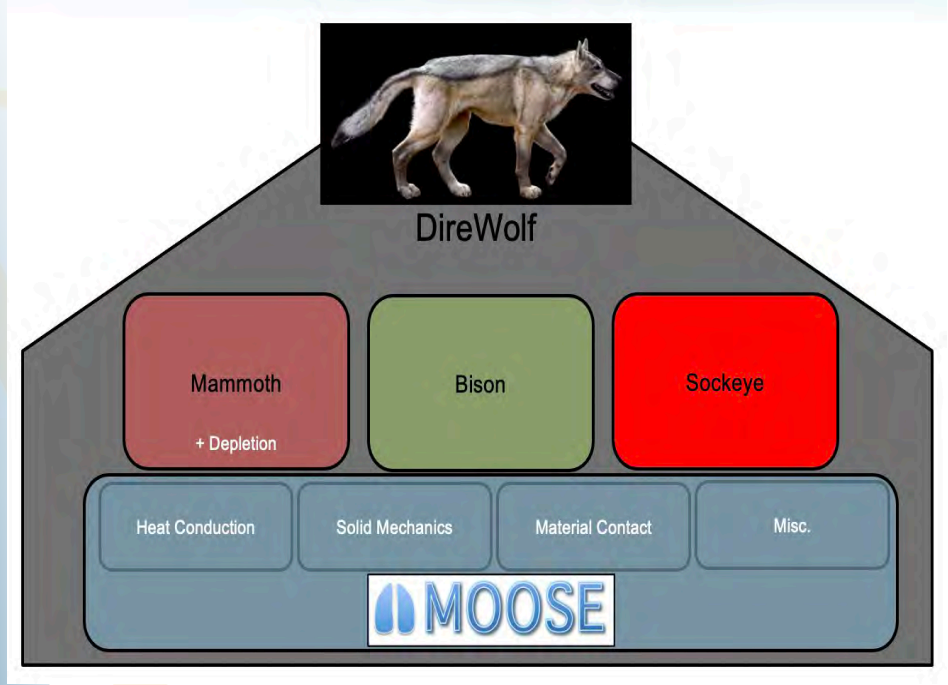
Final temperature distribution:

