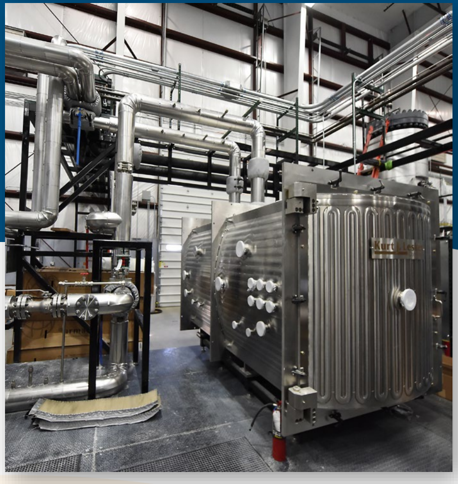
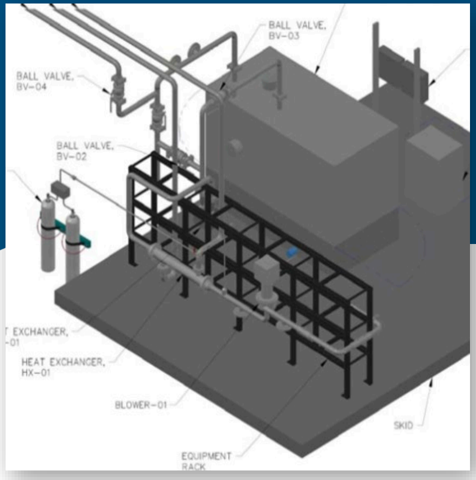
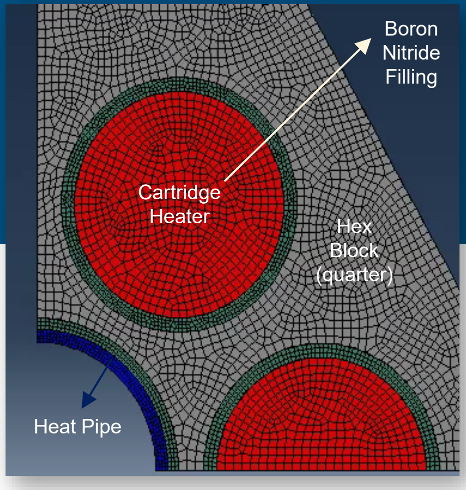
Microreactor Program

DOE-NE Microreactor Program Winter Review Meeting

Demonstration & Support Capabilities







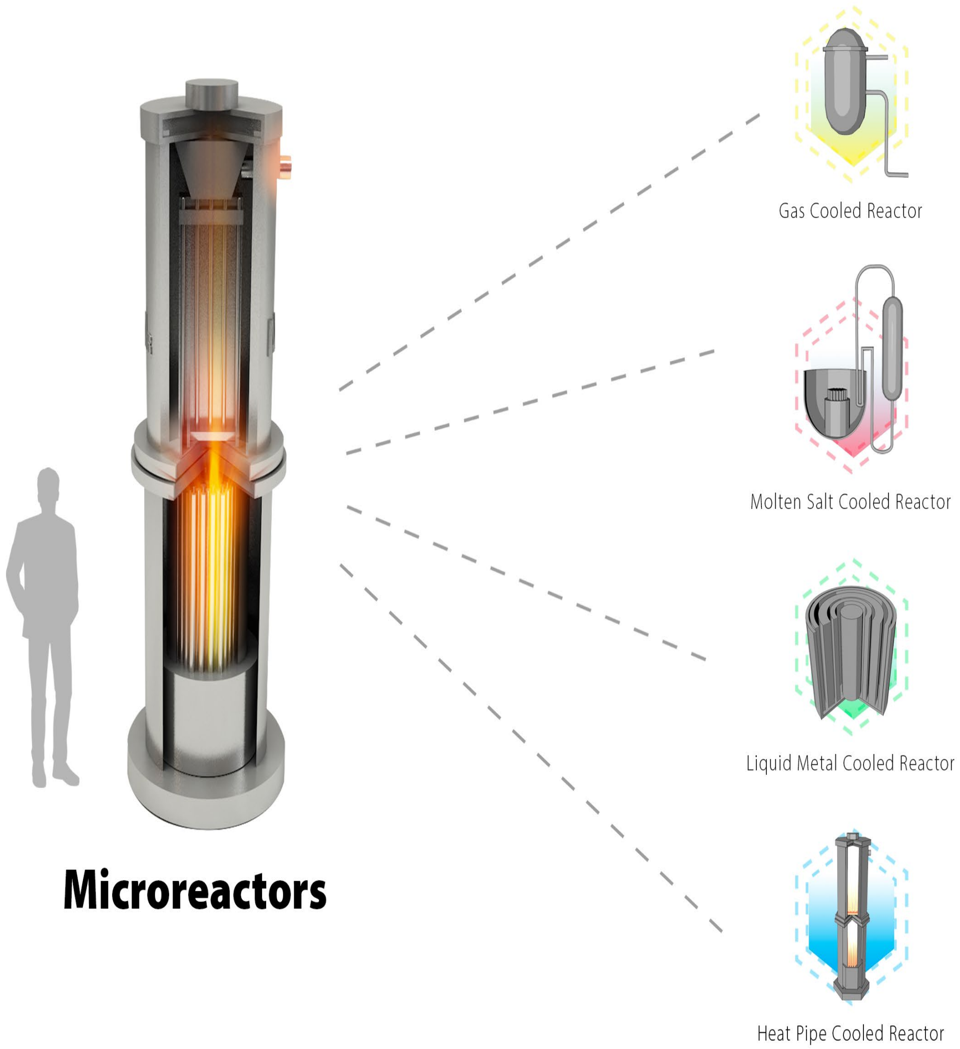
Piyush Sabharwall, Ph.D. | Technical Area Lead, DOE NE-MRP

