GAIN Microreactor Program Workshop

MRP: Demonstration Support and Capabilities

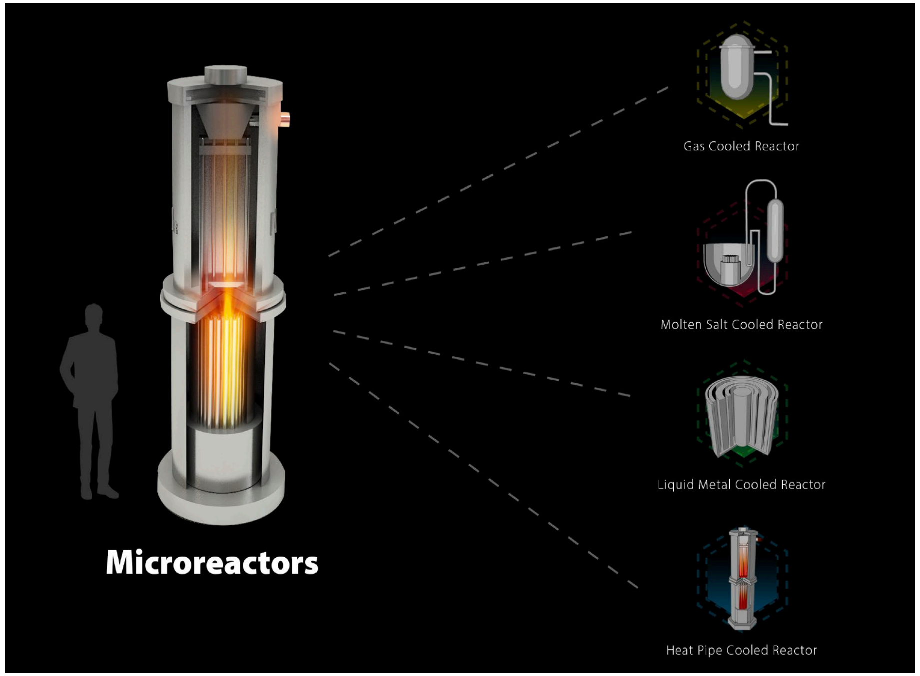
Piyush Sabharwall, Ph.D.
Microreactor Technical Area Lead
US DOE – NE MRP Program

May 13th 2021

Technical Area Overview

Demonstration Capabilities Technical Area includes two major R&D activities:

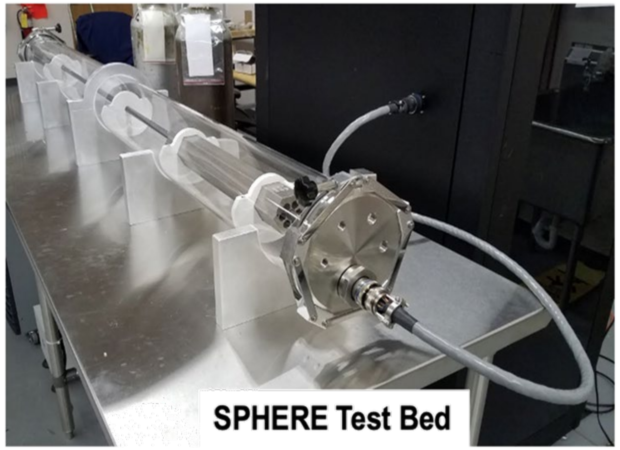
1. Non-Nuclear Testing and Demonstration:
   - Single Primary Heat Extraction and Removal Emulator (SPHERE)
   - Microreactor AGile Nonnuclear Experiment Testbed (MAGNET)
2. Microreactor Applications Research Validation and EvaLuation (MARVEL)



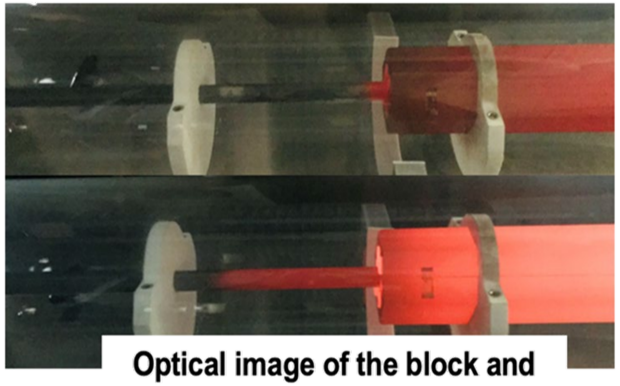
Single Primary Heat Extraction and Removal Emulator (SPHERE)

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

Parameter	Value
Length	243 cm
Diameter	15 cm
Tube material	Quartz
Connections	Flanged for gas flow and instrumentation feed through
Maximum power	20 kW
Max Temperature	750 C
Heat Removal	Passive radiation or water-cooled gas gap calorimeter



SPHERE Test Bed



Optical image of the block and heat pipe operation

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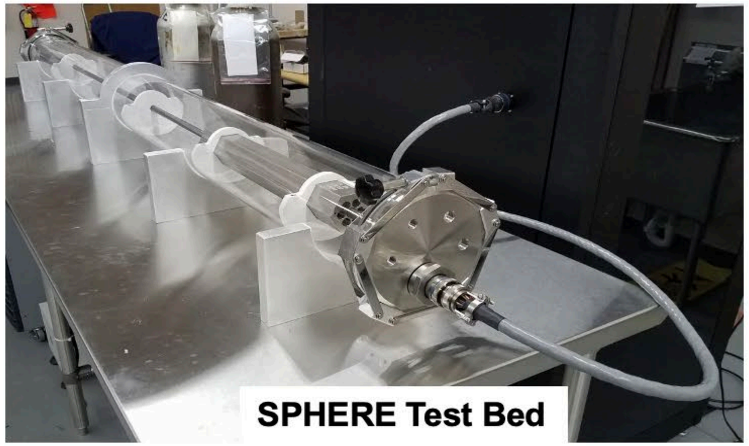
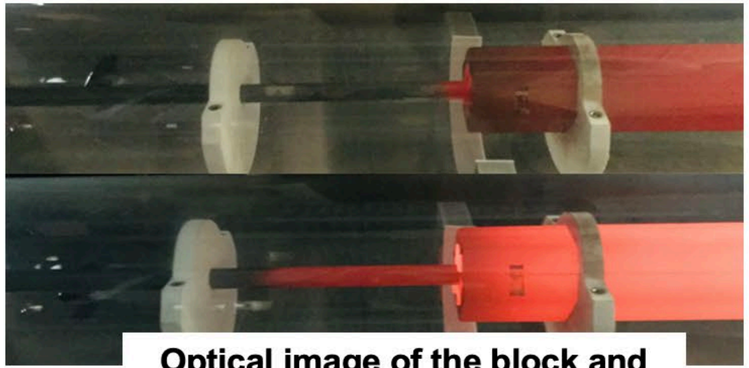
Accomplishment

Single Primary Heat Extraction and Removal Emulation (SPHERE) Completes First Test

- SPHERE is a heat pipe testing capability that allows for detailed testing of the operation and heat transfer for heat pipes to provide performance data and validation data for modeling and simulation.
- The initial testing consisted of vacuum operation of a sodium heat pipe. The temperature was measured at 10 evenly spaced points along the heat pipe.
- Additional exterior thermocouple measurements were also taken on the exterior of the heat pipe to confirm the similarity of thermowell temperatures to exterior heat pipe temperature measurements.
- The initial test was successfully completed, and results measured at INL are consistent with the data from the manufacturer.



SPHERE Test Bed



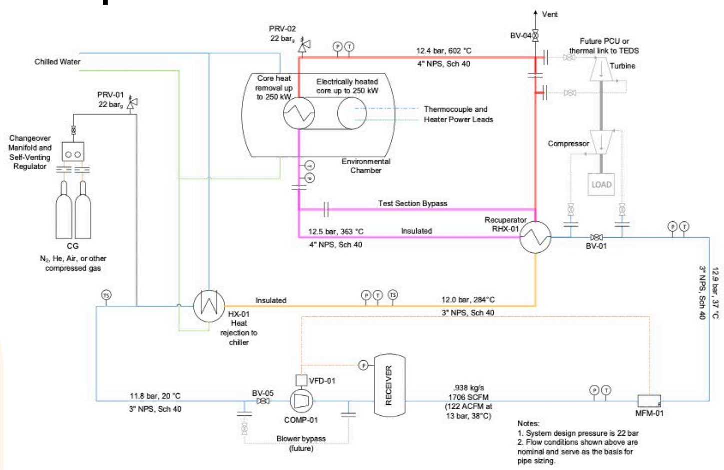
Optical image of the block and heat pipe operation

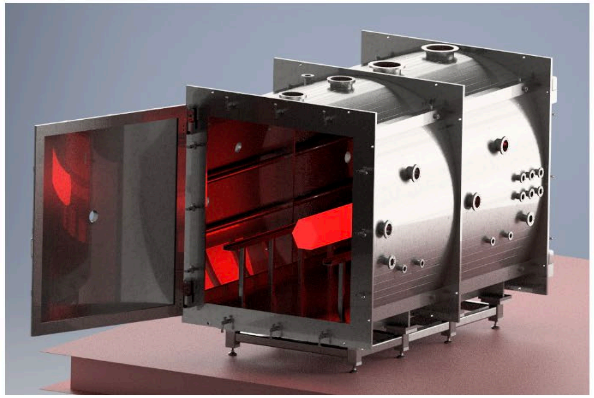
DOE Microreactor Program
For more Information: Piyush.Sabharwall@inl.gov

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 feed through 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





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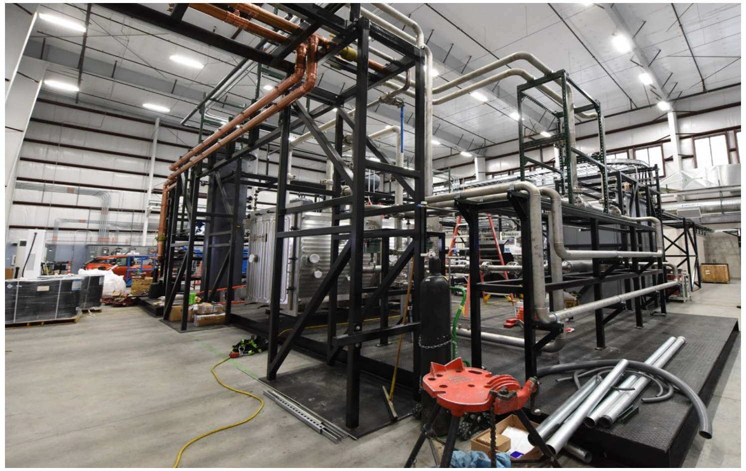
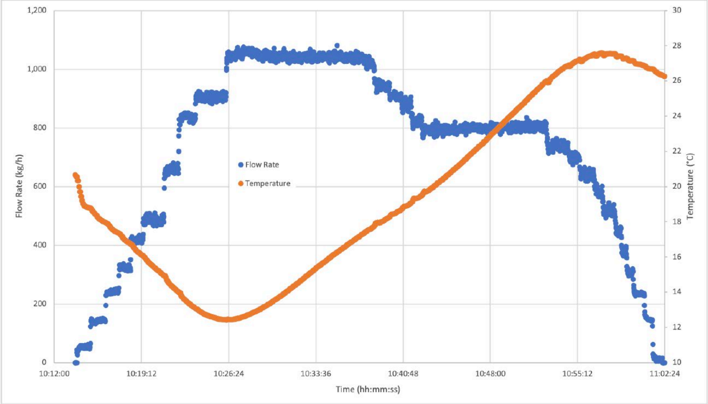
MAGNET Accomplishments and Challenges