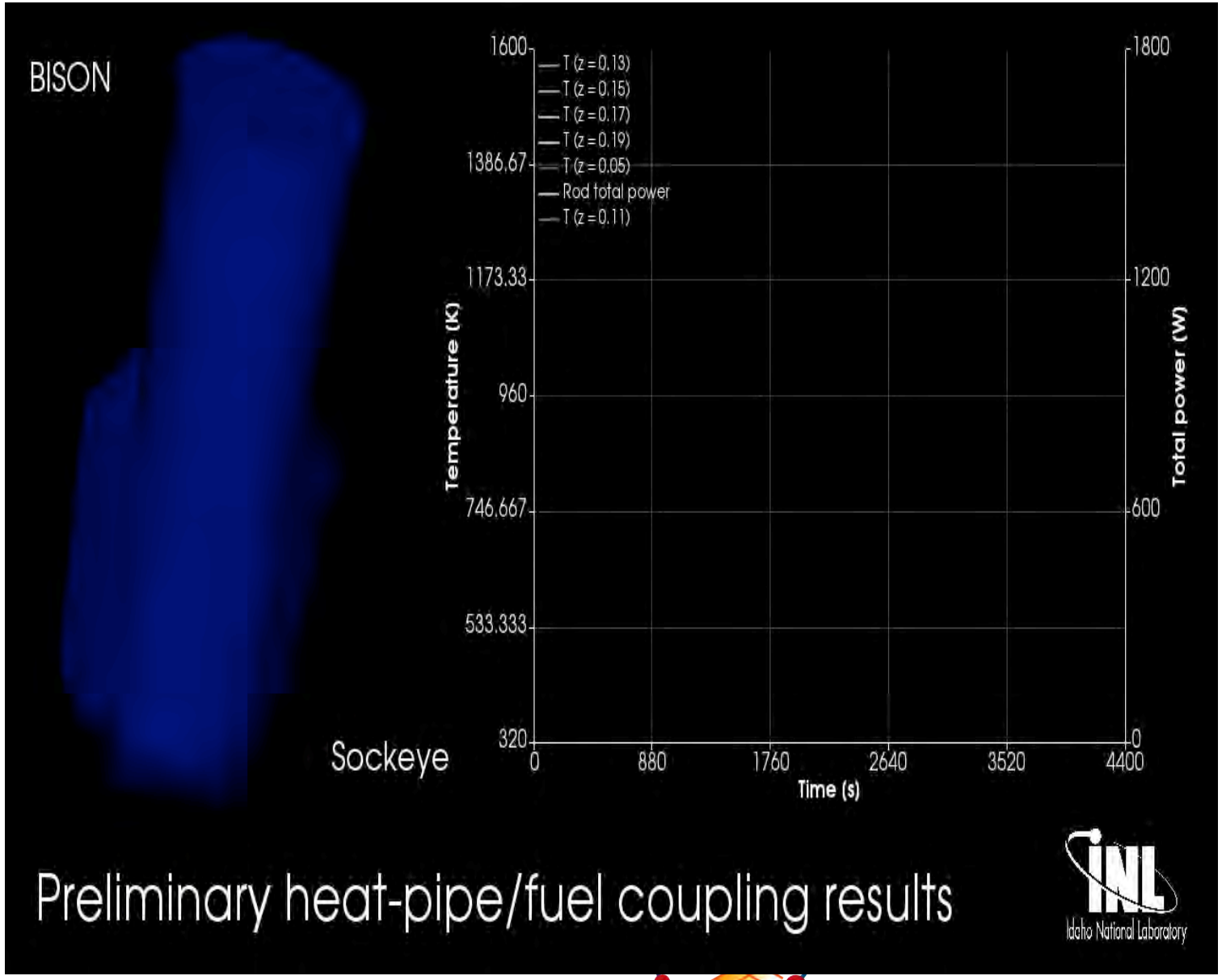


Investigating possible thermocouple error due to wire-tie and no shielding

Credit: Joshua Hansel (DOE NEAMS)

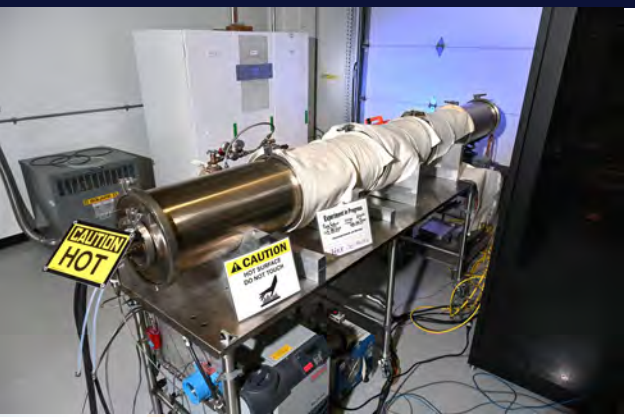
Modeling Informed Designs





MRP Microreactor Program

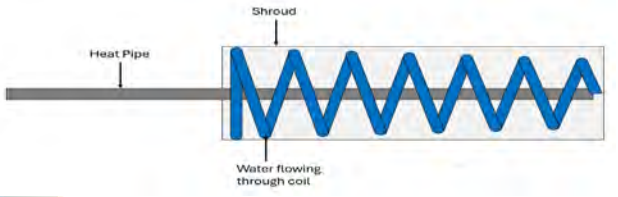
Demonstration Support capabilities (Accomplishments Continued)



SPHERE Test Bed

SPHERE Accomplishments

- **Power Transient Testing – Supporting validation efforts for Sockeye**
- **Long Duration Testing - completed testing over a long duration of a high-performance sodium filled heat pipe while monitoring axial temperature profile, power supplied by the heaters, and heat removed by a gas-gap calorimeter**



Calorimeter for heat removal

Installed HPIHX Prototype

He-CTF Enclosure

MAGNET Accomplishments

- **Worked with University of Wisconsin to support testing of Advanced Integration Heat Exchanger Technology for Micro-Reactors, test ran for 30 hours**
  - **N2 temperature up to 650°C, pressure up to 600 kPa, and flow rate up to 100 g/s**
- **Power Conversion Unit (PCU) Integration:**
  - **Construction to integrate gas-Brayton-cycle PCU in progress**
  - **Structural steel construction complete**

How Demonstration Support capabilities MEETS PROGRAM OBJECTIVES

Developing cross-cutting capabilities to **support microreactor technology demonstration**, with a focus on non-nuclear testing capabilities. This includes thermo-mechanical testing, systems integration, controls testing, and applications for novel microreactor concepts. Additionally, this initiative aims to address knowledge gaps related to high-temperature reactor components and systems.

Design and Development of Single Primary Heat Extraction and Removal Emulator (SPHERE) facility, enables us to:

- Enhance the understanding of thermal performance of heat pipes across a broad spectrum of heating values and operating conditions. This encompasses gaining deeper insights into heat pipe behavior during startup, shutdown, and transient operations. In addition to traditional measurements, the facility is equipped to employ advanced visual imaging techniques in-operando, providing detailed and high-fidelity measurements.

Design and Development of Microreactor Agile Non-Nuclear Experiment Testbed (MAGNET) facility, enables us to:

- Support verification and validation of detailed microreactor thermal hydraulic scaled models under startup, shutdown, steady-state, and off-normal transient behavior and load-following conditions. Also, provide means to better understand system integration with industrial load and power conversion system (such as integration of Brayton Cycle, ongoing activity for FY-25).