March 3rd , 2026

INL/MIS-26-90609

Idaho National Laboratory | Los Alamos National Laboratory | Oak Ridge National Laboratory | MRP Microreactor Program

Focus Areas – *Enabling non-nuclear demonstration to support microreactor development and deployment.*



Idaho National Laboratory

Piyush Sabharwall, TJ Morton, Jeremy Hartvigsen, Katrina Sweetland , Mauricio Tano, Ilyas Yilgor, Brad Couch, Stacie Strain and Edward Beverly

Los Alamos National Laboratory

Holly Trellue

Oak Ridge National Laboratory

Christian Petrie and Holden Hyer

MRP Microreactor Program

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.

MRP Microreactor Program

Demonstration Support Capabilities – *Subdivided into four main areas to support testing needs to deploy microreactors*

- **SINGLE PRIMARY HEAT EXTRACTION AND REMOVAL EMULATOR (SPHERE) –** Development of a platform to support non-nuclear thermal and integrated systems testing capabilities. This capability shall provide a better understanding of **thermal performance of the heat pipe under a wide range of heating values and operating temperatures**, enhancing the understanding of heat pipe during startup, shutdown and transient operation.

- **MICROREACTOR AGILE NON-NUCLEAR EXPERIMENTAL TESTBED (MAGNET) –** Development of a thermal-hydraulic and integrated systems testing capability, called MAGNET, to simulate core thermal behavior, heat pipe and primary heat exchanger performance, and passive decay heat removal **will support verification and validation of detailed microreactor thermal hydraulic models**. **This is applicable under startup, shutdown, steady-state, and off-normal transient behavior in steady-state operation, transient operation, and load-following conditions**. This testing will be done before nuclear system demonstration. The test bed will ultimately be integrated into the INL Systems Integration Laboratory, which includes thermal and electrical energy users such as steam electrolysis, real-time digital simulators for power systems emulation, a microgrid test bed, and renewable energy generation.

- **EVOLVING DEMONSTRATION SUPPORT –** Demonstration and testing infrastructure needs are expected to evolve as technology readiness of microreactors advance. **Development of capability necessary to support this evolution is covered under this subarea**. MAGNET was modified to support component testing for gas cooled systems.

- **VERIFICATION AND VALIDATION SUPPORT –** This subarea focuses on targeted testing supporting verification and validation to meet industrial and licensing organization (such as NRC) needs to **enhance understanding of a phenomenon of interest and reduce uncertainty**.

MRP Microreactor Program

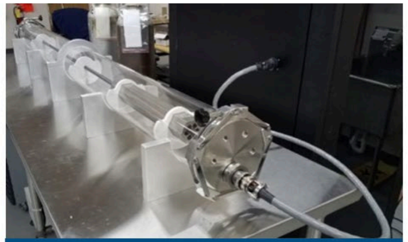
Single Primary Heat Extraction and Removal Emulator

Provide capabilities to perform steady-state and transient testing of heat pipes :

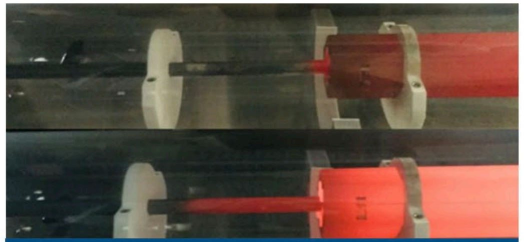
- Wide range of heating values and operating temperatures
- Observe **heat pipe startup and transient operation**

Develop effective thermal coupling methods between the heat pipe outer surface and core structures

