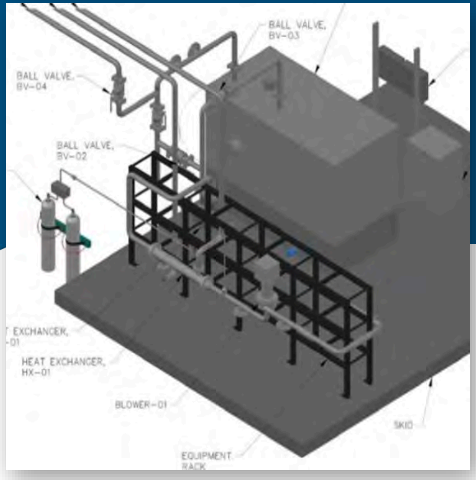
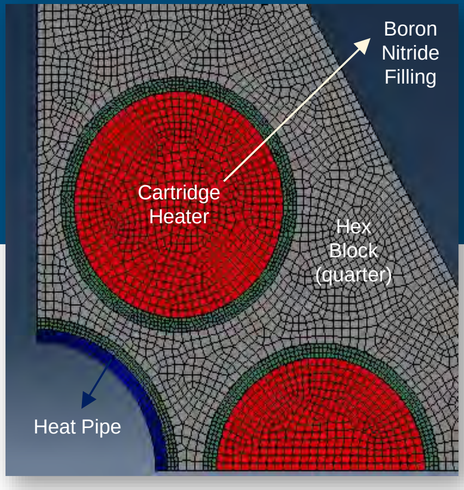
Microreactor Program

DOE-NE Microreactor Program Winter Review Meeting

Demonstration & Support Capabilities





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March 4th, 2025

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.*

Single Primary Heat Extraction and Removal Emulator

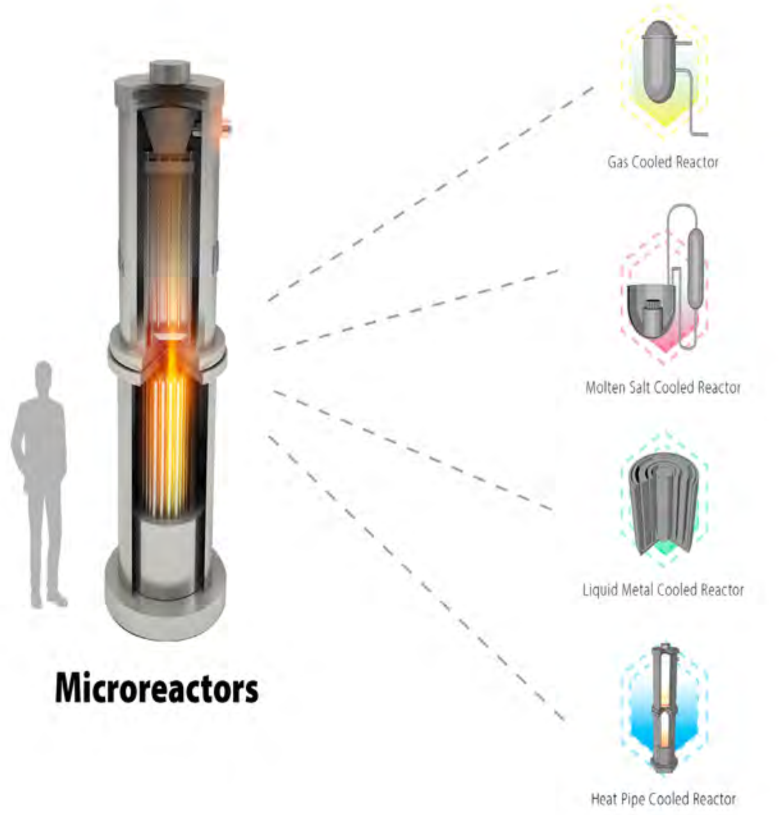
- Update and current status

Microreactor Agile Non-nuclear Experiment Testbed (MAGNET)

- Update and current status

HElium Component Testing Out-of-pile Research (HECTOR) Facility

- Update and current status



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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.
  - High Pressure and High Temperature Helium Facility (HECTOR; 8 MPa and 800°C)
- **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**.