- On December 23, INL staff and members of the construction subcontractor team started MAGNET to **demonstrate system operation**
  - Pressurized system piping to 12 bar and started compressor at minimum speed
  - Ramped compressor speed in increments of 5 Hz to full speed

- On January 20, INL staff installed temporary ceramic fiber heater to system piping for final acceptance test
  - Pressurized system to 20 bar, energized heater, and started compressor
  - Heated system to 120 ° F and performed 30-minute system leak check
- INL quality engineer **accepted** the test
- Insulation installation started



Demonstrating System Operability



System Operational Test Flow Rate And Temperature

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MARVEL – Microreactor Applications Research, Validation & Evaluation Project

- Project Goal: Rapid development of a small scale microreactor that provides a platform to research and development on unique operational aspects and integration with end use applications of microreactors
- Supported by the DOE Microreactor Program and National Reactor Innovation Center
  - **MRP**: Engage with microreactor end-user companies
  - **NRIC**: Develop and exercise capabilities to execute reactor demonstration projects
- Project Schedule: Planned operations by **late 2022 - early 2023**
- Anticipating applications testing:
  - Microgrid integration
  - Remote power and heat for computing, water, buildings, etc.
  - Currently engaging interested end users for testing activities

A conceptual rendering of the MARVEL fission reactor at INL's Transient Reactor Test (TREAT) facility.

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MARVEL Reactor Overview

Parameter	Value
Reactor Thermal Power	100 kW
Nominal Electrical Output	20 kWe
High-grade heat	~45 kWt at 450 C
Coolant	NaK, natural circulation
Fuel	UZrH
Reactivity control	4 control dums
Location	INL, TREAT Facility

Single Primary Heat Extraction and Removal Emulator (SPHERE)

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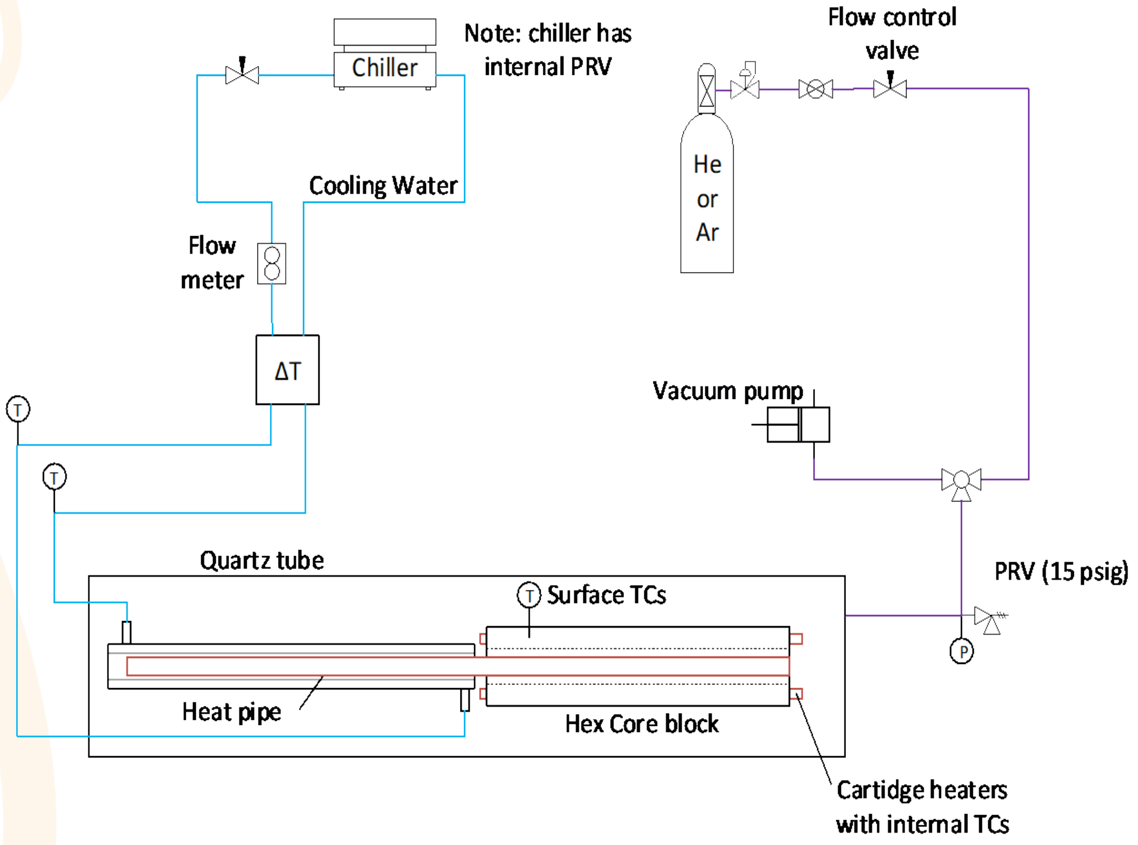
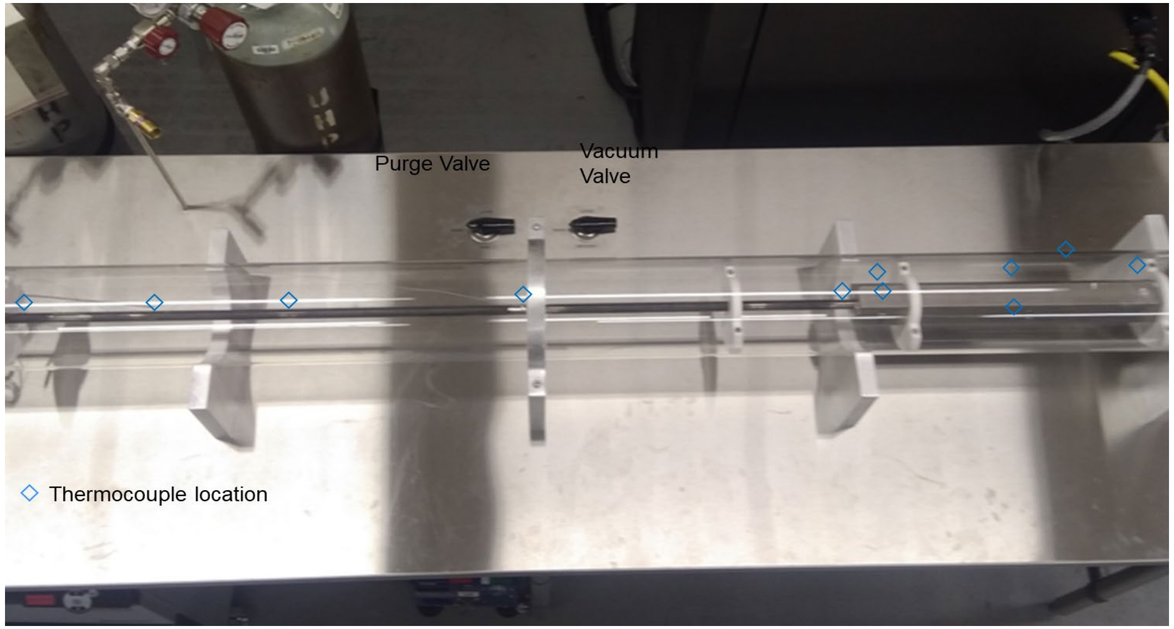
May 13, 2021

Jeremy Hartvigsen | Research Engineer

SPHERE System Design

- 6” diameter 8’ long quartz tube
- Maximum power rating of 10 kW
- Vacuum, Helium, Nitrogen, or Argon atmosphere





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SPHERE MAJOR EQUIPMENT LIST

- Ohio Semitronics, Model PC5-118X5Y25; single phase, 2-wire, 0–150 VAC, 0-25 A, 5-sec response for zero-crossing signal
- National Instruments PXI data-acquisition system
- Watlow Din-A-Mites, 100–240 VAC, 24 Amp, single-phase 4–20 mA control input
- Watlow RMC temperature controllers
- Watlow FIREROD cartridge heaters
- Flow Technology turbine flow meter, Model FTO-5NIXW-LHC-5 with linearization electronics, Linear Link RF input, 0–10 VDC output
- Small vacuum pump for removing air from test fixture (quartz tube enclosure), prior to back-fill with inert gas
- ThermoFisher Thermoflex TF 2500, 2.5 kW cooling capacity, up to 4 gpm water flow rate.