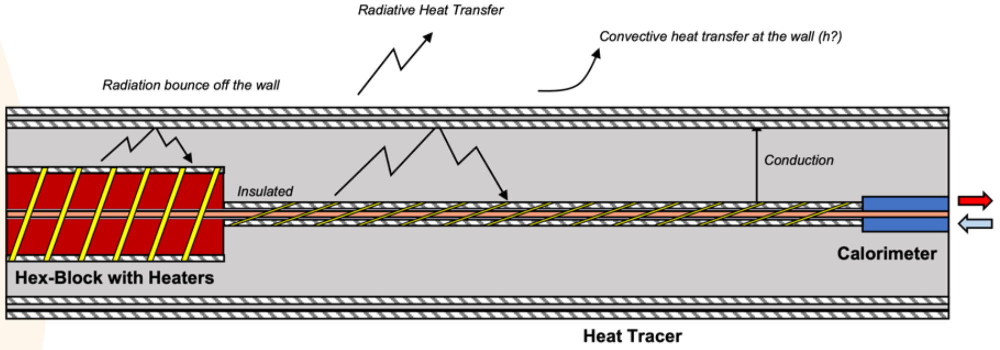
Measure heat pipe axial temperature profiles during **startup, steady-state, and transient operation** using thermal imaging and surface measurements



SPHERE Test BED



Optical image of the block and heat pipe operations

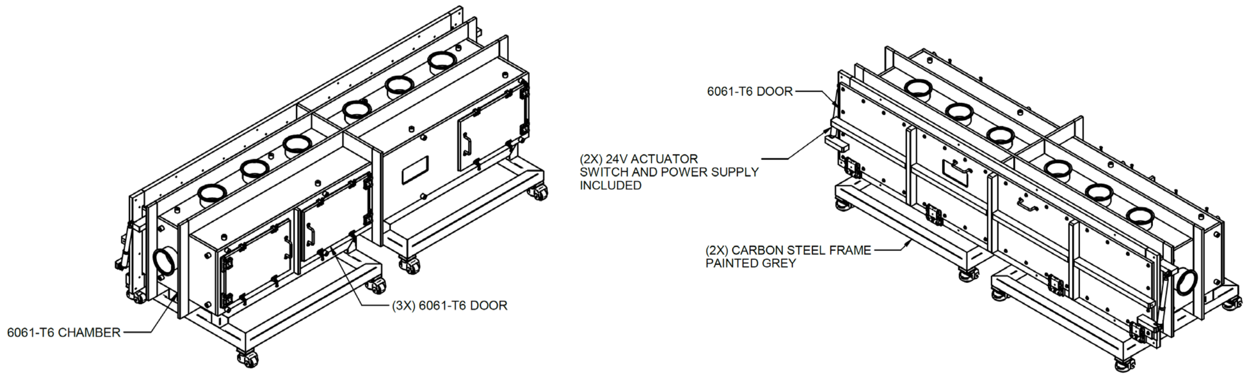


Parameter	Value
Length	10 ft
Diameter	12 in
Tube material	Stainless steel
Connections	Flanged for gas flow and instrumentation feedthrough
Maximum power	20 kW
Max temperature	900 C
Heat removal	Passive radiation or water-cooled gas gap calorimeter

MRP Microreactor Program

Impact of Expanded Capabilities

- Greater accuracy and repeatability of experiments via improved design which minimizes losses
  - Repeatability of experiments is crucial especially for V&V, the evaluation of manufacturing methods, and the investigation long-term performance degradation
- Extremely high-resolution measurements
  - Provides a more comprehensive dataset for V&V efforts
- Flow visuals provide imperative data on heat pipe operation
- Expanded testing capabilities allows for high resolution in measurement for heat pipe testing