- Evaluate interfaces between simulated microreactor components

Working closely with DOE programs such as - NEAMS & IES, NRC, SBIR's and NEUP universities to support experiments for modeling and validation.

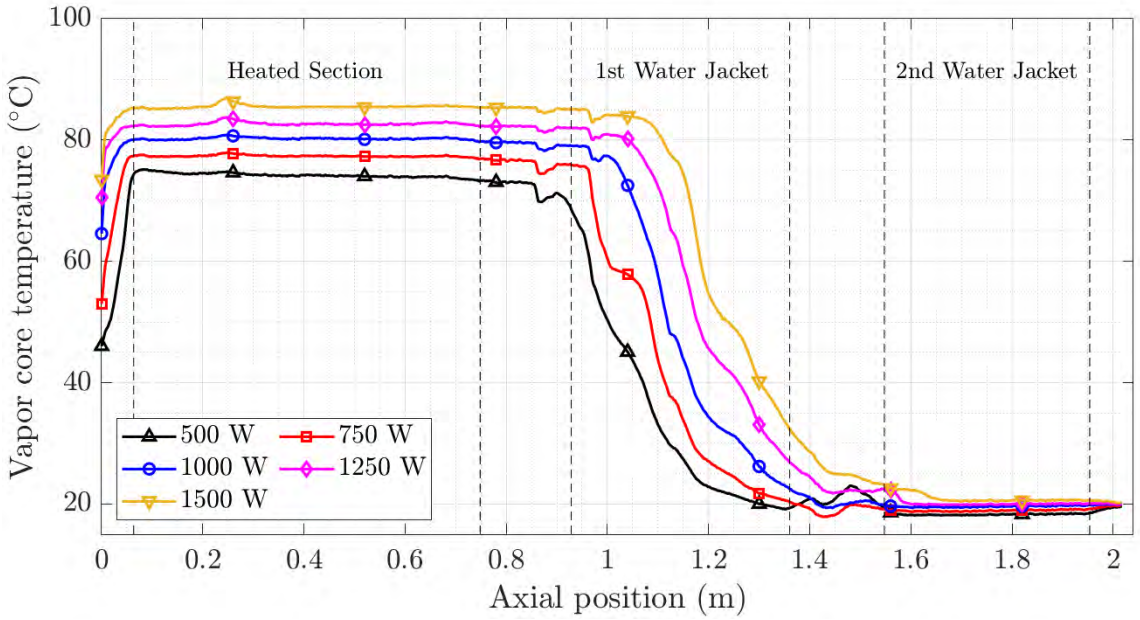
Validation and successful demonstration of the novel concepts and system integration in the designed test beds will pave the way for the first-of-a-kind deployment and commercialization of microreactor technologies and advanced energy systems.

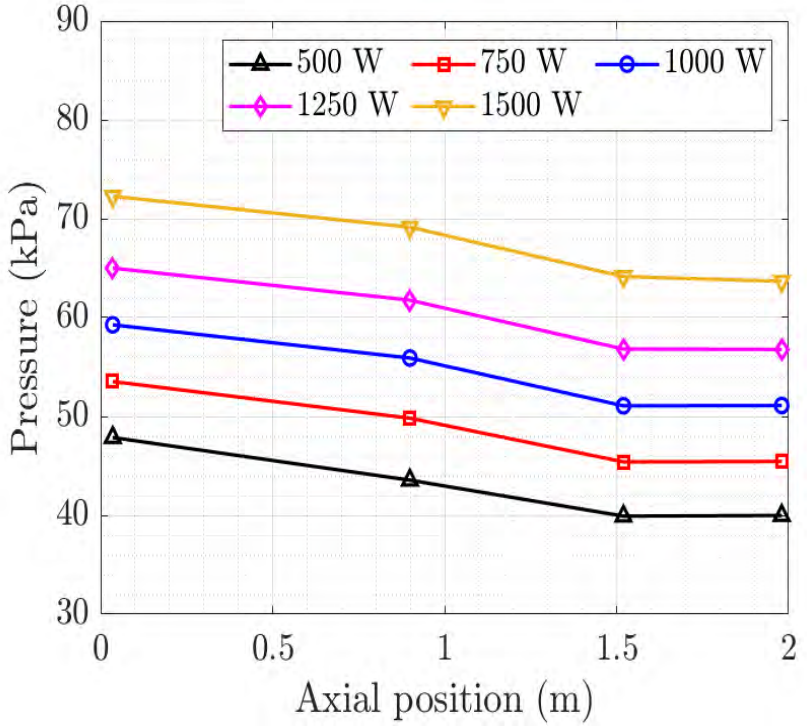
Partnerships and Collaborations (Universities & Industries)