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Single Primary Heat Extraction and Removal Emulator

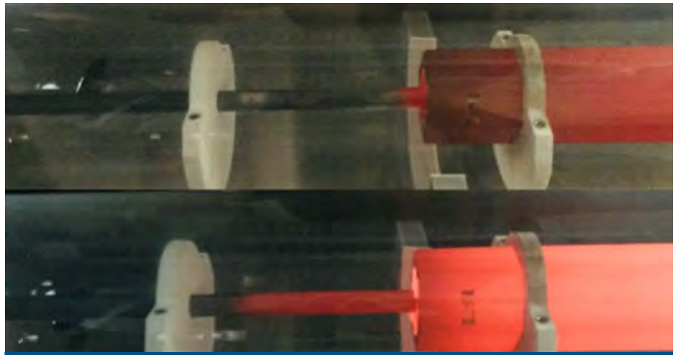
Provide capabilities to perform steady-state and transient testing of heat pipes :

- 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	243 cm
Diameter	15 cm
Tube material	Quartz
Connections	Flanged for gas flow and instrumentation feedthrough
Maximum power	20 kW
Max temperature	750 C
Heat removal	Passive radiation or water-cooled gas gap calorimeter

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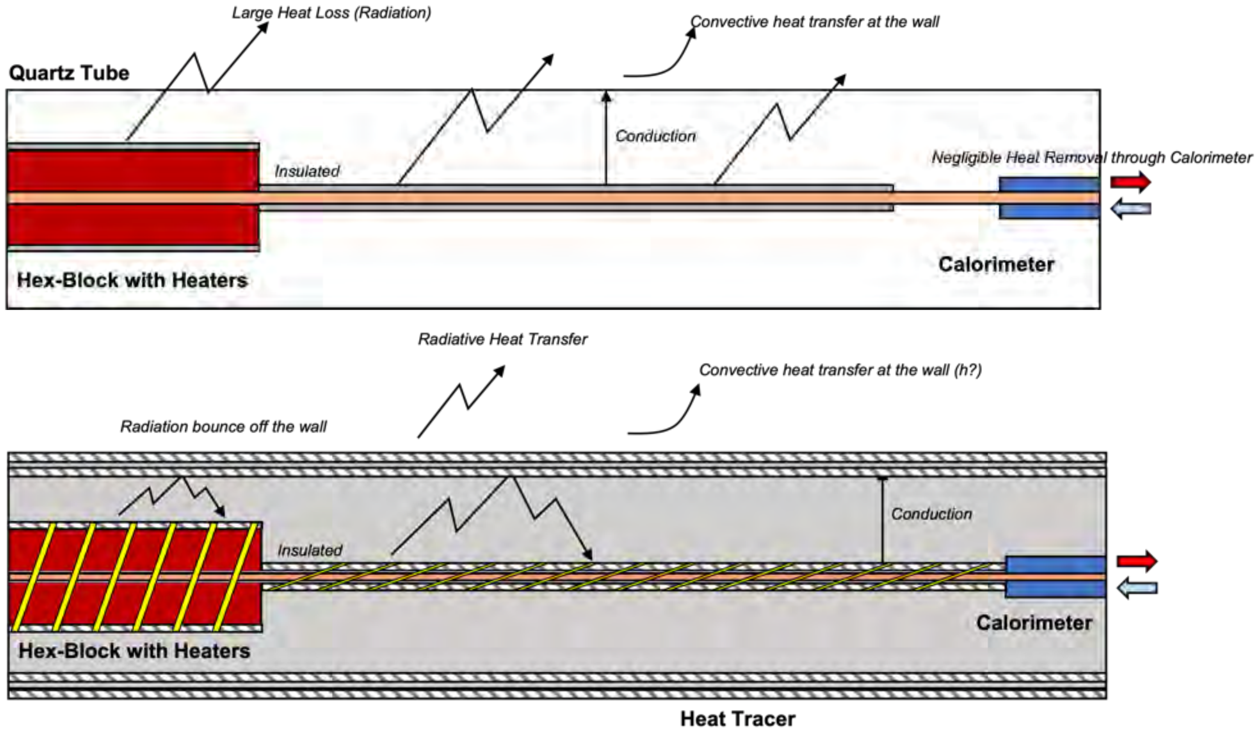
Experimental Setup Changes

- Quartz tube to stainless steel tubing
- Wrapped the hex block and adiabatic section of the heat pipe in heat trace to limit heat loss in those regions
- Wrapped inside of the stainless tubing with a layer of insulation to further reduce heat loss



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

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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