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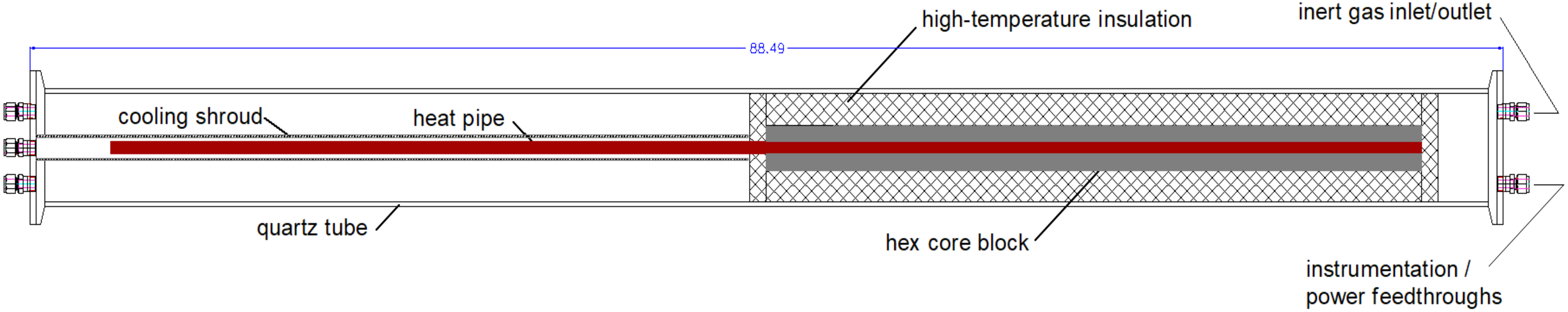
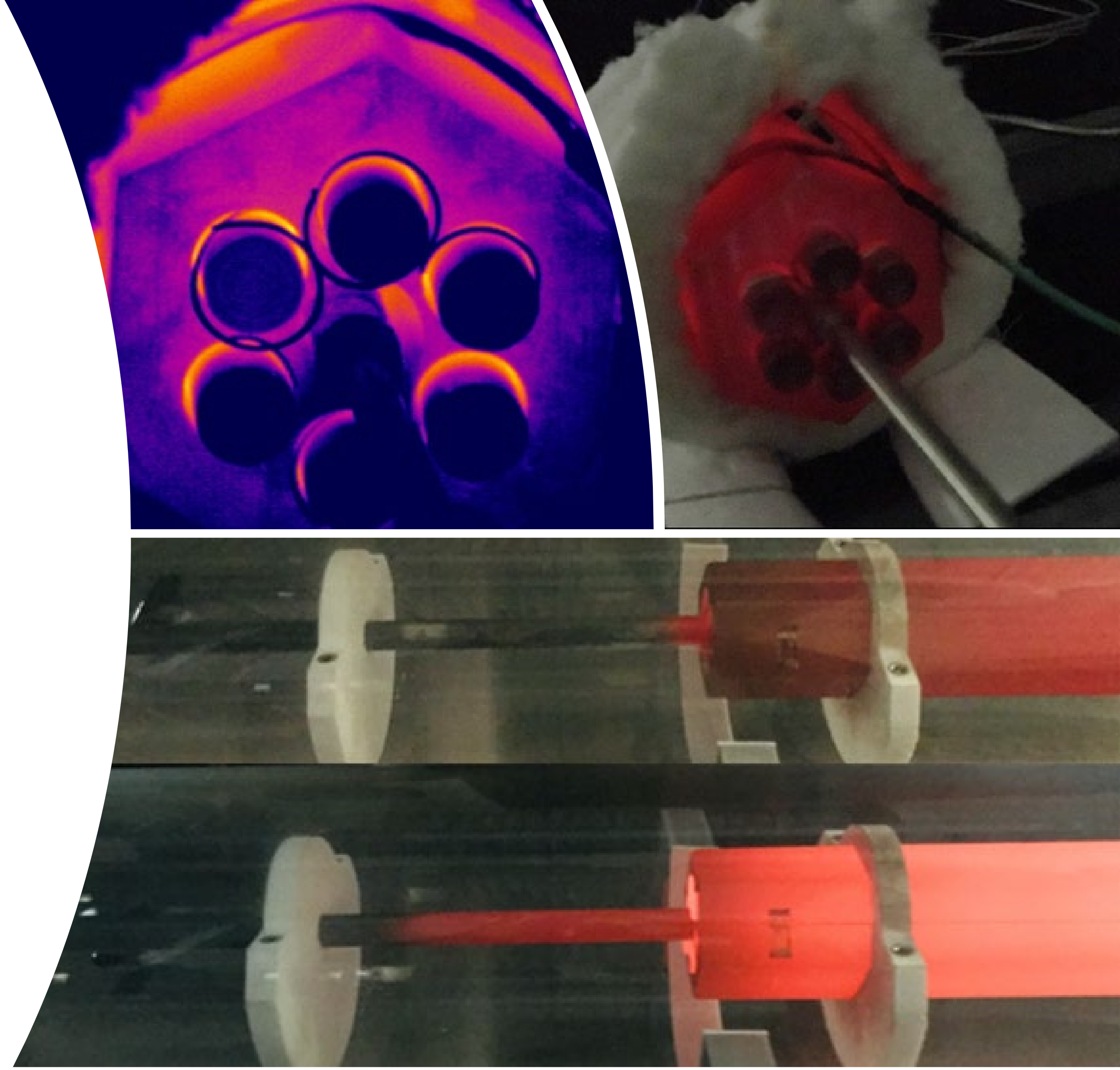
SPHERE: Single Heat Pipe Experiments Objectives

- Single heat pipe experimental capability has been established at BCTC
- Document **heat pipe thermal performance** under a 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 the core block and between the cartridge heaters and the core block
- **Measure** heat pipe axial temperature profiles during **startup, steady-state, and transient operation** using thermal imaging and surface measurements
- **Measure** core block and heater temperatures during heat pipe operation
- **Measure heat removal rates** from heat pipe condenser and compare to total heater power input



SPHERE: ACT Heat Pipe



ACT Heat Pipe

- Pipe material: SS 316
- Geometry: smooth-wall tube, proprietary wick
  - Wick: sintered stainless steel
- Length: 2 m, Diameter: 0.625-in.
- Working fluid: sodium, non-condensable inert gas
- Operating temperature, ~740°C
- Heat-removal rating: 1 kW

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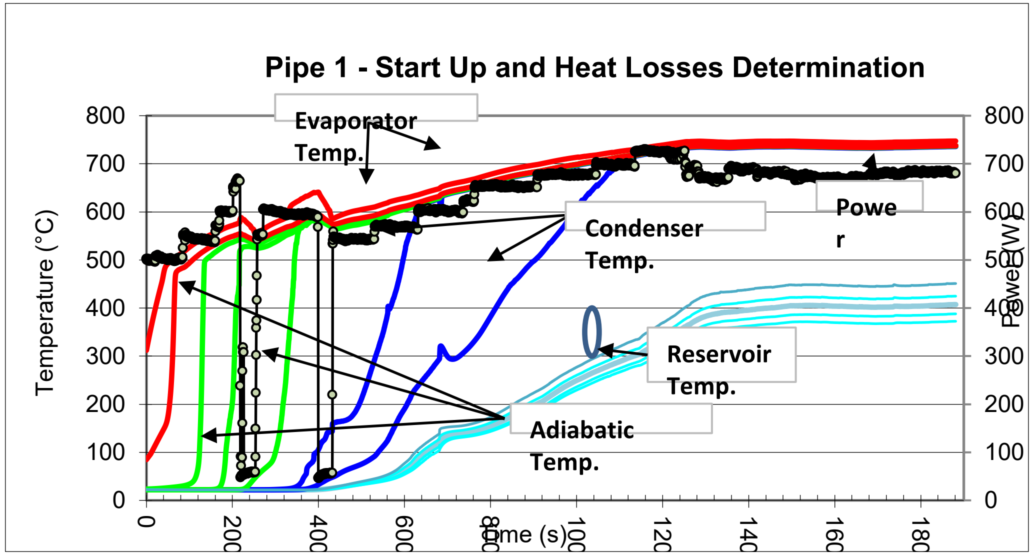
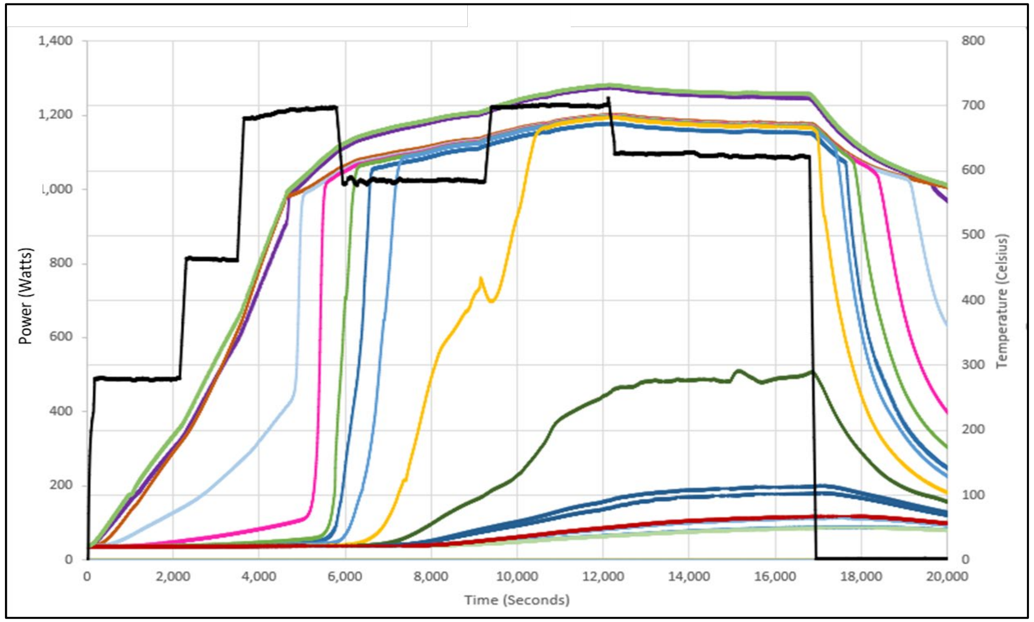
Testing of Commercial Heat Pipe





Accomplishments

- Verify instrumentation and controls
- NEAMS and SOCKEYE use the data from the testing to validate and tune their models
- Experimental data correlates with manufacturer data
- Initial data from shakedown testing being used to help with tool validation

Ongoing Activities

- Interlayer gap conductance testing
- Heat pipe orientation experiments

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Microreactor AGile Non-Nuclear Experimental Test Bed (MAGNET)

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May 13, 2021

T.J. Morton| Engineering Lead

Idaho National Laboratory · Oak Ridge National Laboratory · MRP Microreactor Program · Los Alamos National Laboratory · Argonne National Laboratory

MAGNET Objectives

- General-purpose, non-nuclear test bed for prototype microreactor design evaluation
- Provide thermal-hydraulic performance data
  - Test article and flow loop temperature and pressure data for start up, shut down, steady state, and transient operations
  - Displacement and temperature data for design performance verification and accompanying analytical model validation (V&V)
- Provide expansion capability to demonstrate an integrated power conversion unit (PCU)
- Identify, develop, and test advanced sensors for potential autonomous operation
- Enhance readiness of public stakeholders, particularly DOE laboratories and the U.S. NRC, to design, operate, test, and license high-temperature microreactor components