MRP Microreactor Program

Experimental Work in University Partners - RPI

- Low-Temperature Heat Pipe Test Facility (LTHPF)
  - Fiber optic vapor core axial temperature profiles
  - Axial pressure profiles
  - High-speed flow visualization in the adiabatic section and condenser
  - Film thicknesses for thermosyphons



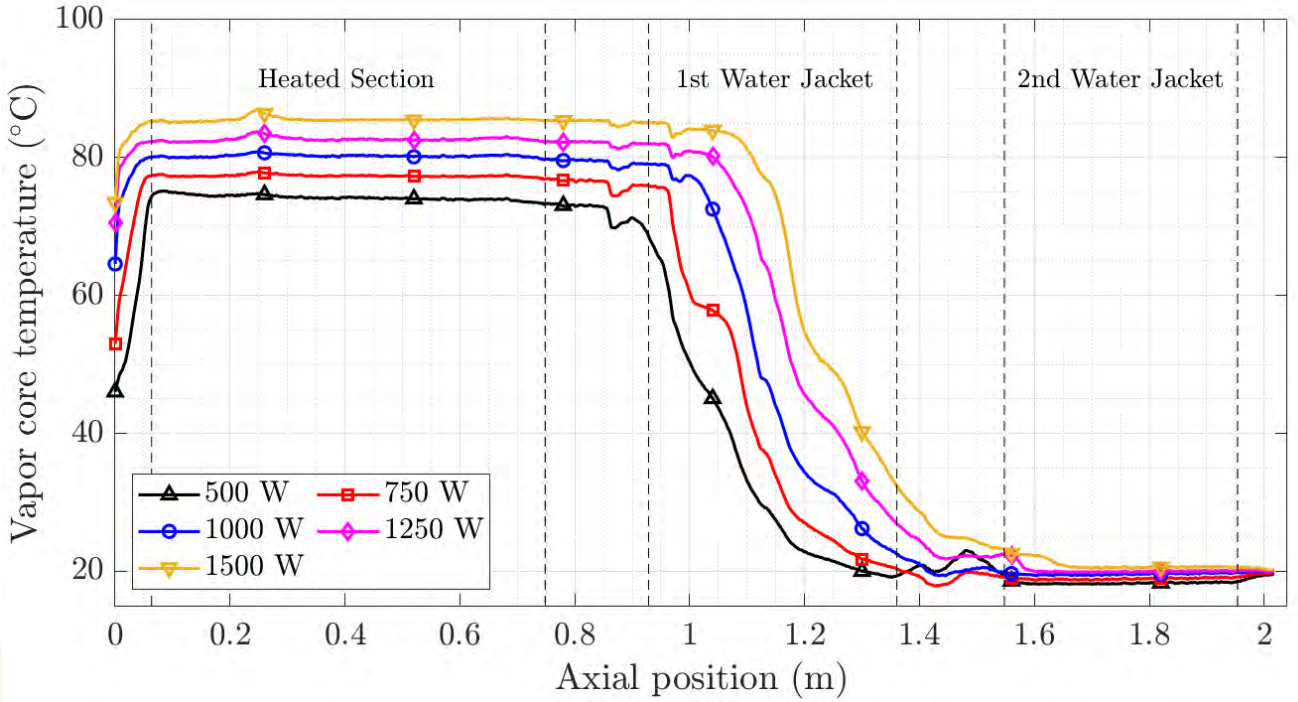


I. Yilgor, *and S. Shi, "Experimental Investigation of Heat Pipe Flow Dynamics and Performance," 20th Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-20), 2023.*