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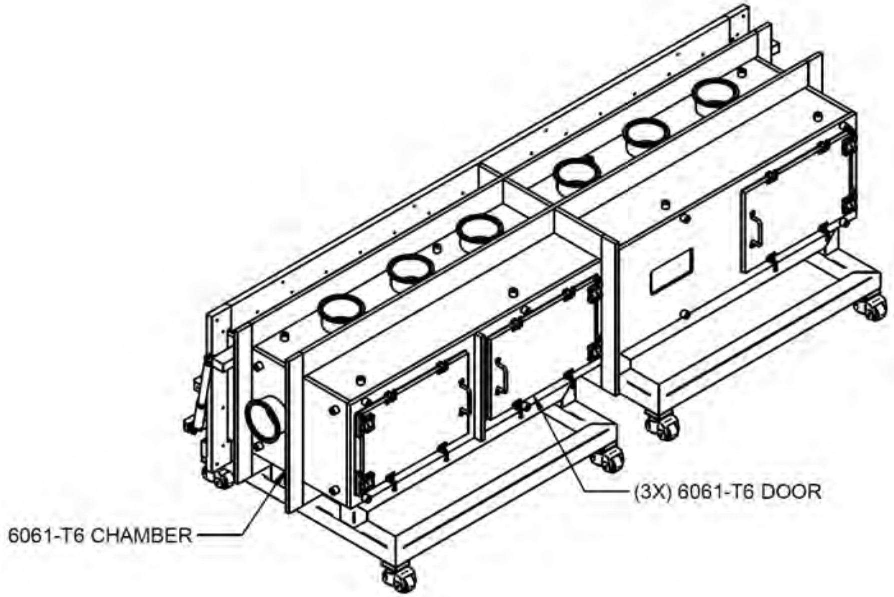
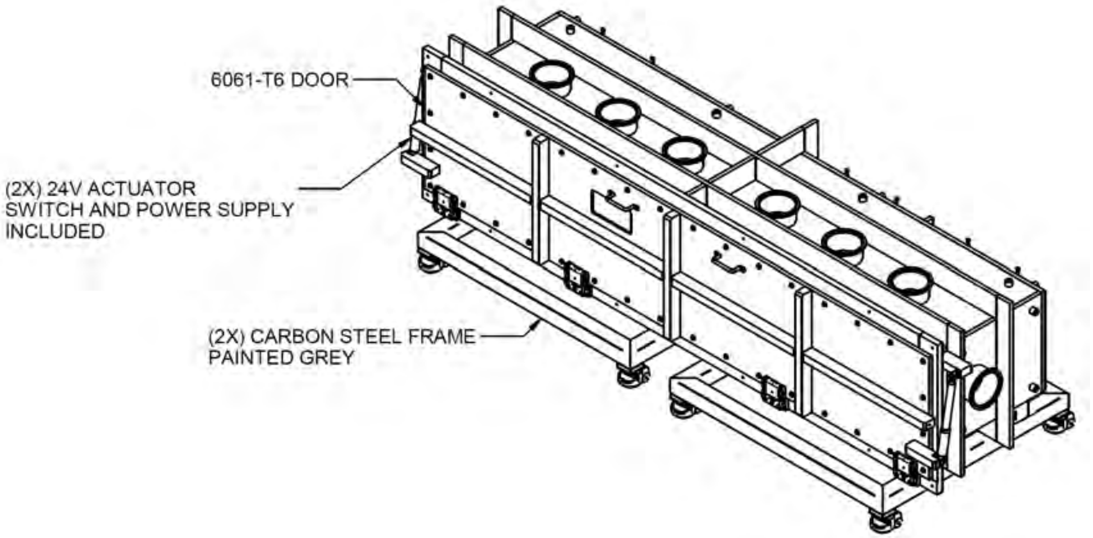
Environmental Chamber

- New environmental chamber from Kurt J. Lesker
  - Allows x-ray visualization under vacuum through aluminum 6061 walls
    - Enhances repeatability
    - Enables more robust calculations of condenser output power
  - Extensive space for fluid, power, and instrumentation lines
  - Can accommodate test articles other than heat pipes





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Summary of Expanded Capabilities

- Testbed Upgrades
  - SS casing with insulation linings significantly reduces radiation heat loss compared to the original design
  - Heat trace wrapped around the insulation in the evaporator and adiabatic section compensates for heat losses
  - The open-air x-ray test stand will be used to demonstrate the x-ray flow visualization technology
  - The new environmental chamber under construction will allow x-ray flow visualization under vacuum and inert gas atmosphere conditions

- Instrumentation Upgrades
  - Fiber optic sensors, ultrasonic sensors, and multi-point thermocouples provide high spatial resolution temperature measurements

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

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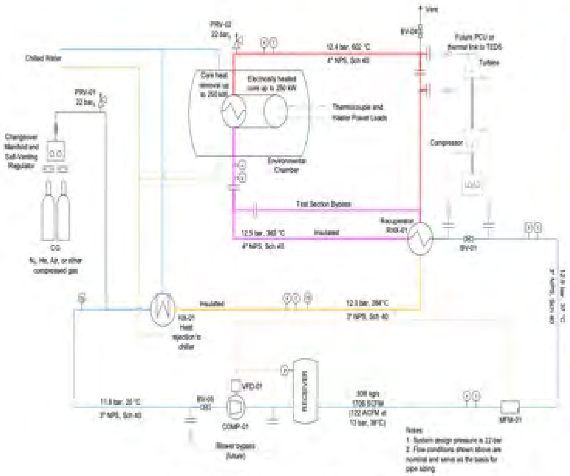
Microreactor AGile Non-nuclear Experimental Testbed *(MAGNET)*