MRP Microreactor Program

SPHERE – PROGRESS *(from initial startup)*

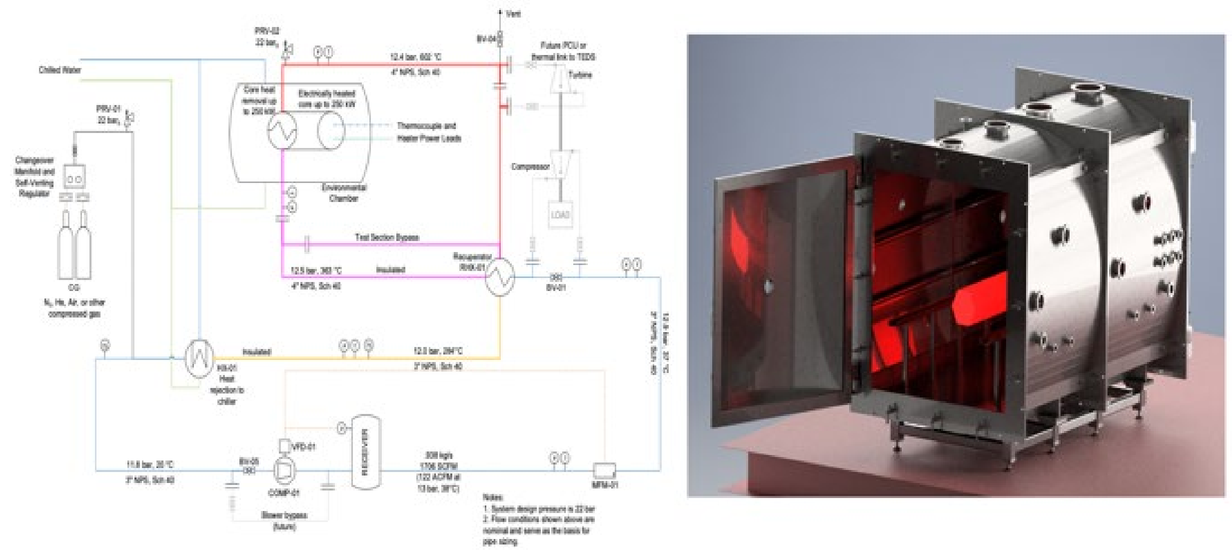
- Demonstrate initial startup (shake-down testing) and operation of a single heat pipe experiment in the SPHERE test bed
- Develop coupled thermal and structural analysis for high temperature heat pipe experiments
- Complete engineering design of test article, develop test plan and instrumentation needs for gap conductance testing
- Complete fabrication and procurement of test article, perform test for gap conductance testing and report on findings (worked closely with NRC)
- Create, maintain and add experimental data to shareable database on transient heat pipe performance in coordination with NEUP heat-pipe projects
- Work with industry under WFO Program – Heat Pipe Performance
- Advanced internal characterization of in operando heat pipes
  - In operando heat pipe testing completed
- Procure, operate and test advanced heat pipes for SPHERE test bed
- Power Transient Testing - provided data to Sockeye development team for model V&V for a series of power transients and heating profiles
- Long Duration Testing (up to 1000 hours) – provided data on heat pipe degradation to Sockeye team
- New environmental chamber from Kurt J. Lesker
  - Allows x-ray visualization under vacuum through aluminum 6061 walls
- Development of a targeted **Phenomena Ranking and Identification Framework** to Pinpoint Critical Modeling, Simulation, and Engineering Needs for Heat Pipe Operation and Transient Studies

MRP Microreactor Program

Microreactor AGile Non-nuclear Experimental Testbed *(MAGNET)*

- General purpose test bed for performance evaluation of microreactor design concepts (heat pipe, gas-cooled, other)
- Provide detailed reactor core and heat removal section thermal hydraulic performance data for prototypical geometries and operating conditions
- Demonstrate interface of heat removal section to power conversion system for power generation
- Provides for integrated materials, instrumentation testing
- Co-located with integrated energy systems R&D capabilities

Parameter	Value
Chamber size	5 ft x 5 ft x 10 ft
Heat removal	Liquid-cooled chamber walls, gas flow
Connections	Flanged for gas flow and instrumentation feedthrough and viewing windows
Coolants	Air, inert gas (He, N2)
Gas flow rates	Up to 43.7 ACFM at 290 psig
Design pressure	22 barg
Maximum power	250 kW
Max temperature	750°C
Heat removal	Passive radiation or water-cooled gas gap calorimeter