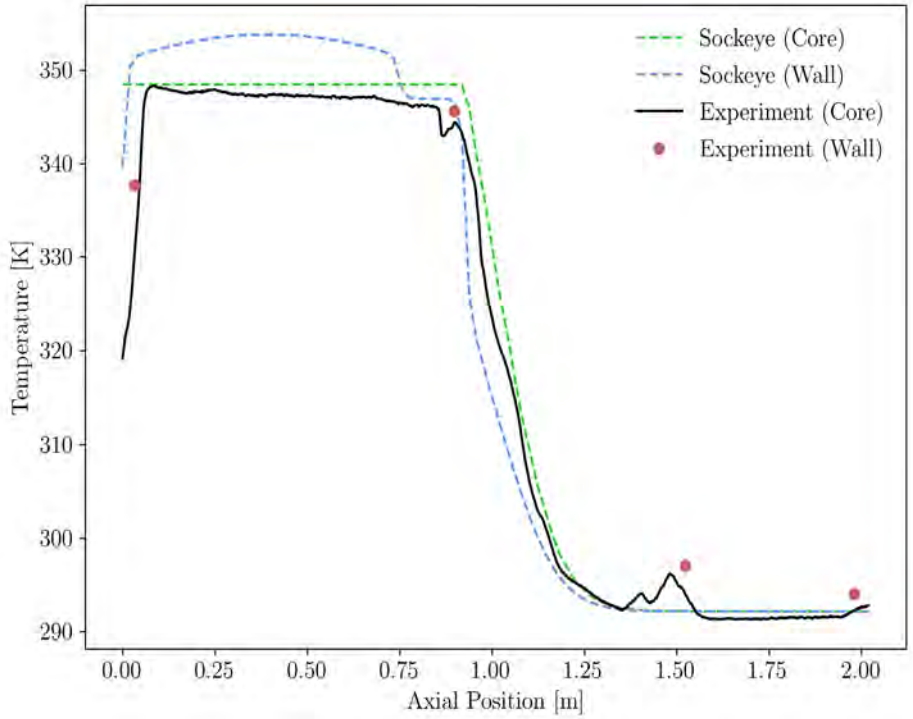
MRP Microreactor Program

Sockeye Verification & Validation (Ongoing)

- Axial temperature profile validation via fiber optic distributed temperature sensor measurements
  - **Dataset from RPI** including cases with different evaporator power inputs and condenser flow rates
  - Initial investigations show good agreement with experimental data
  - The model considers the presence of non-condensable gases, and convection in the condenser section



Axial vapor core temperature profiles for the 0.10 kg/s condenser flow rate case at steady state