- 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

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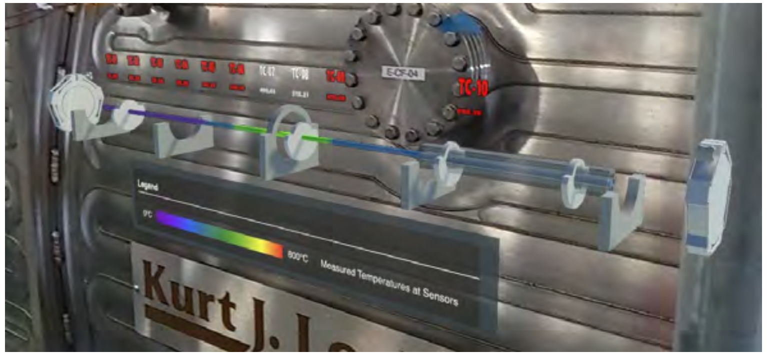
Single Heat Pipe Test Digital Twin Collaboration

MAGNET Control Station



Virtual Image of Test Article via Microsoft HoloLens for Digital Twin Effort

- Single heat pipe testing in MAGNET to demonstrate MAGNET's operation (heater control, instrumentation, and gas cooling flow rate control were all validated)

- Collaborated with researchers from across INL to demonstrate a small-scale digital twin using machine learning to maintain steady state

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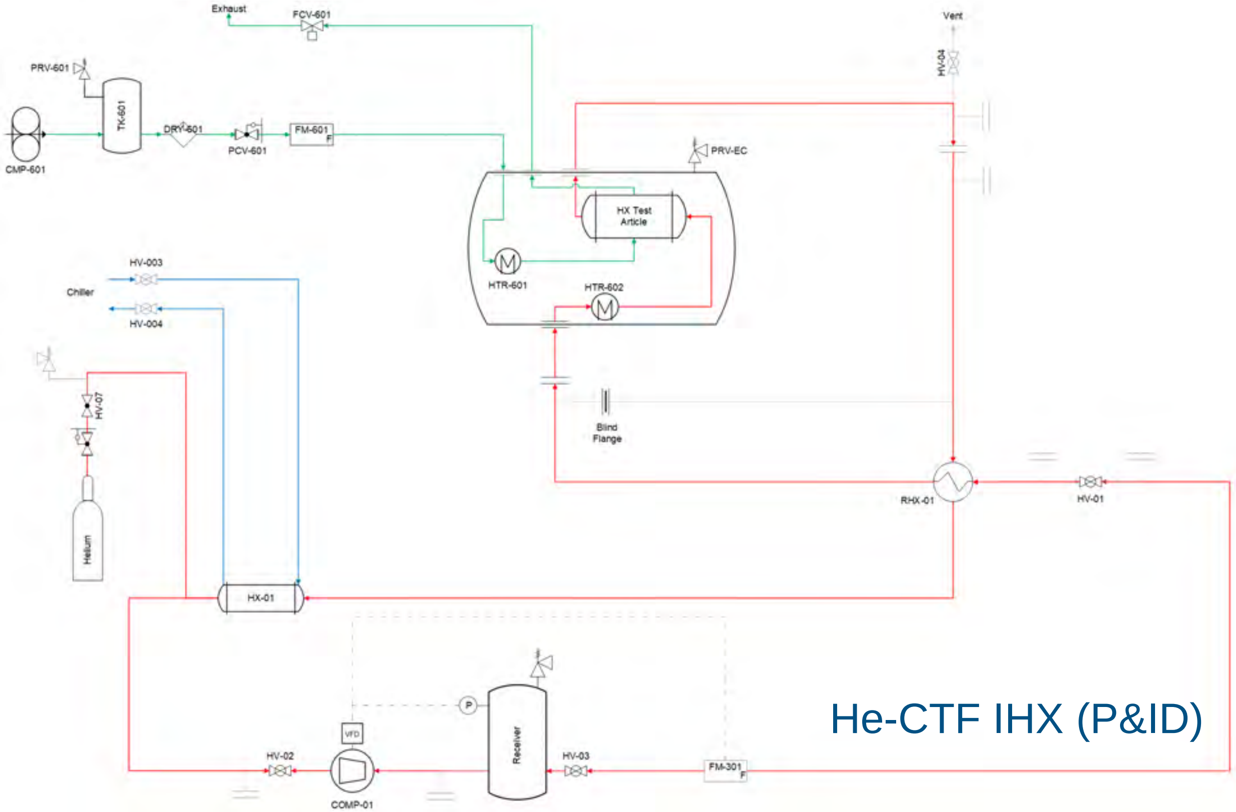
MAGNET / He-CTF
Commercial Developer HX Testing