a) MAGNET Process Flow Diagram

b) MAGNET Environmental Enclosure

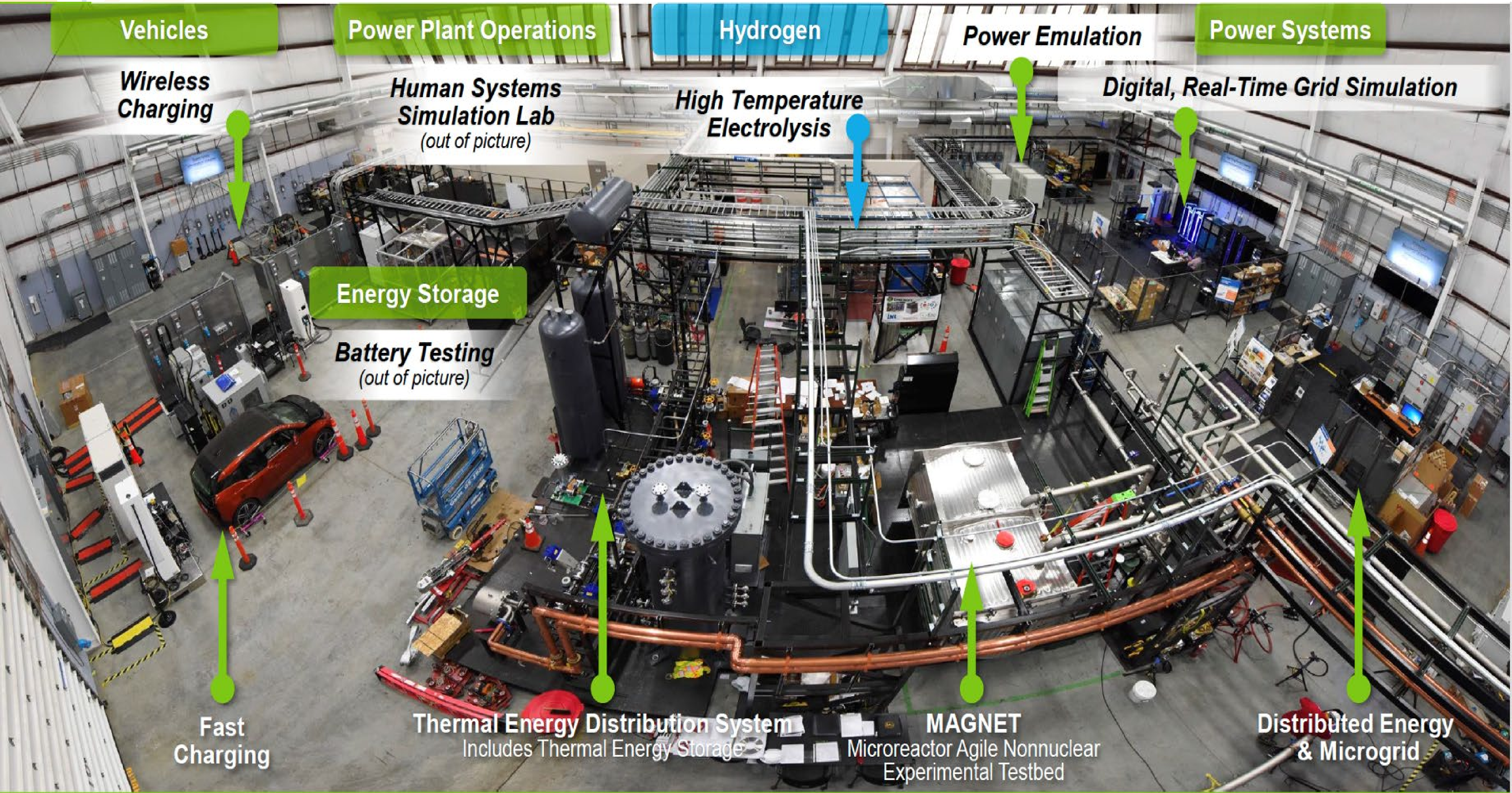
MRP Microreactor Program

MAGNET Facility

- MAGNET deployment in the INL Energy Systems Laboratory (ESL) building, Systems Integration Laboratory
- Co-located with the Thermal Energy Distribution System (TEDS) and the High-Temperature Steam Electrolysis (HTSE) System

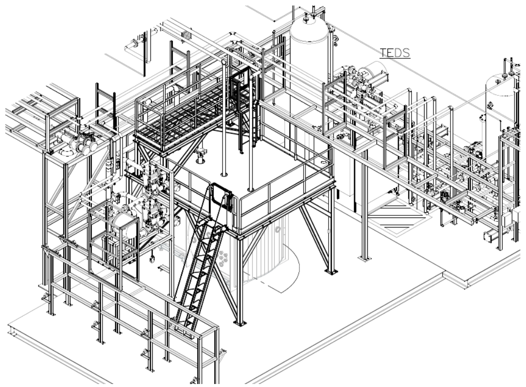
MRP Microreactor Program

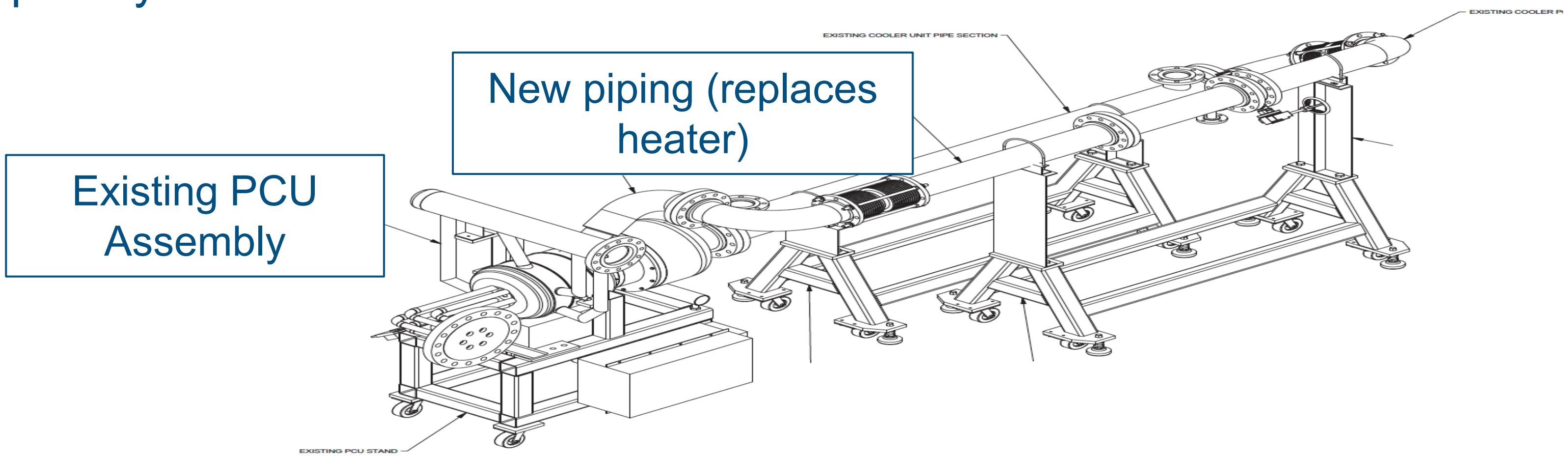
Integrating Systems For Nation's Energy Future