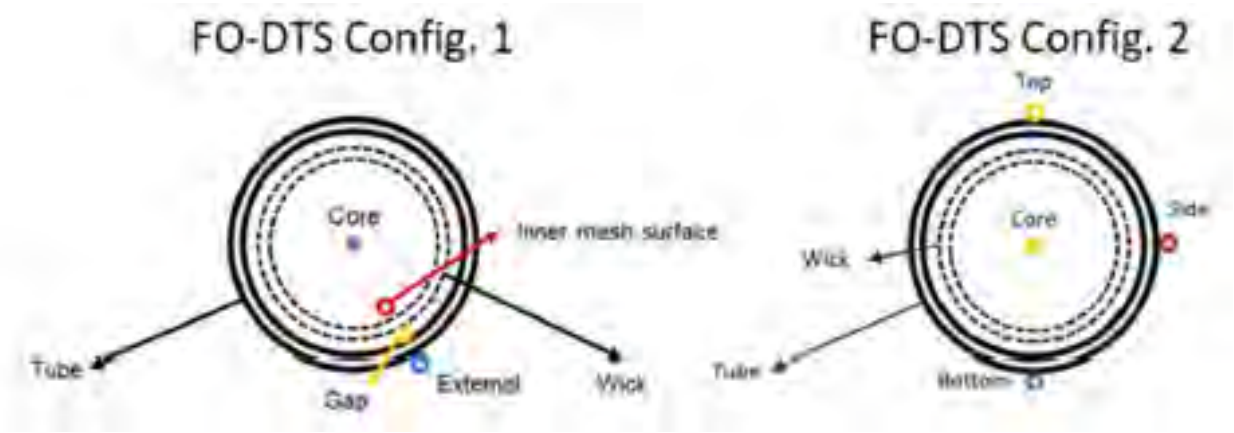


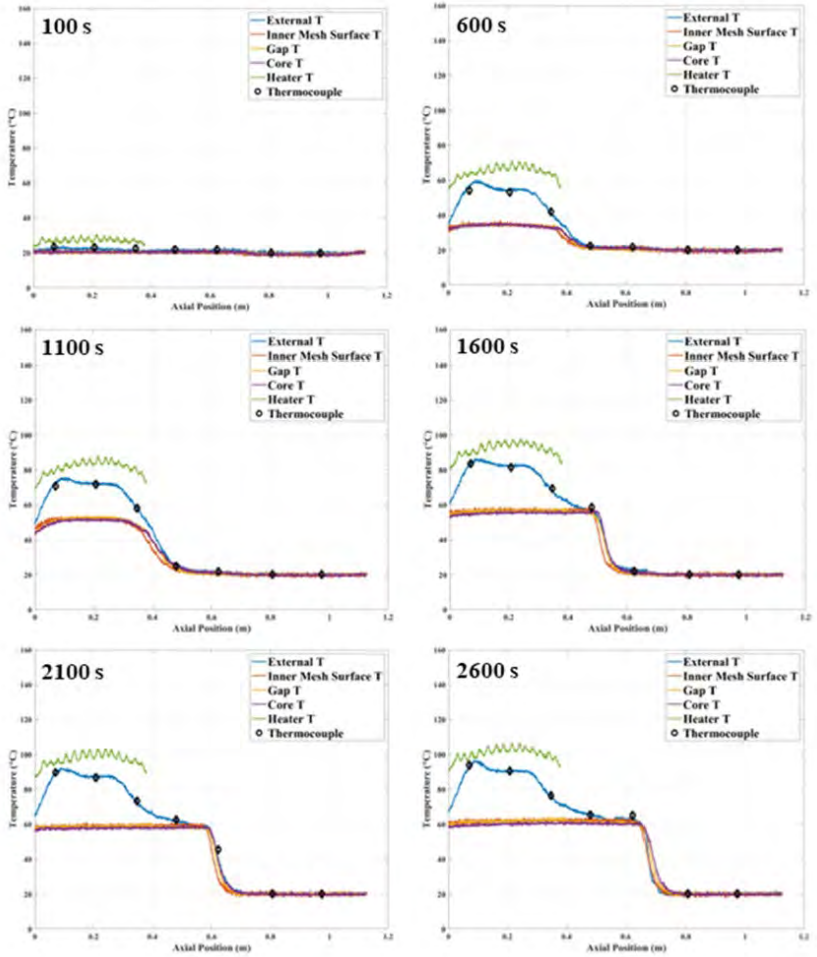
Sockeye simulation of the 500 W case

MRP Microreactor Program

Experimental Work in University Partners - TAMU

- 4 fiber optic temperature sensors
  - At different locations within the HP or the outside wall
- Wick characterization capabilities
- Horizontal test stand
- Future liquid metal heat pipe testing