- Successfully tested proprietary HX design for commercial microreactor developer
- Ran helium at 70 g/s at design temperature and pressure (650°C and 22 bar)



He-CTF IHX (P&ID)

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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

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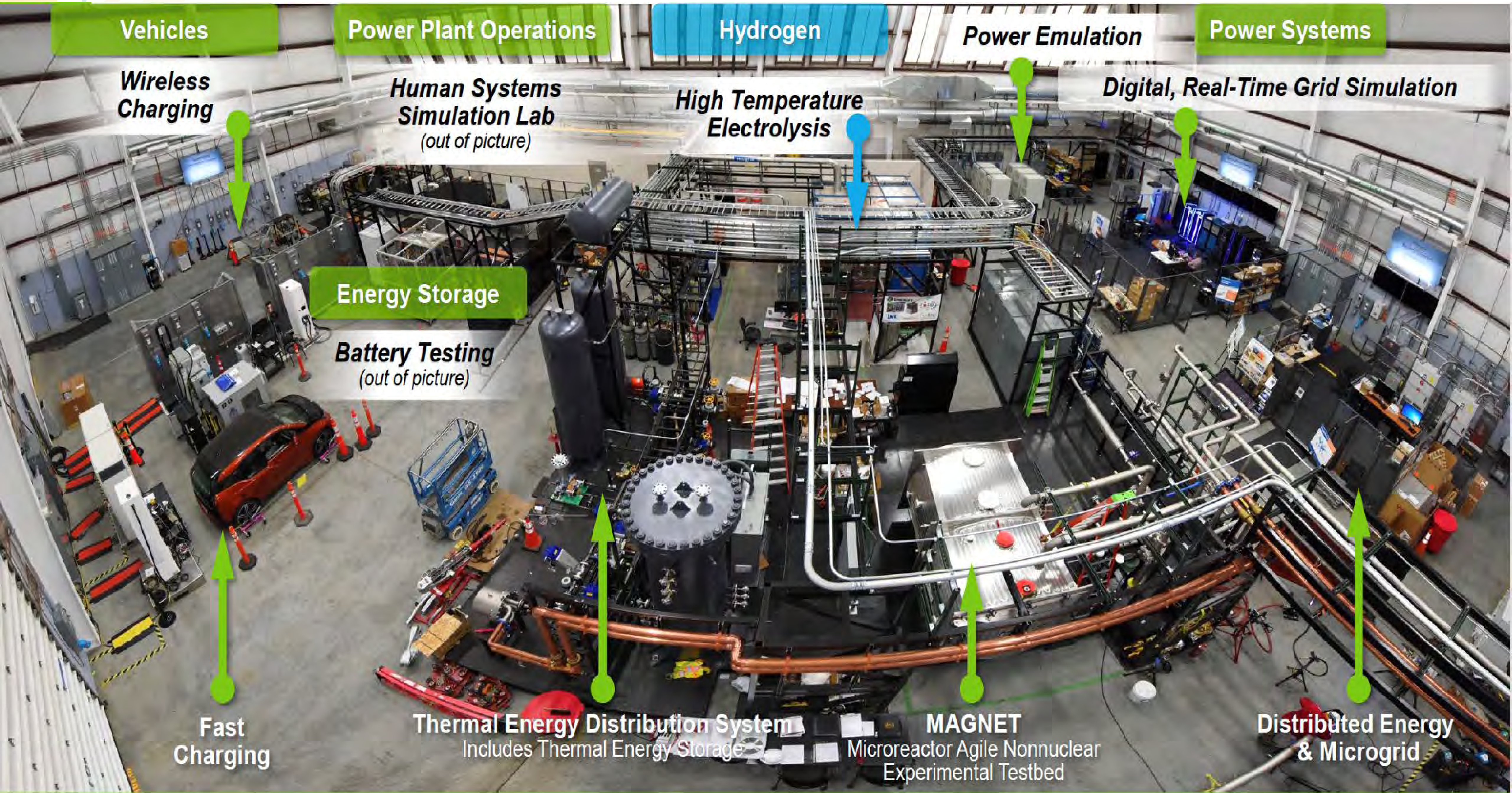
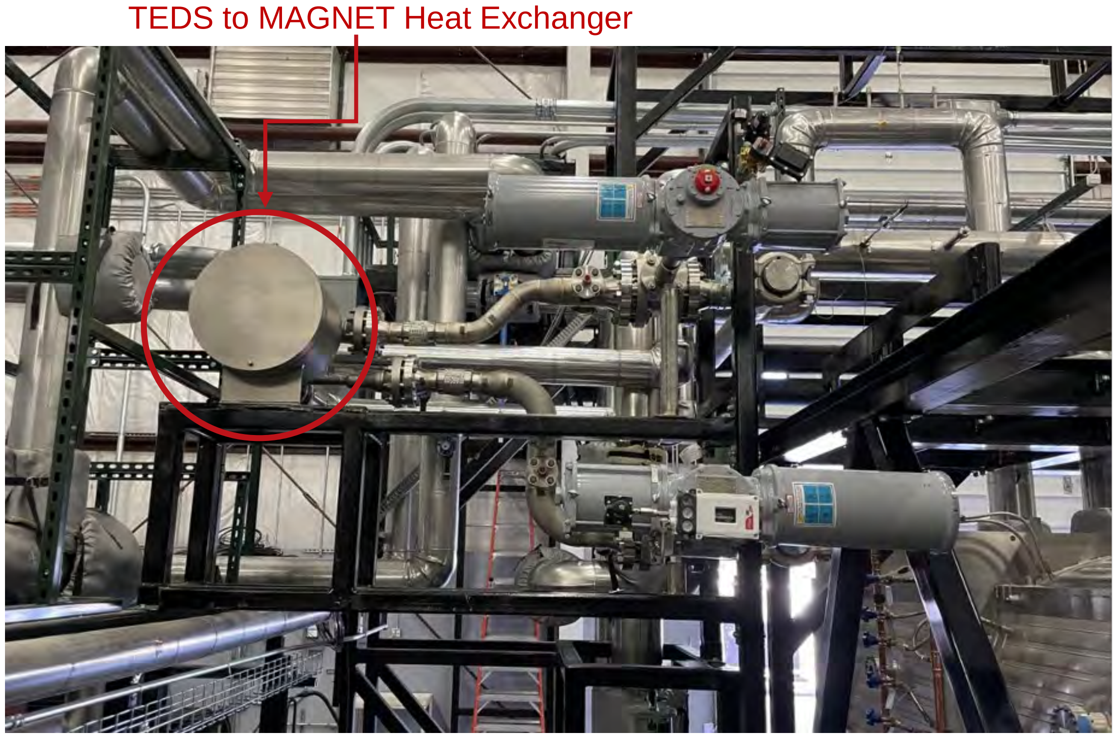
Integrating Systems For Nation's Energy Future