MAGNET – PROGRESS *(from initial startup)*

- Complete shakedown and preliminary testing of MAGNET facility with test article bypass
- Complete test matrix for seven-hole test article
- Complete engineering design for PCU integration
- MAGNET modification to support proprietary HX testing (from a commercial developer)
- Demonstrated digital twin of a single-heat-pipe test article in MAGNET with autonomous, self-adjusting capability
- Mezzanine construction completed (replaced temporary scaffolding)
- Advanced Heat pipe Interface Heat Exchanger Testing (NEUP with University of Wisconsin)
- Completed construction to integrate PCU (completion planned for end of March 2025)
- LANL graphite core assembly (March 2026)
- PCU Integration Testing (March 2026)





Demonstration Support Capabilities – Activities and Milestones for FY 26

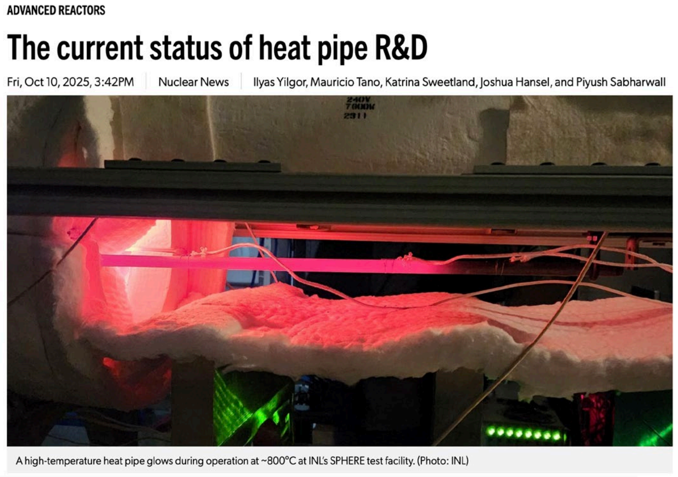
- **SINGLE PRIMARY HEAT EXTRACTION AND REMOVAL EMULATOR (SPHERE)**
  - Complete testing on Los Alamos National Lab high-capacity heat pipes for steady state thermal heat transfer characterization (03/31/2026) – M3
  - Assess mid-year progress toward development of Best Estimate Plus Uncertainty methodology (04/22/2026) – M4
  - Develop methodology for interior measurements of vapor and liquid flows in heat pipes (09/16/2026) – M3
  - Develop Best Estimate Plus Uncertainty methodology for heat pipe characterization (09/16/2026) –M3

- **MICROREACTOR AGILE NON-NUCLEAR EXPERIMENTAL TESTBED (MAGNET)**
  - Complete Performance Testing of Electrically Heated, Graphite Core Assembly (03/01/2026) – M3
  - Complete PCU Shakedown Testing (03/31/2026) – **M2**
  - Perform TPMS HX Testing (03/26/2026) – M3
  - Validate Communications and Power Connections Between MACS, MAGNET, and MIB (06/04/2026) – M4
  - Demonstrate Power Production With Integrated MAGNET PCU, Microgrid, and Mobile Data Center (08/27/2026) – **M2**

MRP Microreactor Program

MACS -Microreactor Automated Control System; MIB - Microgrid in a Box

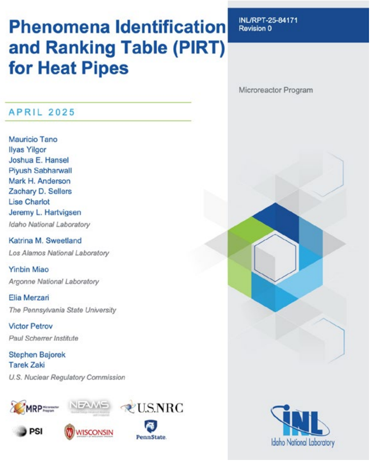
Key Accomplishment - PIRT for Heat Pipes