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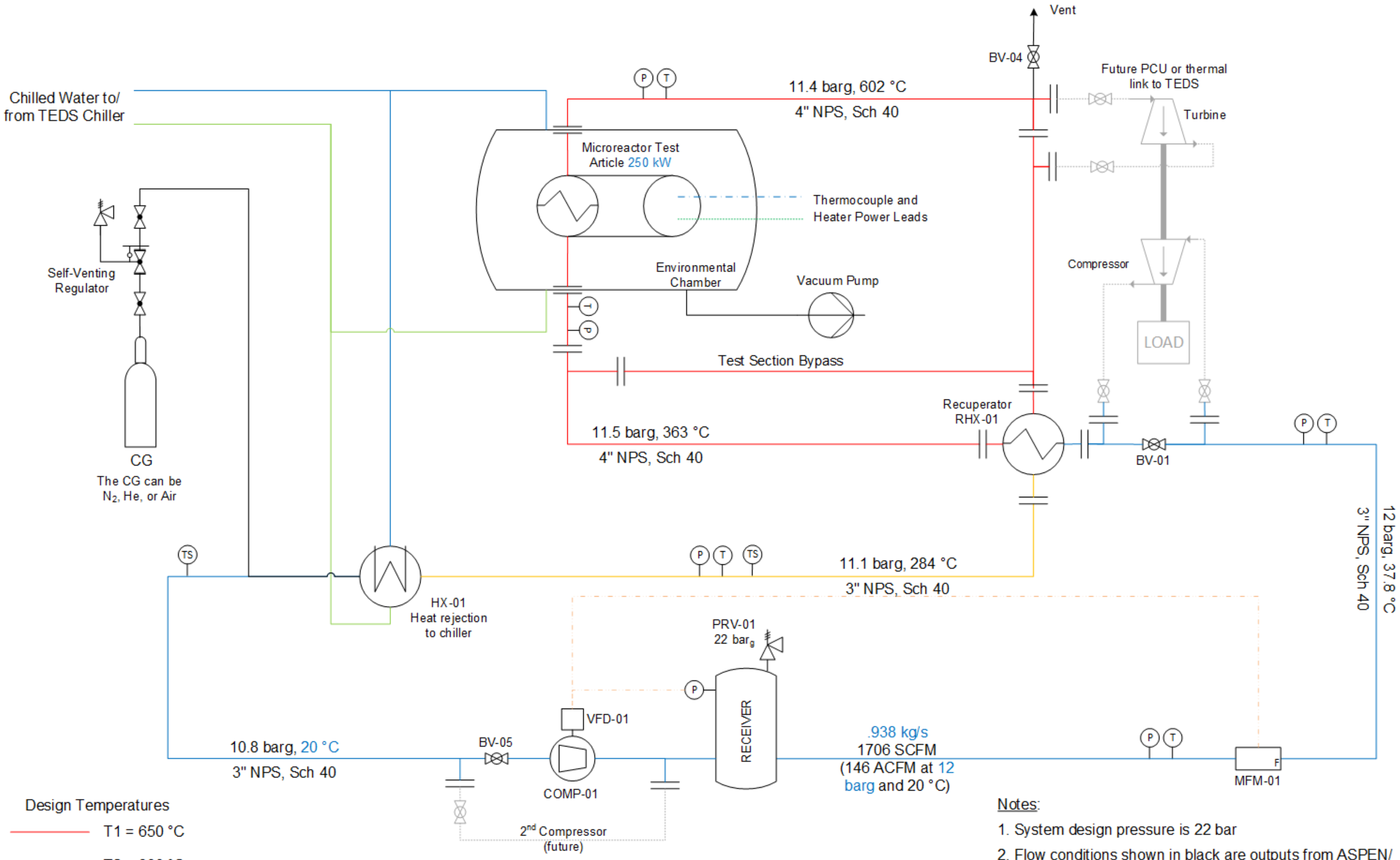
MAGNET Process Flow Diagram (PFD)



Design Temperatures

- T1 = 650 °C
- T2 = 300 °C
- T3 = 60 °C

Notes:

1. System design pressure is 22 bar
2. Flow conditions shown in black are outputs from ASPEN/ HYSYS, and those shown in blue are inputs to the ASPEN/ HYSYS model.

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MAGNET Basic Design Parameters

- Support electrically-heated test articles of ≤ 250 kW
- Support test articles with temperatures ≤ 750 °C
- Provide closed-circuit, inert-gas, coolant flow loop (N_2 or He)
- Flow loop design temperature: 650 °C (see PFD for more information)
- Flow loop design pressure: 22 bar_g
- Ultimate heat sink: chilled water at 44 °F
- 350 kW recuperator (compact platelet heat exchanger)
- Environmental chamber for test article: vacuum (~10^{-4} torr) or back-filled inert gas (atmospheric pressure) 5 ft x 5 ft x 10 ft long inside dimensions
- Expandable for integration of power conversion unit or other systems via heat exchanger
- National Instruments PXI data acquisition and control

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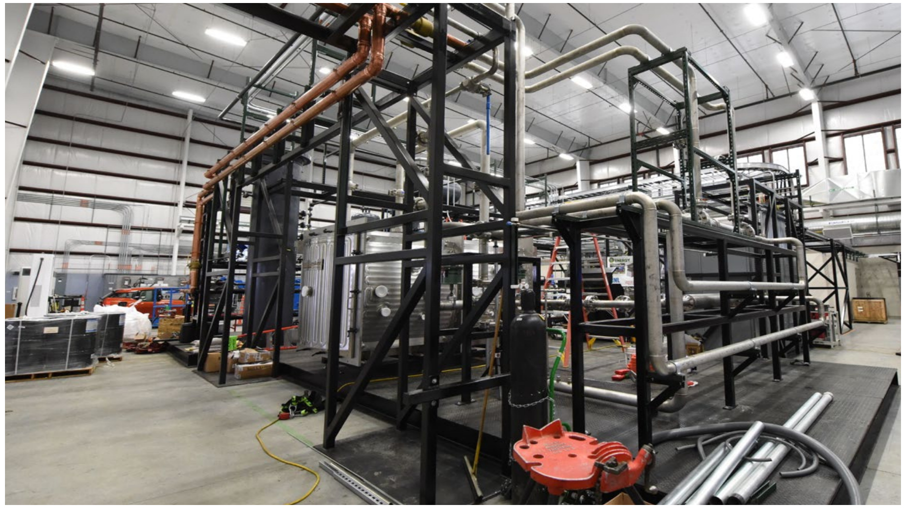
Construction Progress

Construction delays due to late arrival of recuperator and unforeseen problems with high-temperature thread sealant (instrumentation thread-o-lets) pushed start back to June of 2021

- December 2021 – pressurized system to 12 bar_g and ran compressor for one hour to demonstrate system operability
- March 2021 – completed pneumatic test and inspection of all welded joints (test pressure 355 psi_g)
- Insulation work ongoing in parallel with resolving instrumentation port sealing



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Future Work

MAGNET Experimentation

- Finish Engineering design for PCU integration: June 2021
- Complete single heat pipe test article campaign: September 2021
- Construction work to integrate TEDS with MAGNET*: September 2021 - TBD
- Perform He component testing for commercial vendor: September 2021- March 2022
- Install 37 heat pipe test article in MAGNET: April 2022 – May 2022
- Complete 36 heat pipe test article test campaign: ~September 2022
- Design MAGNET upgrades based on operating experience: May 2022 – September 2022
- Resume He component testing for commercial vendor: September 2022 – TBD

* - Funded by Cross-Cutting Technology Development Integrated Energy Systems (CTD-IES)

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Microreactor Applications Research, Validation & EvaLuation (MARVEL) Project

GAIN Microreactor Workshop

May 13th, 2021

Yasir Arafat| MARVEL Technical and Project Lead

MARVEL Project Goals and Objectives

Project Goals:

- Rapid development of a small-scale microreactor that provides a platform to test unique operational aspects and applications of microreactors

Primary Objectives:

- Project shall produce an operational microreactor in the most accelerated timeline possible
- Project shall result in an operational reactor that produces **combined heat and power (CHP)** to a functional **microgrid**
- ***DOE Sponsor Programs:***

MRP Microreactor Program

Create momentum, champion rapid technology maturation, and engage microreactor end-user companies.

NRIC National Reactor Innovation Center

Develop and exercise capabilities to execute reactor demonstration and demonstrate integrated energy systems and non-electric applications.

MARVEL Project Burndown = 11 months

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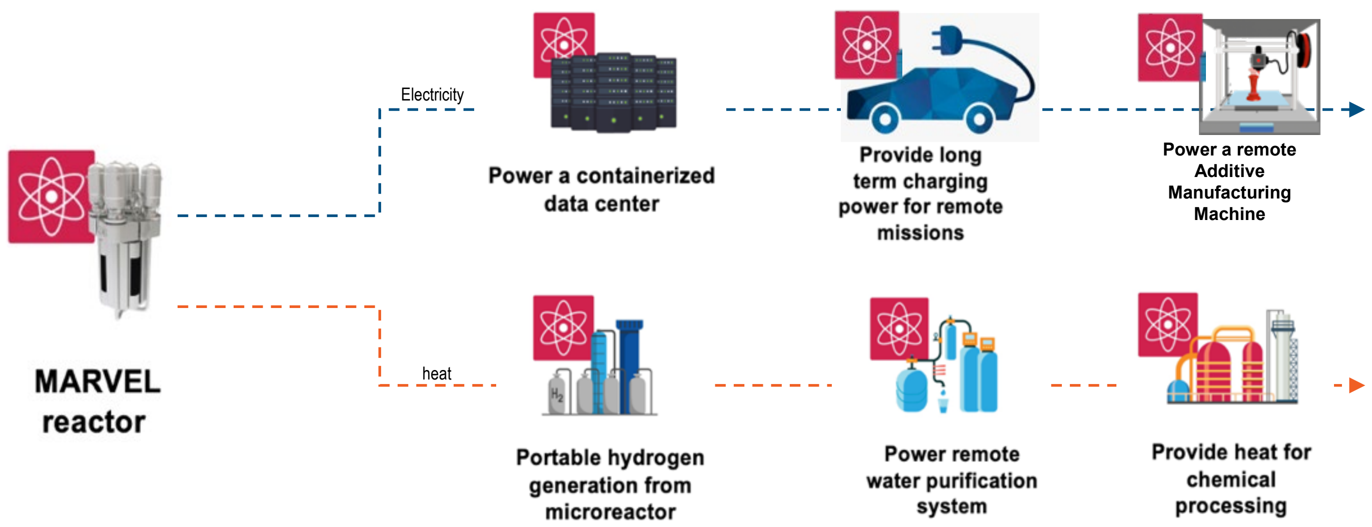
Microreactor Applications R&D

- Engage potential end user companies (B2B, B2C): interested in bringing application assets for testing and ultimate deployment
- End-users are actively being engaged to plan for integration tests: 20 companies

Examples of potential CHP applications



List of companies engaged:

✓Dell
✓Tesla
✓Electrify America
✓Chargepoint
✓ExxonMobil
✓Oxeon
✓Bloom
✓Fuelcell Energy
✓Envoy Public Labs
✓Eastman/Kodak
✓GSE
✓Shell
✓Chevron
✓AVEC
✓Idaho Power
✓Southern Company
✓Holtec
✓Battery 500
✓Proton Conduction H2
✓LIFEPo4

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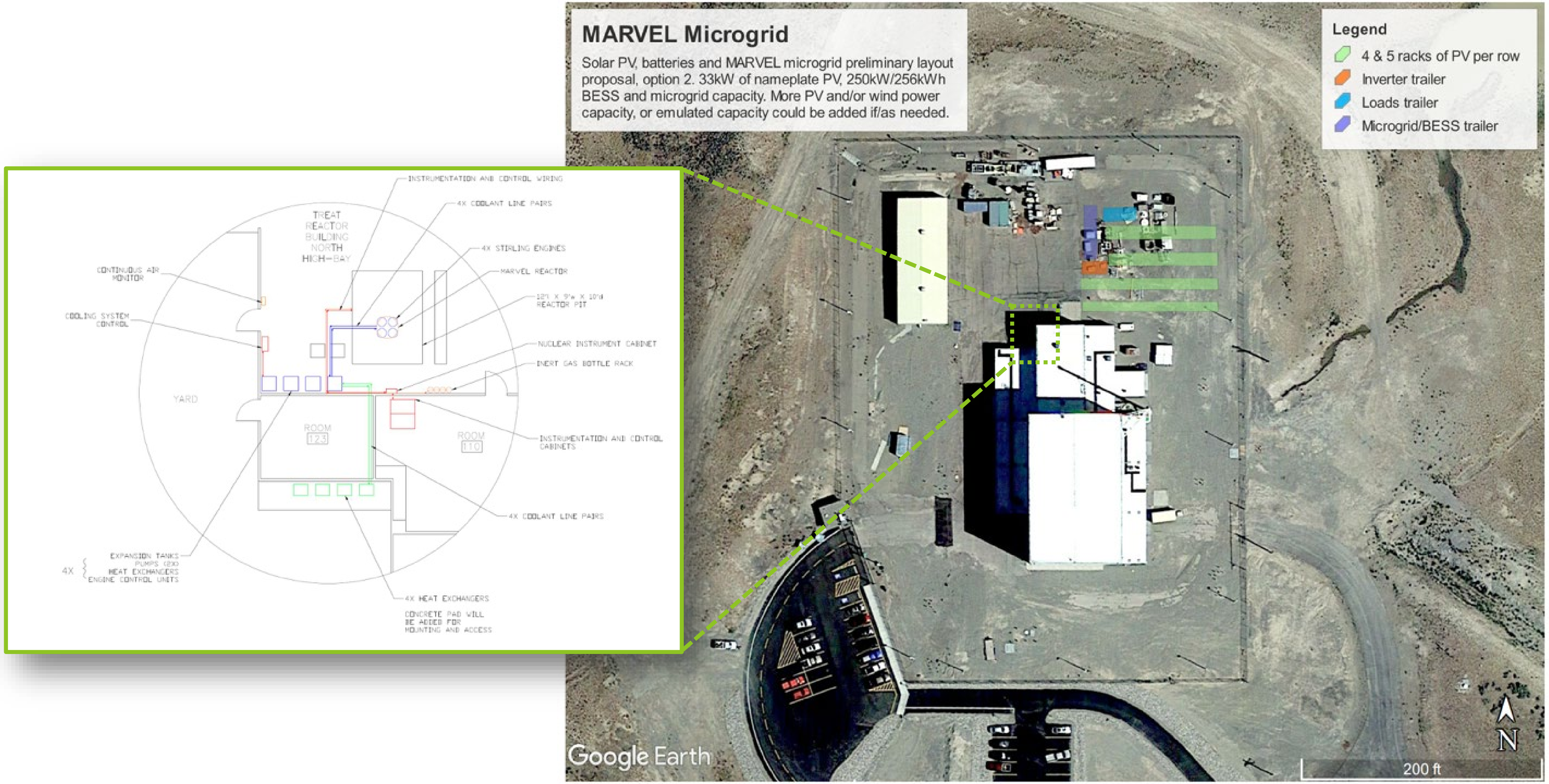
Integration of MARVEL with a Microgrid



MRP Microreactor Program

MARVEL Environmental Assessment (EA) to Pioneer Reactor NEPA

- ***Pursuing EA*** (not EIS) for DOE Authorization
- ***Completed***
  1. NRIC submitted legal white paper to justify basis of EA for reactor to DOE-ID
  2. Environmental Assessment Determination received from DOE-ID
  3. Technical Studies and Evaluations
  4. Purpose and Need in Project Review
  5. Consultations with Tribal (Shoshone, Fort Hall) and State (Governor's Office, Congressional Staffers)
  6. Complete Draft EA and 10 technical ECARs (Jan 11)
  7. DOE review of Draft EA
  8. DOE release Draft EA for public comments
  9. Address Public Comment (Feb 9)
  10. DOE-ID drafted Final EA and FONSI

Title: "*Draft Environmental Assessment for the Microreactor Applications Research, Validation and Evaluation (MARVEL) Project at Idaho National Laboratory*"
Link: **DOE Office of Energy**
Press: ANS Newswire; Local News 8

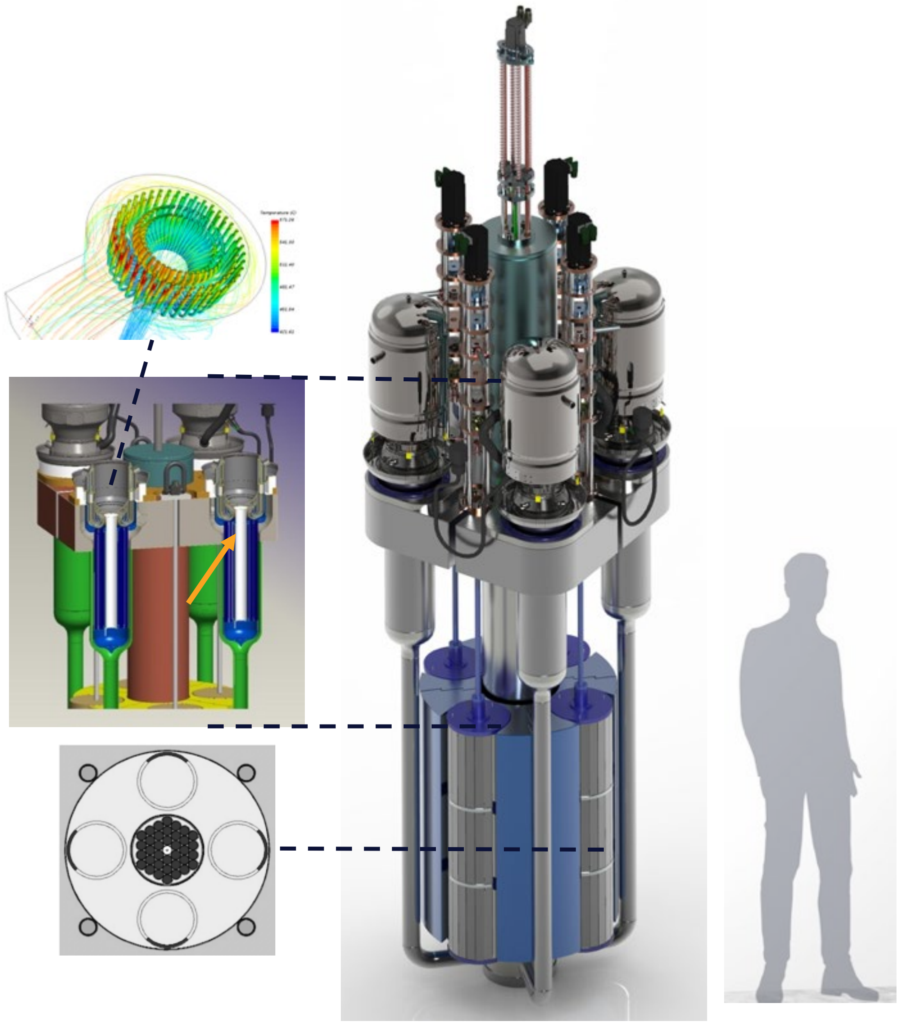
Status *(blue = complete)*

MARVEL is the first reactor to complete EA for NEPA Compliance

MRP Microreactor Program

MARVEL Reactor Parameters

- ***Inspired by*** SNAP 10A core geometry: 37 pins
  - Thermal Power – 100 kWth
  - Four ex-core reactivity control drums
  - Modified TRIGA fuel- $UZrH_{1.6}$
- ***Primary Circulation*** (natural convection) – NaK eutectic
- ***Secondary Circulation*** (natural convection) – PbBi eutectic
- ***Four helium Stirling eng***ines @ 400–500 C inlet T
  - Electrical Output ~20 kWe
  - Max High Grade heat ~ 45 kWth @ 450°C
  - Max Low Grade heat ~ 75 kWth @ 50°C



Site: TREAT Storage Pit (8’x12’x10’) and TREAT control room

Storage pit → T-REXC
TREAT microReactor EXperiment Cell

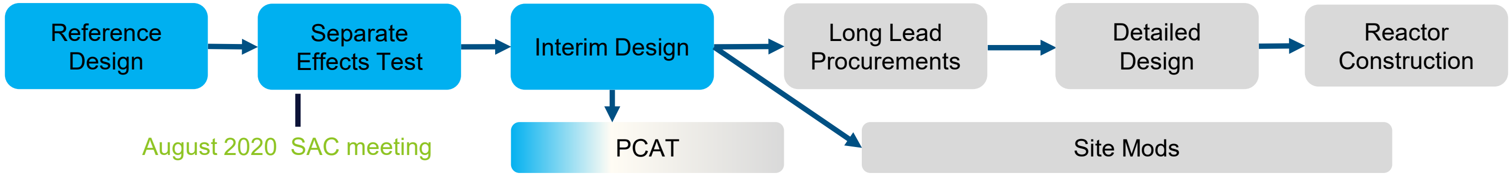
Control Room

MRP Microreactor Program

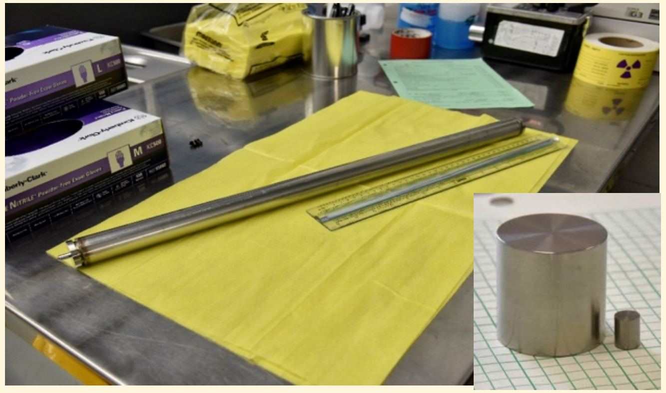
Design & Testing Updates

- **June 2020:** Reference Design Completed
- **July–Sept. 2020:** Separate Effect Tests Performance
- **Oct. 2020–Jan. 2021:** Integral Effects Test (PCAT) Designed
- **Oct. 2020–Jan. 2021:** Interim Design Reports Archived