Installed TEDS to MAGNET Heat Exchanger

- Allow for interfacing between the thermal storage unit at INL
- This coupling improves MAGNET's capability to provide data on excess heat offloading
- Allows for integrated energy system testing with IES program
  - Expands cooperatives efforts across INL



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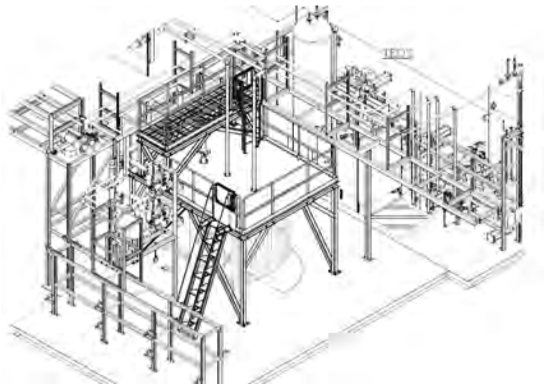
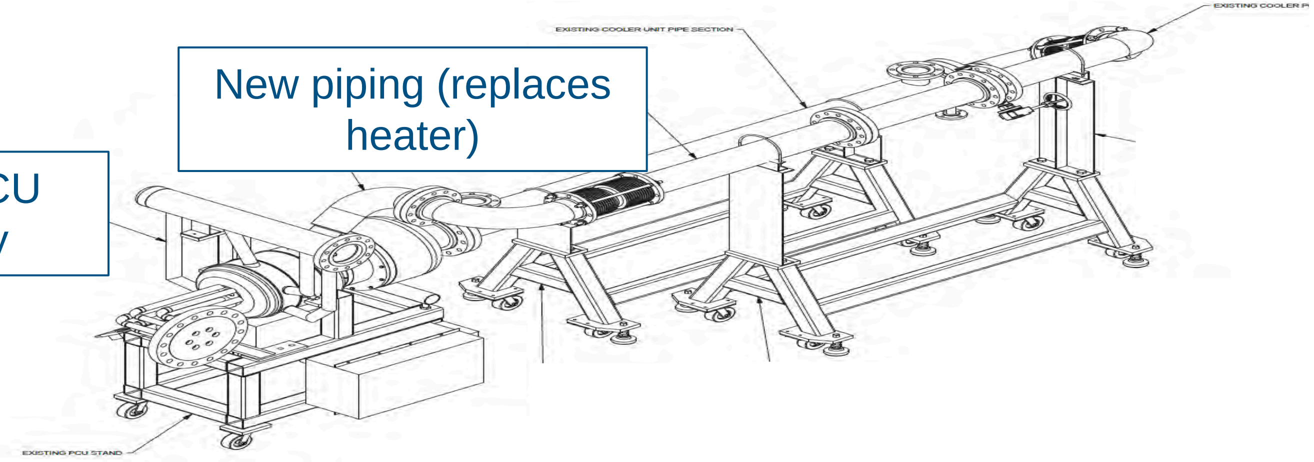
MAGNET – PROGRESS *(from initial startup)*