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

A high-temperature heat pipe glows during operation at ~800°C at INL's SPHERE test facility. (Photo: INL)


Phenomena Identification and Ranking Table (PIRT) for Heat Pipes

INL/RPT-25-84171
Revision 0

Microreactor Program

APRIL 2025

Mauricio Tano
Ilyas Yilgor
Joshua E. Hansel
Piyush Sabharwall
Mark H. Anderson
Zachary D. Sellers
Lise Charlot
Jeremy L. Hartvigsen
Idaho National Laboratory

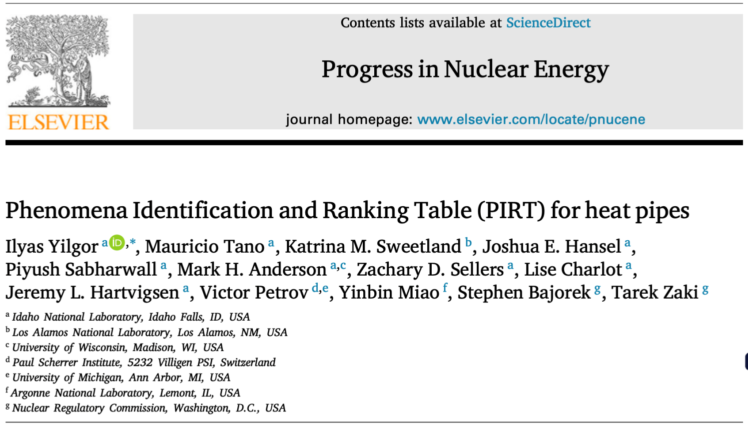
Katrina M. Sweetland
Los Alamos National Laboratory

Yinbin Miao
Argonne National Laboratory

Elia Merzari
The Pennsylvania State University

Victor Petrov
Paul Scherrer Institute

Stephen Bajorek
Tarek Zaki
U.S. Nuclear Regulatory Commission


Contents lists available at ScienceDirect

Progress in Nuclear Energy

journal homepage: www.elsevier.com/locate/pnucene

ELSEVIER

Phenomena Identification and Ranking Table (PIRT) for heat pipes

Ilyas Yilgor [a,*], Mauricio Tano [a], Katrina M. Sweetland [b], Joshua E. Hansel [a], Piyush Sabharwall [a], Mark H. Anderson [a,c], Zachary D. Sellers [a], Lise Charlot [a], Jeremy L. Hartvigsen [a], Victor Petrov [d,e], Yinbin Miao [f], Stephen Bajorek [g], Tarek Zaki [g]

[a] Idaho National Laboratory, Idaho Falls, ID, USA
[b] Los Alamos National Laboratory, Los Alamos, NM, USA
[c] University of Wisconsin, Madison, WI, USA
[d] Paul Scherrer Institute, 5232 Villigen PSI, Switzerland
[e] University of Michigan, Ann Arbor, MI, USA
[f] Argonne National Laboratory, Lemont, IL, USA
[g] Nuclear Regulatory Commission, Washington, D.C., USA

or

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 Qlim and sub-limits.

Graphite Test Article Performance Testing

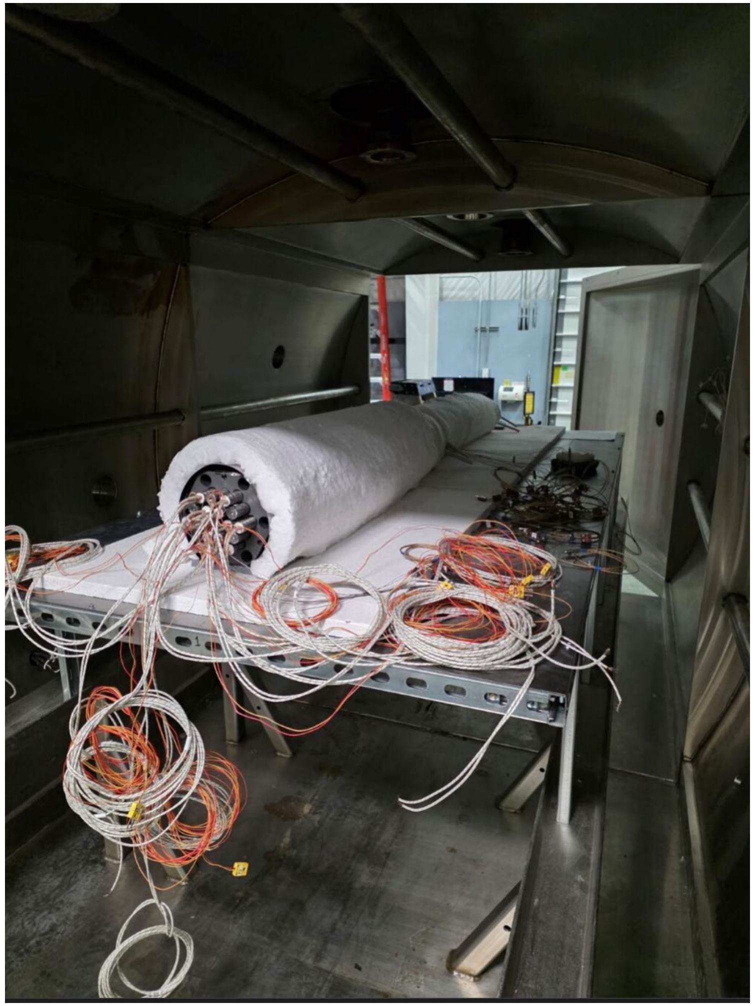
Testing a graphite-core, heat pipe–cooled design as a scalable platform to validate thermal management technologies before full-scale deployment.