Status *(blue = complete)*

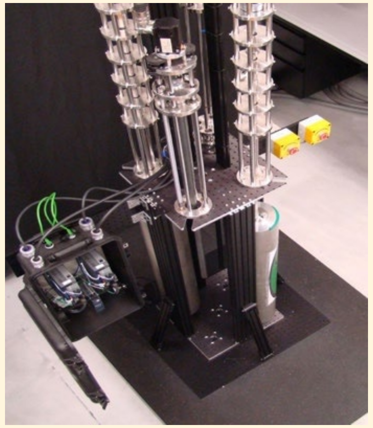


Fuel Pin Assembly



Loaded partial-length pin, Length: 65.38 cm (25.74”), 17 surrogate fuel slugs, 2 surrogate reflectors, ~4.9g Na

MARVEL Control Systems



Control Drums prototype

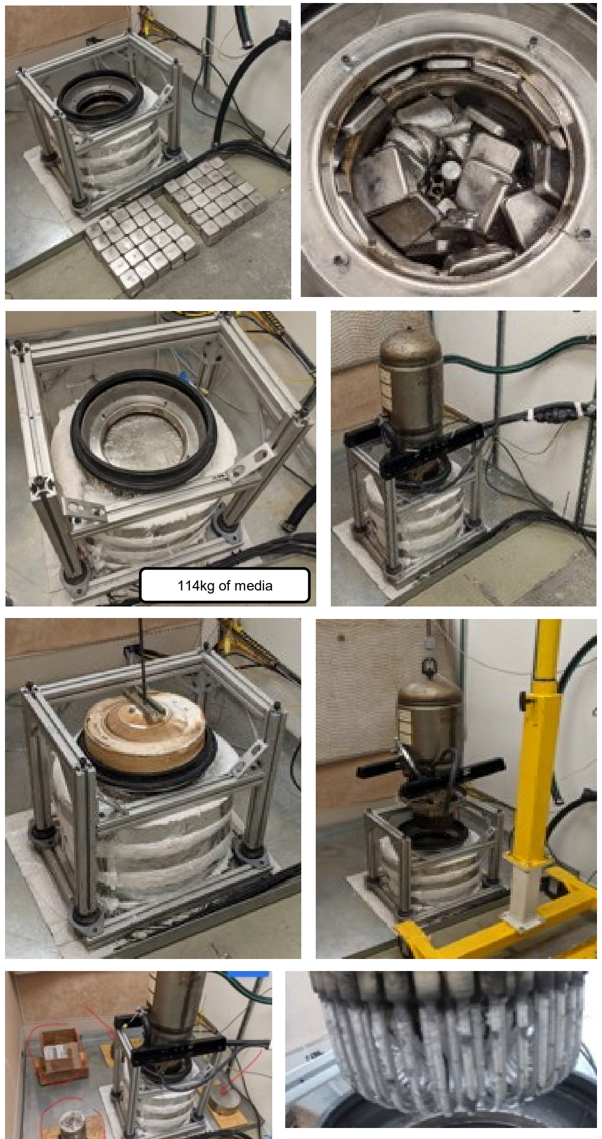
Power Conversion System

Stirling Engine

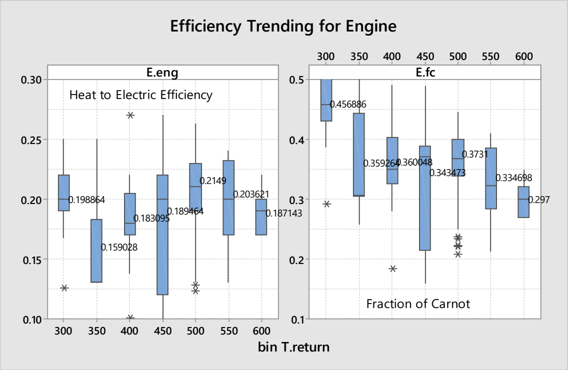
Risk Reduction Tests

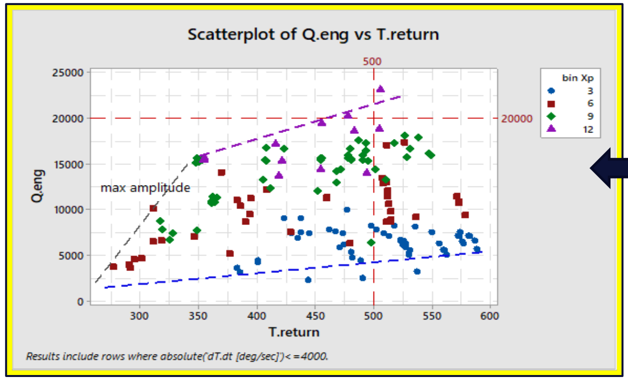
- ***LBE-Stirling is Novel***
- ***Stirling Interface Characterization***
  - Operate on QEC brake – no 'customer' load
  - Evaluate hot start and cold stop (140–180°C)
  - Load/unload convertor into fluid
  - Evaluate vibration transfer (qualitative) to fluid
  - Approximately confirm ROM convection coefficient
  - NDE – Review tubes for any evidence of attack (post-operation)

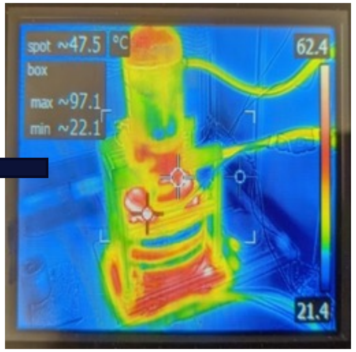
Tank Loss ~0.8 W/K
Engine Conductance ~2 W/K
Circulating Convection ~2 kW/m^2.K
Engine LMTD <100K
Electric Power 4-5kW
Vibration MAX 8-10Grms
Correlations Approximate



- Load engine
- Charge with working gas







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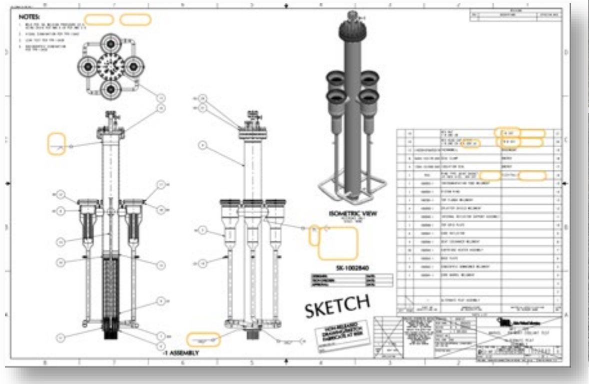
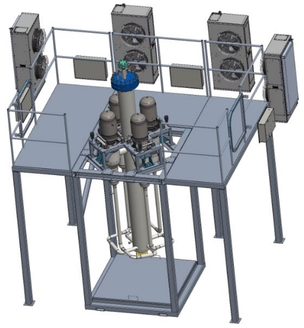
Integral Effects Test “PCAT”

- ***Primary Coolant Apparatus Test (PCAT)***
  - Non-Nuclear Prototype (i.e., physical twin of reactor)
  - Full-Scale, 100kWth
  - Build at INL
  - Tested at Creative Engineers, Inc. (in PA)
- ***Objectives***
  - Flow and heat transfer characteristics
  - Benchmark modeling & simulation
  - Streamline manufacturing methods
  - Train operators





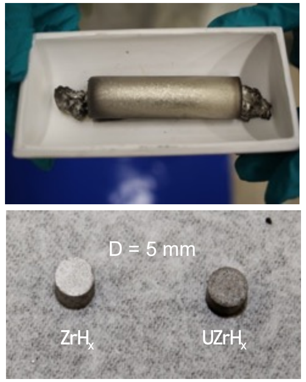
Status *(blue = complete)*

- Conceptual Design → Preliminary Design → Final Design
- Preliminary Design → Long Lead Procurements
- Final Design → Short Lead Procurements
- Final Design → Electrical I&C Assembly → Functional Test at INL
- Final Design → Mechanical Fabrication → Mechanical Assembly at INL
- Final Design → Flow Meter construction → Frame Construction at CEI
- Functional Test at INL / Mechanical Assembly at INL / Frame Construction at CEI → On-Site Installation → Testing (July/August)

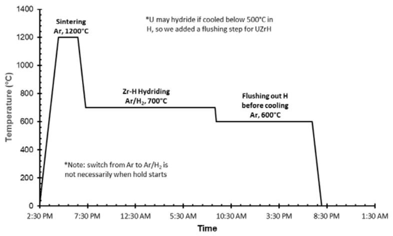
MRP Microreactor Program

Fuel Fabrication (INL, LANL)

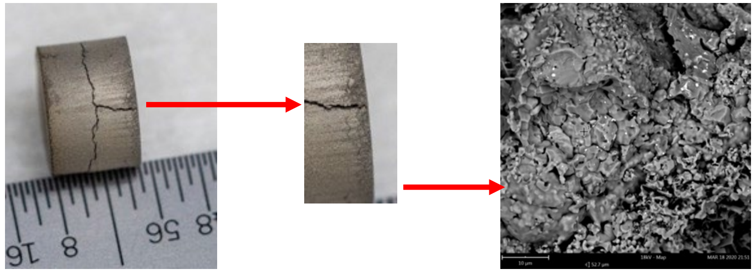
- **Uranium Zirconium Hydride fuel fabrication**
- **Fuel R&D at INL and LANL**
  - ZrH and DUZrH sintering demonstrated
    - Direct hydride, crush/grind powder, press, sinter
    - 30, 35, 40 wt% blend ZrH and UH
    - Analytical Chemistry: XRD, LECO
  - Challenge
    - Fuel Density
    - Oxygen content
- **Fuel Fabrication entails both fabrication and schedule risks**
  - Mitigation:
    - Direct hydriding R&D
    - TRIGA International procurement feasibility for fuel pellet supply
  - Decision point this FY