- 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)
- Shakedown testing of PCU (completion planned for end of May 2025)
- LANL graphite core assembly – Performance Testing (scheduled for end of August 2025)





HElium Component Testing Out-of-pile Research *(HECTOR)* Facility

Test bed being designed to enable testing of components such as heat exchangers, valves, circulators, etc., at operating conditions up to 8 MPa and at 800°C.

US Reactor Design Concepts

Developer	Name	Power Output (MWe / MWth)	Fuel	Coolant	Moderator	Gas Pressure	Outlet Temperature
BWXT	BANR	17 / 50	TRISO	He	Graphite	–	–
HolosGen	Holos Quad	10-13 / –	TRISO	He/CO_2	–	7 MPa	620ºC
NuGen, LLC	NuGen Engine	2-4 / –	TRISO	He	–	–	–
Radiant Nuclear	Kaleidos	1.2 / –	TRISO	He	Graphite	–	700ºC
Nano Nuclear	KRONOS	5 / 15	TRISO	He	Graphite	3 MPa	565ºC
X-energy	Xe-100	80 / 200	TRISO	He	Graphite	6 MPa	750ºC
General Atomics	GA-EMS	50 / 112	UO_2	He	–	7 MPa	800ºC

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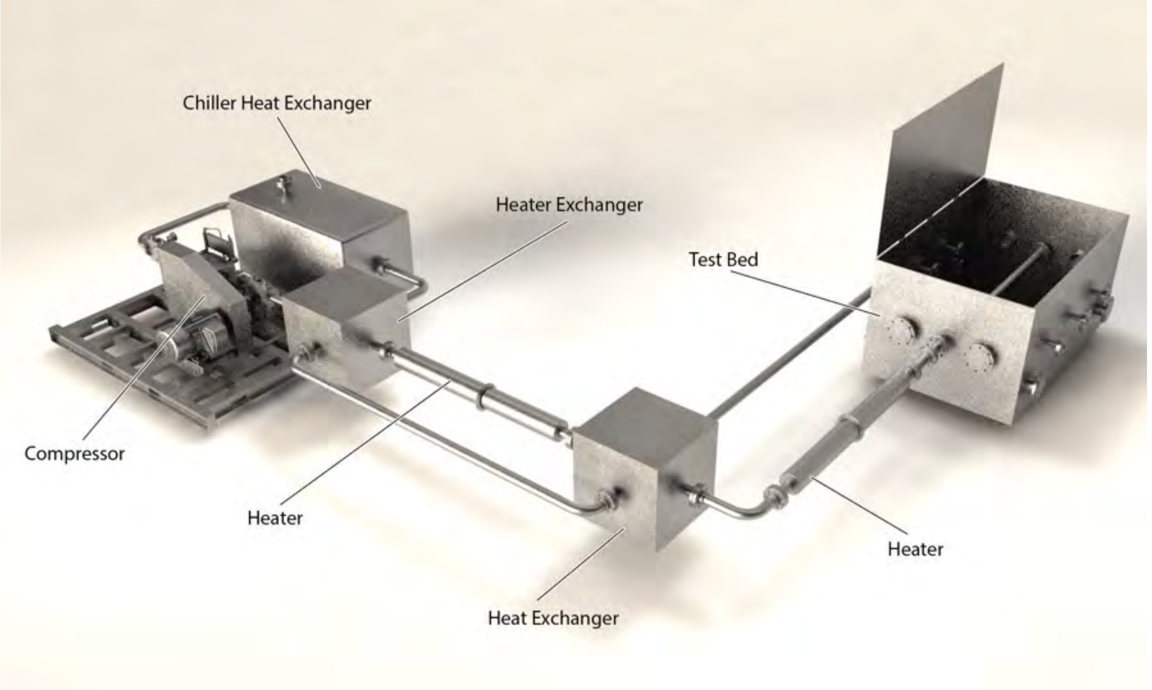
HElium Component Testing Out-of-pile Research Facility

Operating Conditions	
Pressure	8 MPa
Temperature	Up to 800°C
Mass Flow	0.01 – 0.15 kg/s
Reynold’s Number Range	11,700 – 1,610,000