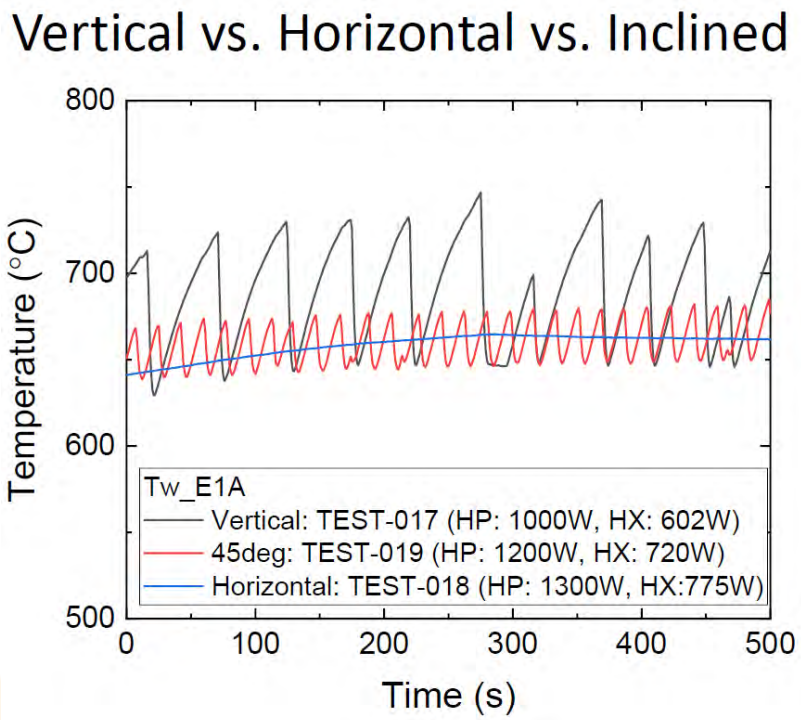


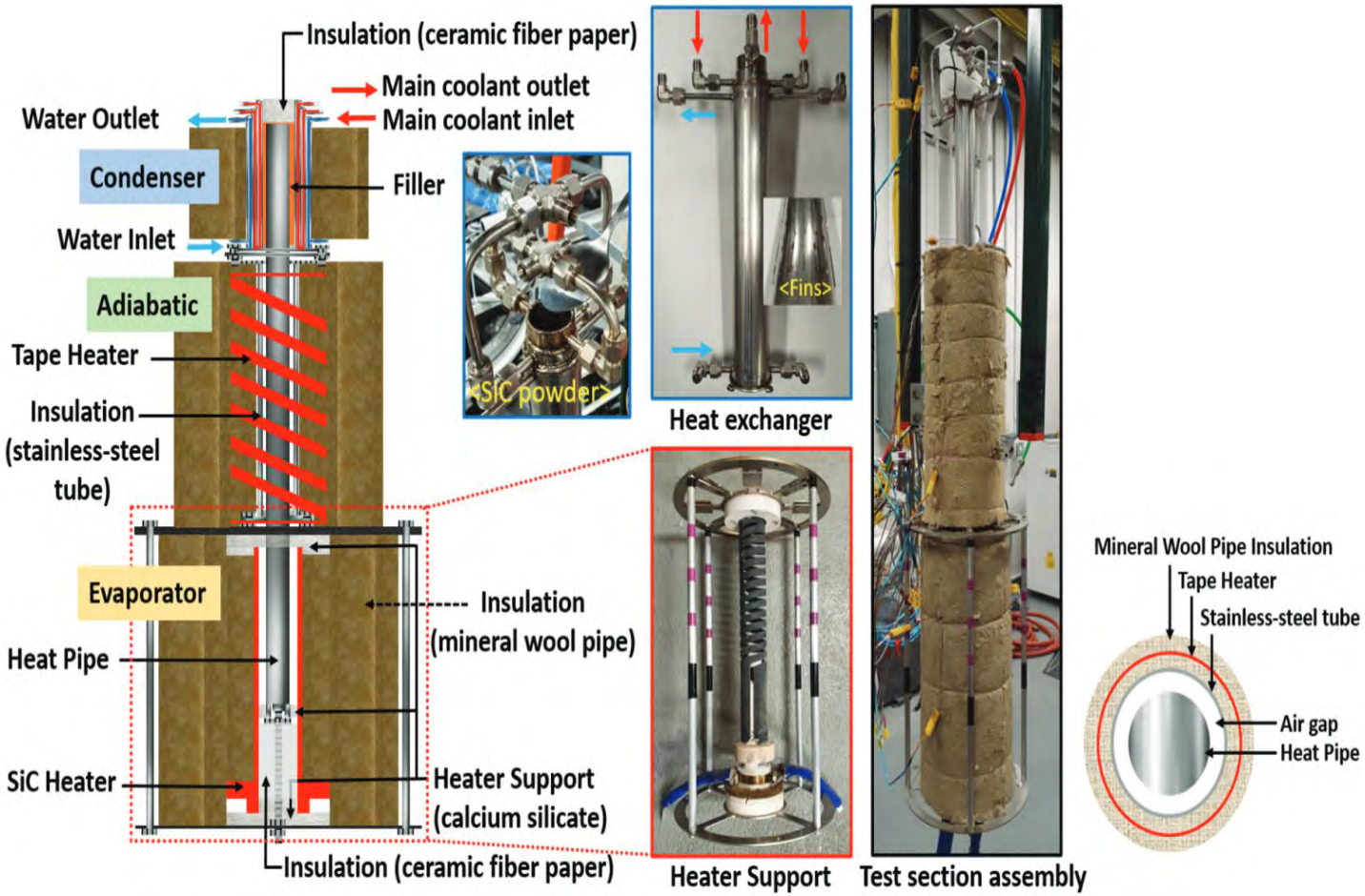
Joseph Seo, Hansol Kim, Yassin A. Hassan, "Experimental study on the startup of the annular wick type heat pipe using fiber optical temperature measurement technique," Physics of Fluids, 2023