Test the **LANL** manufactured Graphite Test Article in MAGNET.

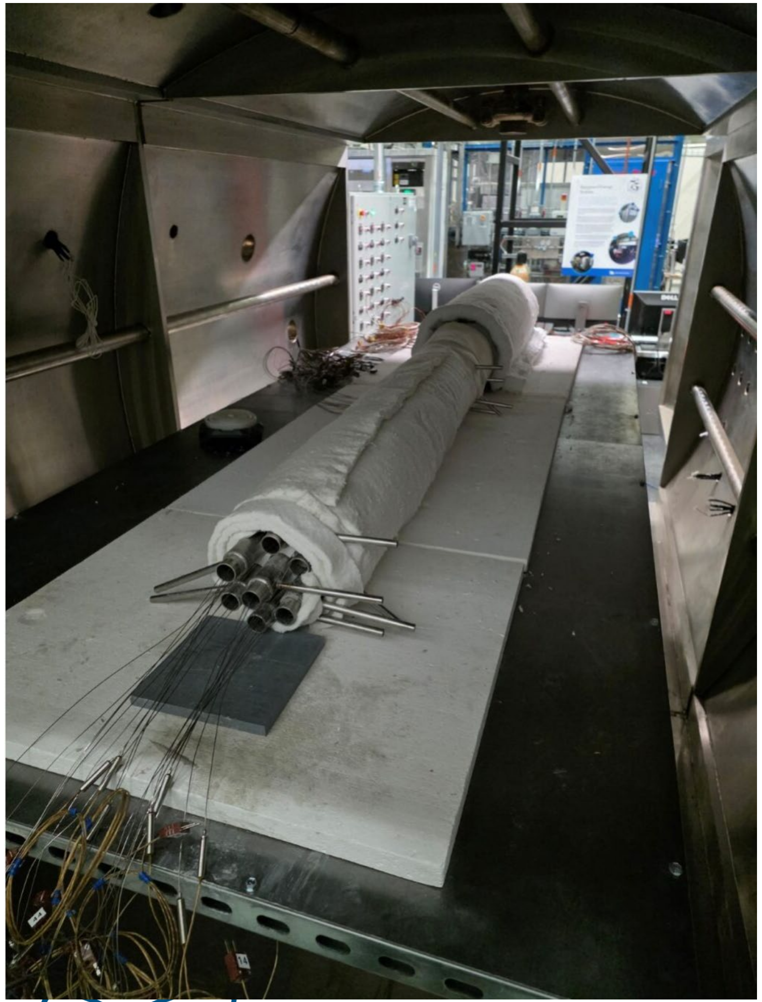
Test Article Description

- Three 10-inch-long graphite blocks
- Twelve 1.8 kWth heaters
- 7 LANL high performance heat pipes
- 7 LANL gas gap heat exchangers using helium as coolant.

Heated Side



Cooled Side

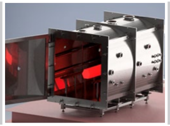


MRP Microreactor Program

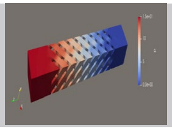
Upcoming Presentations

SPHERE Testing and Validation - Jeremy Hartvigsen and Ilyas Yilgor

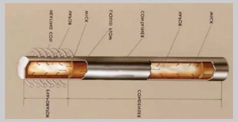
Sockeye Current Status – Joshua Hansel



MAGNET Brayton Cycle PCU Integration – TJ Morton and Katrina Sweetland



Triply Periodic Heat Exchanger– Austen Fradeneck



Na Heat Pipes: Design and Failure Mode Assessment (NEUP 24-31551) – Nikona Rousseau and Mark Anderson

Demonstration Capabilities Summary and Wrap Up

MRP Microreactor Program