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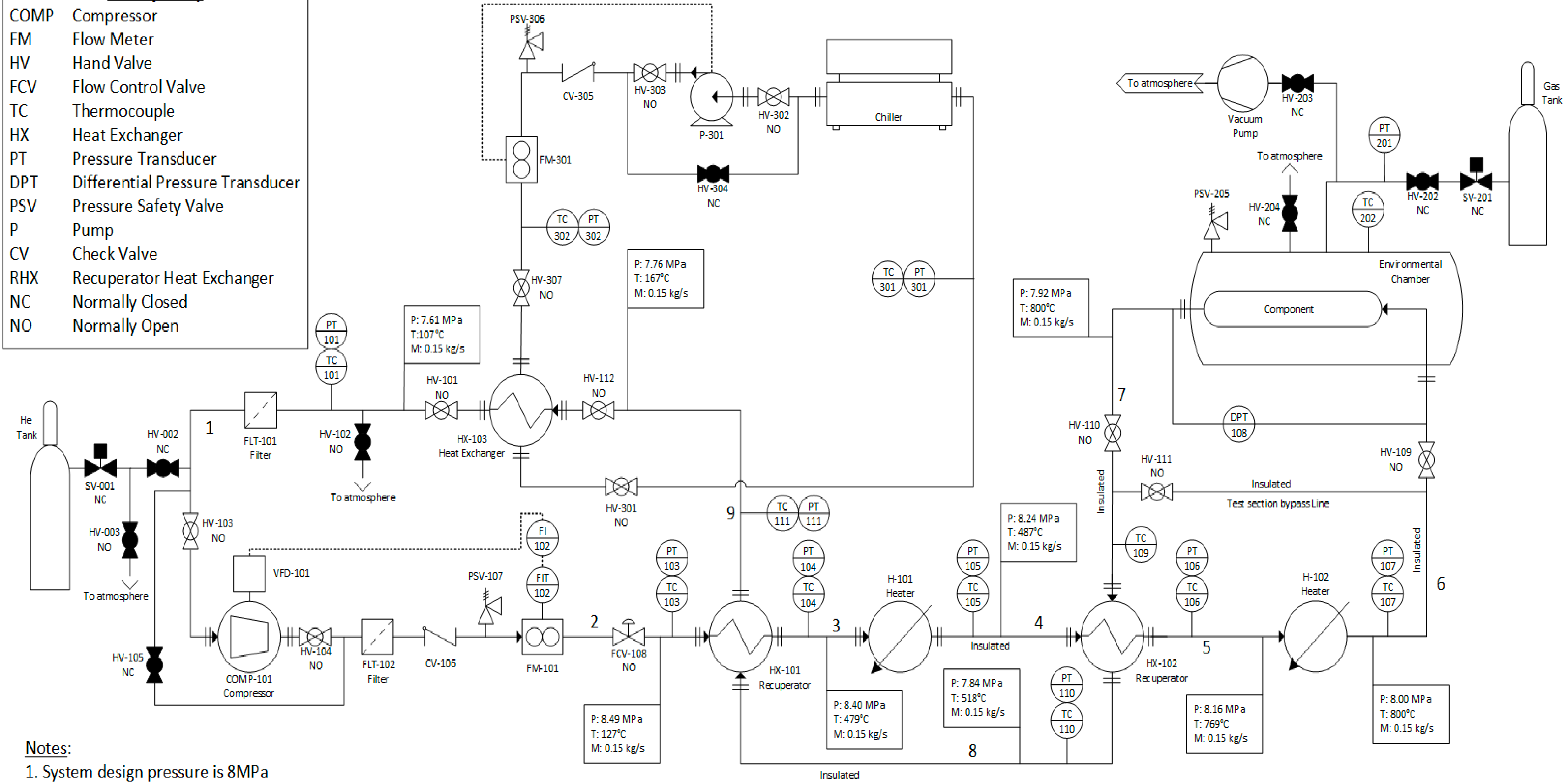
Acronym Key

COMP	Compressor
FM	Flow Meter
HV	Hand Valve
FCV	Flow Control Valve
TC	Thermocouple
HX	Heat Exchanger
PT	Pressure Transducer
DPT	Differential Pressure Transducer
PSV	Pressure Safety Valve
P	Pump
CV	Check Valve
RHX	Recuperator Heat Exchanger
NC	Normally Closed
NO	Normally Open



Notes:

1. System design pressure is 8MPa
2. 1.5" SCH 160 piping for the primary helium loop
2. Flow conditions shown are outputs from ASPEN/HYSYS model

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**)

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Upcoming Presentations

SPHERE Testing and Validation - Zach Sellers

MAGNET Brayton Cycle PCU Integration – TJ Morton

NEUP Presentations - Prof. Bindra and Prof. Anderson

Demonstration Capabilities Summary and Wrap Up

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