MRP Microreactor Program

Experimental Work in University Partners - UMich

- High-temperature facility
- X-ray imaging
- Variable heat pipe orientation



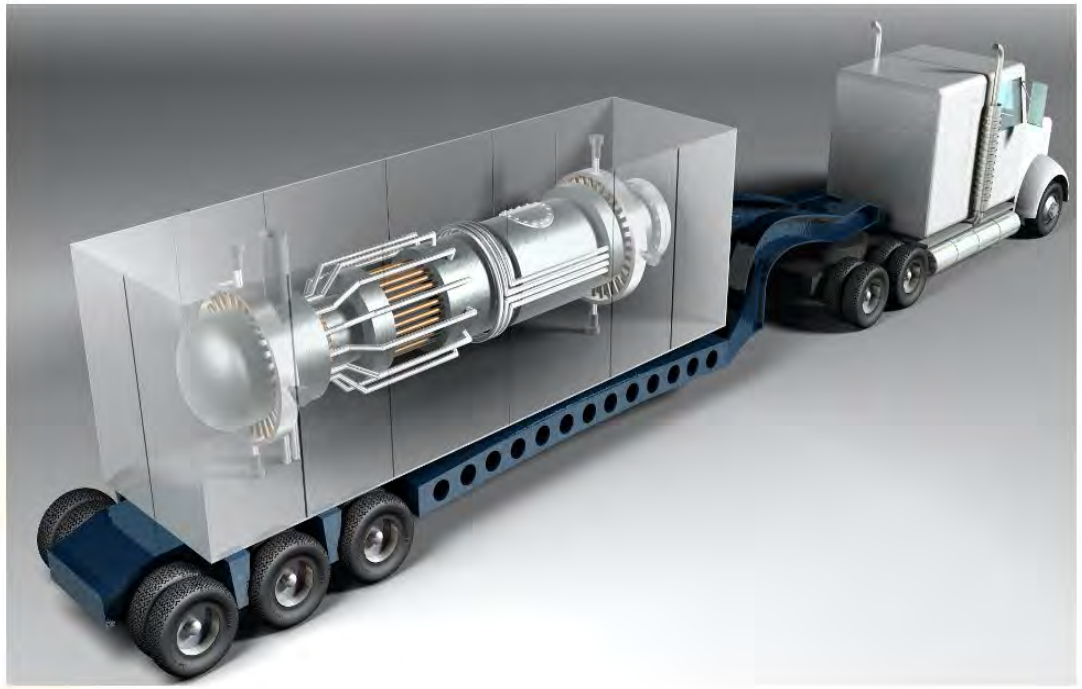


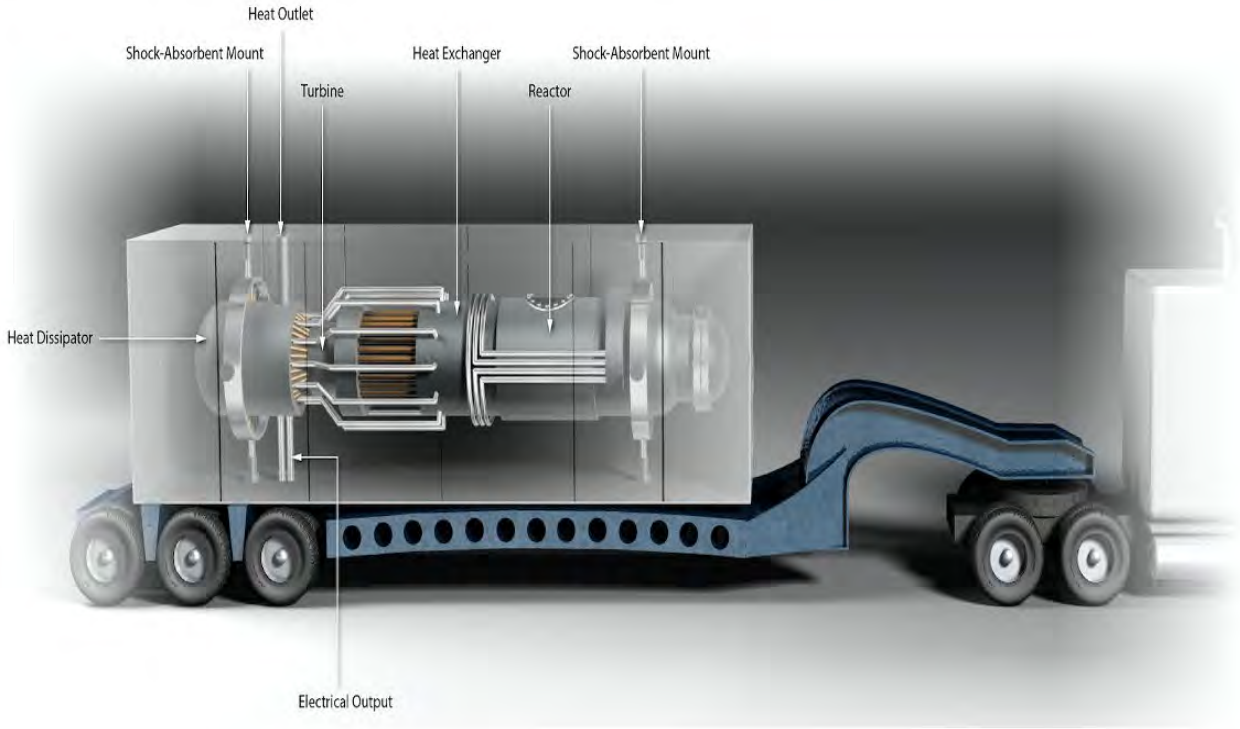
Carolina da Silva Bourdot Dutra et al., "High-Fidelity Modeling and Experiments to Inform Safety Analysis Codes for Heat Pipe Microreactors", Nuclear Technology, 2023

MRP Microreactor Program

Thank You..!

MRP Microreactor Program





Piyush.Sabharwall@inl.gov

Credit & Acknowledgement

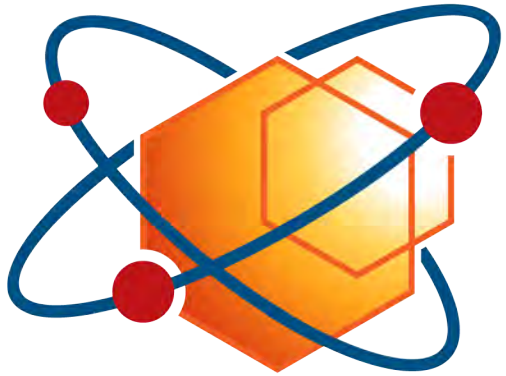
U.S. DEPARTMENT OF ENERGY Nuclear Energy

INL Idaho National Laboratory

Los Alamos NATIONAL LABORATORY

OAK RIDGE National Laboratory

Argonne NATIONAL LABORATORY



MRP Microreactor Program