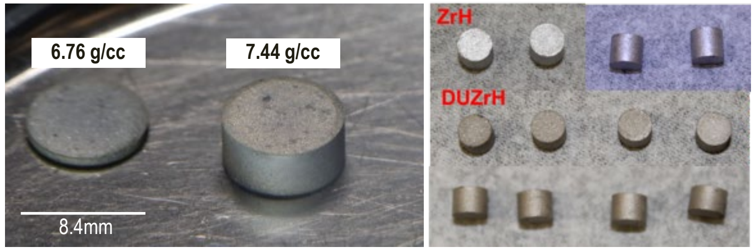
Sample Sintering Profile



Cracking of pellets likely due to the volume expansion during hydride formation



Sample 03152021-UZrHx, 1075°C, 5 hour (Ar), 625°C, 8 hours (9.4/0.6 LPM Ar/H_2). Pressed at 450 Mpa 40 wt% U



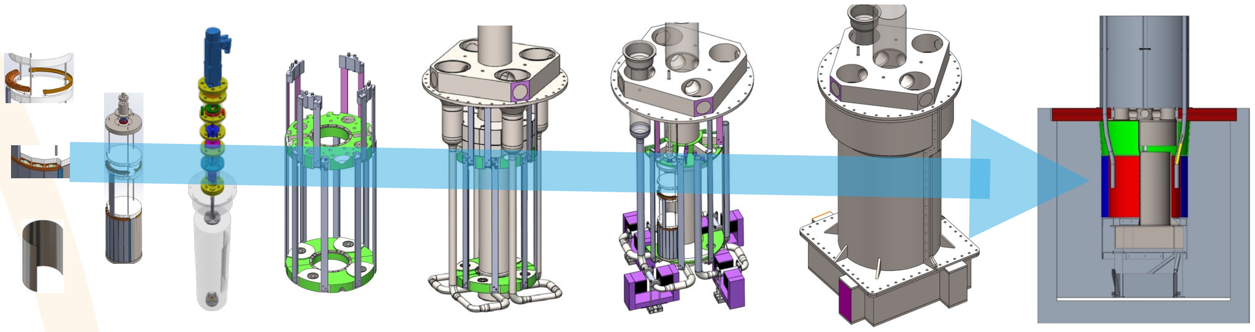
INL LANL

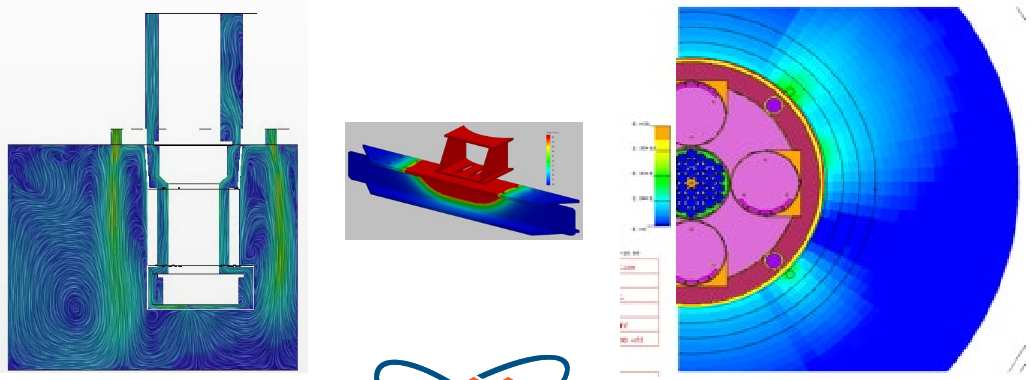
MRP Microreactor Program

Interim Design (~ Preliminary Design)

- ***Engineering Verification Phase: Interim Design Reports, Rev 0 Complete***
  - Fuel
  - Nuclear Design
  - Reactivity Control System
  - Instrumentation & Control System
  - Power Generation System
  - High Grade Heat Extraction System
  - Thermal Design
  - Reactor Structure

- ***Analyses (preliminary)***
  - Thermal performance simulation using RELAP5-3D
  - Preliminary Accident Analyses using RELAP5-3D, BISON
  - Reactor physics - shutdown margin, diff. control drum worth, xenon buildup, etc., using MCNP, SERPENT
  - Flooding, Source term, activation, and personnel dose analyses
  - Structural analyses: analytical and finite element analyses (FEA)
  - Conjugate heat transfer model: T distribution and dP

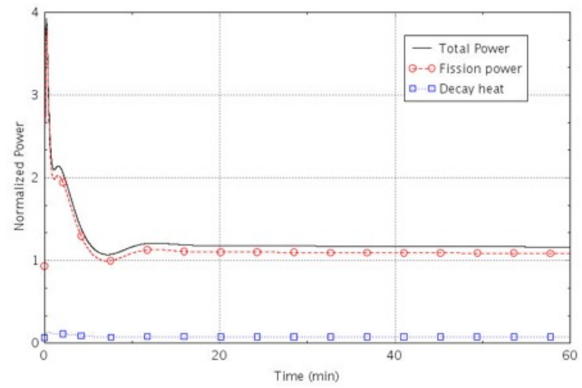




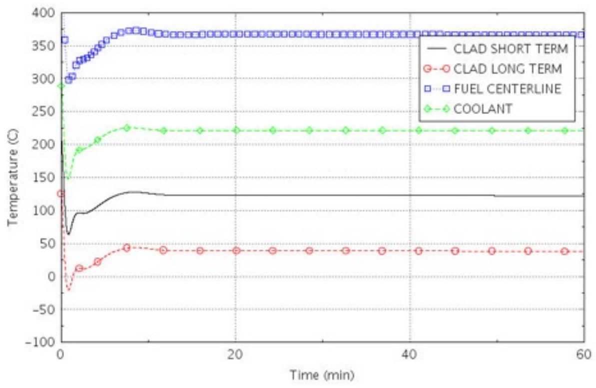
MRP Microreactor Program

Safety analysis – UTOP

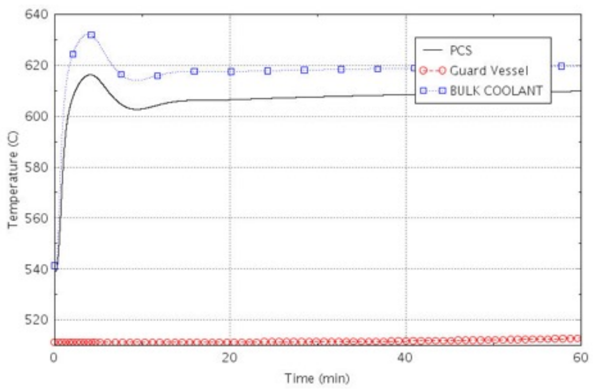
- Transient Analyses: **Unprotected Transient Overpower**
  - Step reactivity insertion (0.4$) → 1 CD out from critical position to the mechanical stops
  - No SCRAM
  - Includes Hot Channel Factors
  - Reactor power peaks ~3.9 P_{NOM} at t = 24 s
  - Negative reactivity feedbacks counters the power surge → system back to a steady higher power (1.16 P_{NOM}) and higher temperature by t = ~ 15 min
  - **No safety concerns** during 1 hr long transient – Manual Scram Terminates Sequence



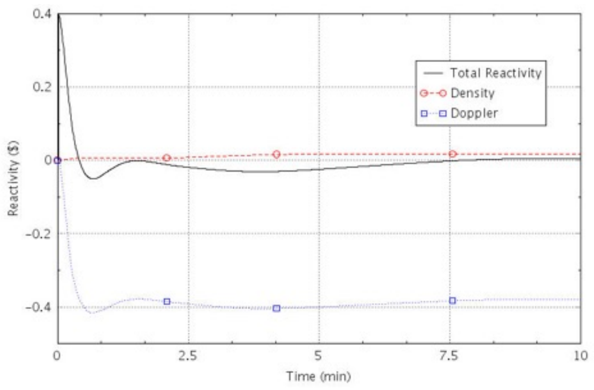
Reactor Power



Temperature Safety Margins



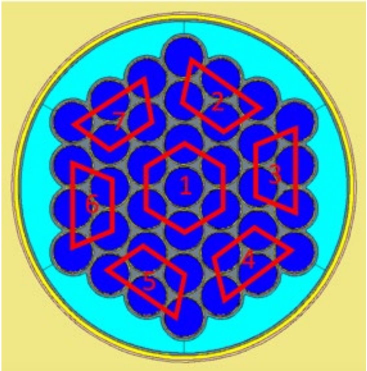
PCS & SCS Temperatures

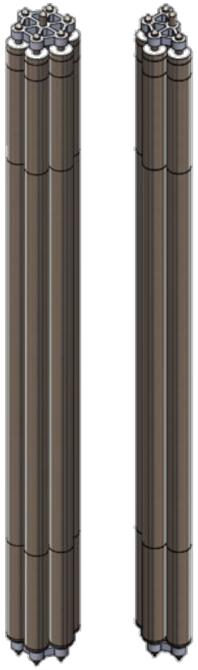


Reactivity

Fuel Load and Startup: Validation

- **Fuel Load:** 1/M approach to critical will be used to prevent inadvertent criticality
  - BF3 startup channels used, along with neutron source
  - The loading of the fuel always begins by loading the fuel in the highest worth positions
- **Measure reactor physics parameters**
  - differential and integral control drum shim worths
  - critical drum shim position
  - the shutdown margin and excess reactivity are calculated and compared to the technical specifications
- **Perform heat balance calibration** of the nuclear instruments
  - Performed at Low temperature for accuracy
  - Temperature measurements will indicate heat losses in system→ decay heat removal capability
- **Testing of Power Production**
  - Performed at high temperature, to start Stirlings
  - Measure power incrementally from 0-100%
  - Validate power produced, engine efficiency and system performance





MRP Microreactor Program

Next Steps (months 11+)

FY 2021-Q3

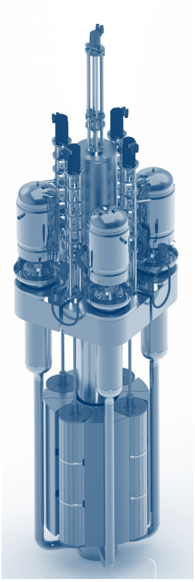
- PCAT Fabrication
- Preliminary Safety Analyses
- FONSI (approval for long lead procurement) by DOE-ID

FY 2021-Q4

- Preliminary TREAT SAR Addendum
- PCAT Assembly
- Detailed Design for long lead procurement
- Fuel Fabrication Process Finalization

FY 2022
Site Prep,
Fuel Production,
Reactor Construction

FY 2023
Fuel Load,
Criticality,
MARVEL Microgrid



MRP Microreactor Program

Key Project Challenges

- Fuel R&D and fabrication risks
  - Fuel R&D may not achieve formulated specifications
  - Fuel schedule too long
  - External supplier limitations
- Lack of precedence makes it challenging for project estimation
  - Bottom-up cost estimate based on detailed schedule helps increase confidence
- Team Credit:

Idaho National Laboratory
NS&T | MFC

Los Alamos National Laboratory EST. 1943
Argonne National Laboratory
Walsh Engineering Services
Qnergy Reliable Remote Power
Creative Engineers, Inc. United States | Canada | International

MRP Microreactor Program

Potential Areas Where Industry Can Leverage MARVEL

- Detailed Engineering
  - Reactivity Control Systems
  - Instrumentation & Control Systems
  - Fuel Design
  - Startup Plan
  - INL Engineering Job Process
- Model Based Systems Engineering (NRIC)
  - Requirements Management
  - Risk Management
- NEPA (for DOE Authorization)
  - EA Process
  - Technical Studies
- Safety Basis (for DOE Authorization)
  - Safety Design Strategy
  - Safety Analyses (design dependent)

MRP Microreactor Program

Thank You

- NEPA
- Reactor Site
- Microgrid and end users
- Design, Testing, Fuel
- Next Steps & Challenges

Contact Information

Yasir Arafat

MARVEL Technical & Project Lead

yasir.arafat@inl.gov | 412-736-4886 *(cell)*

MRP Microreactor Program

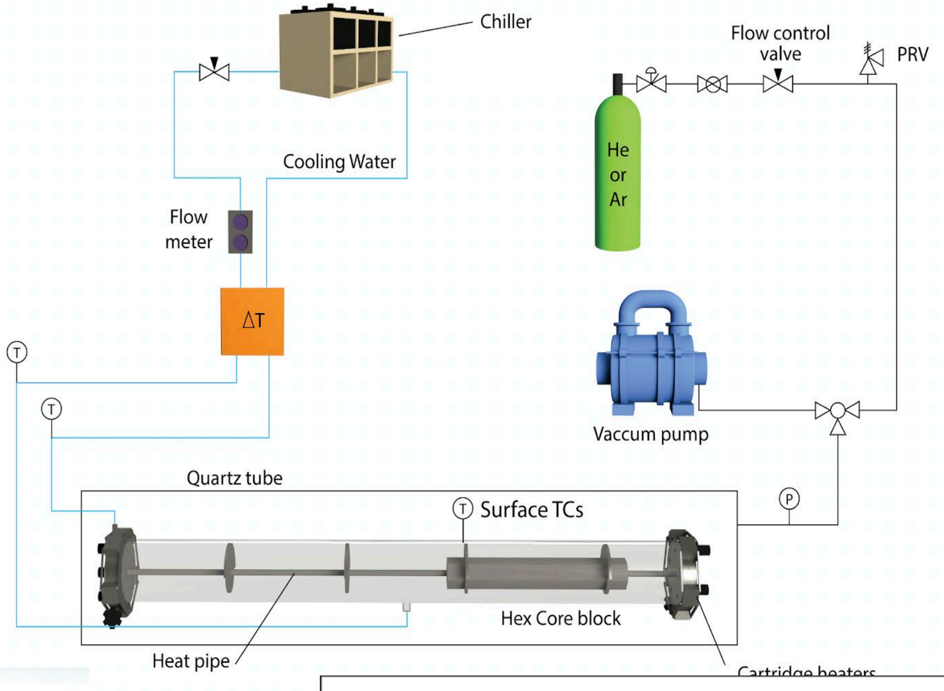
Demonstration Capabilities Path Forward and Opportunities

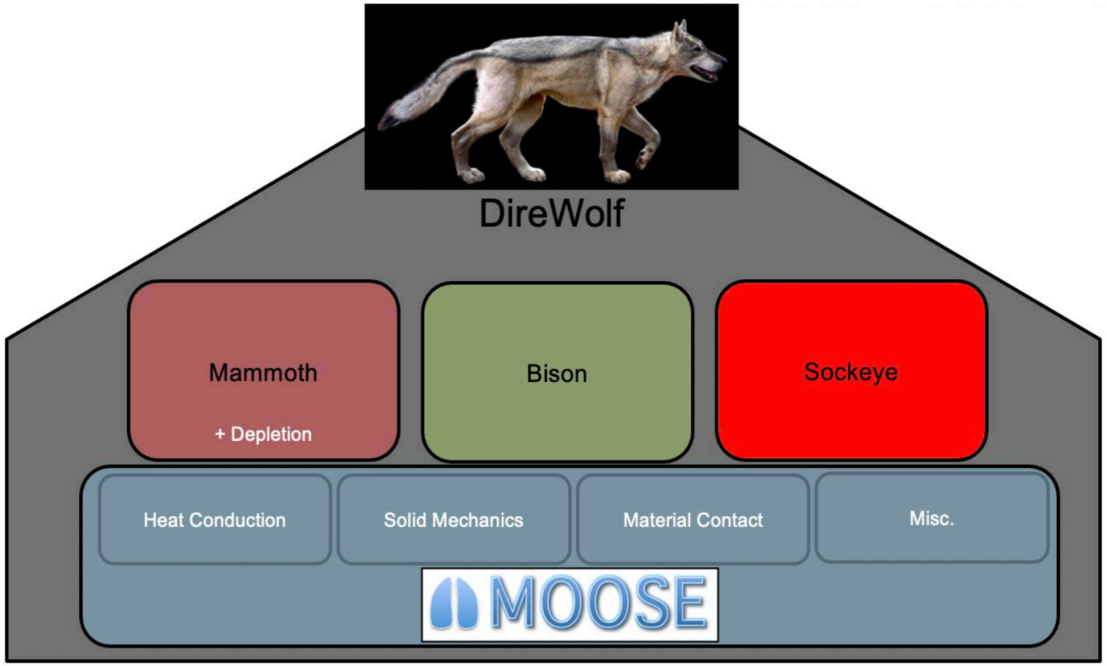
Piyush Sabharwall, Ph.D.
Microreactor Technical Area Lead
US DOE – NE MRP Program
May 13th 2021

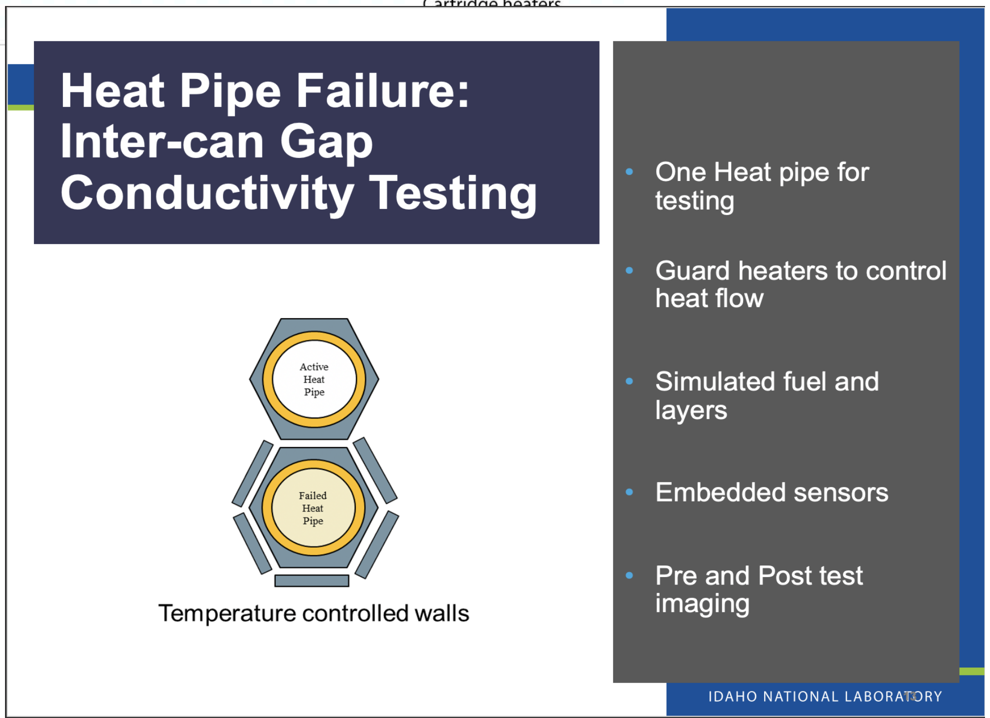
Summary of FY-21

SPHERE FY 2021

- Demonstrate Initial Startup (Shakedown Testing)
- Gap Conductance Testing Preliminary Safety Analyses
- Working Closely with DOE-NEAMS Prog to Jointly Support V&V Activities







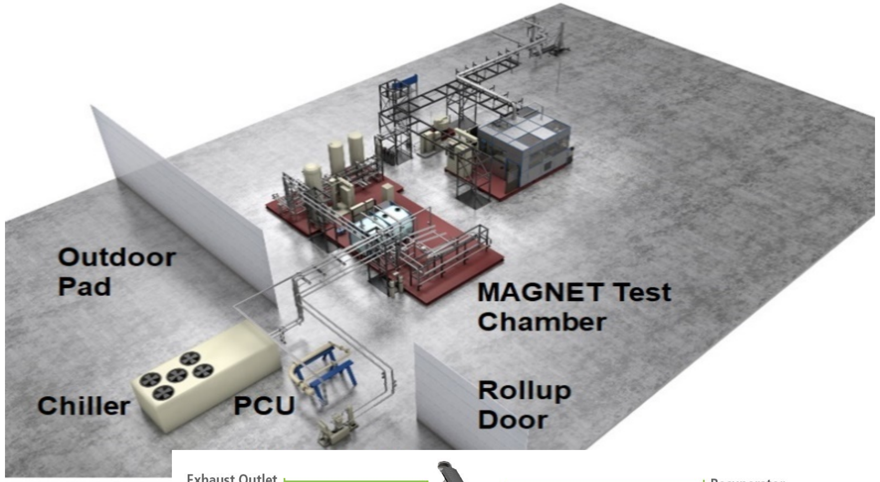
Summary of FY-21

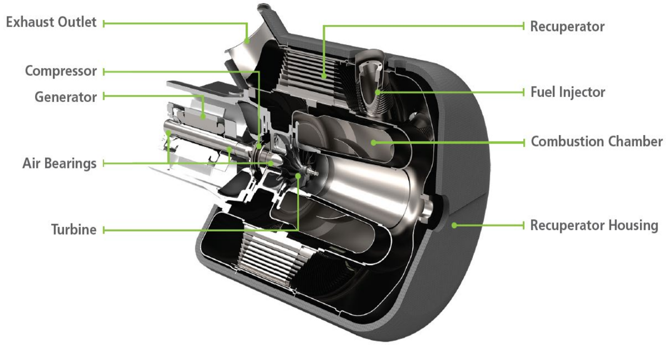
MAGNET FY 2021

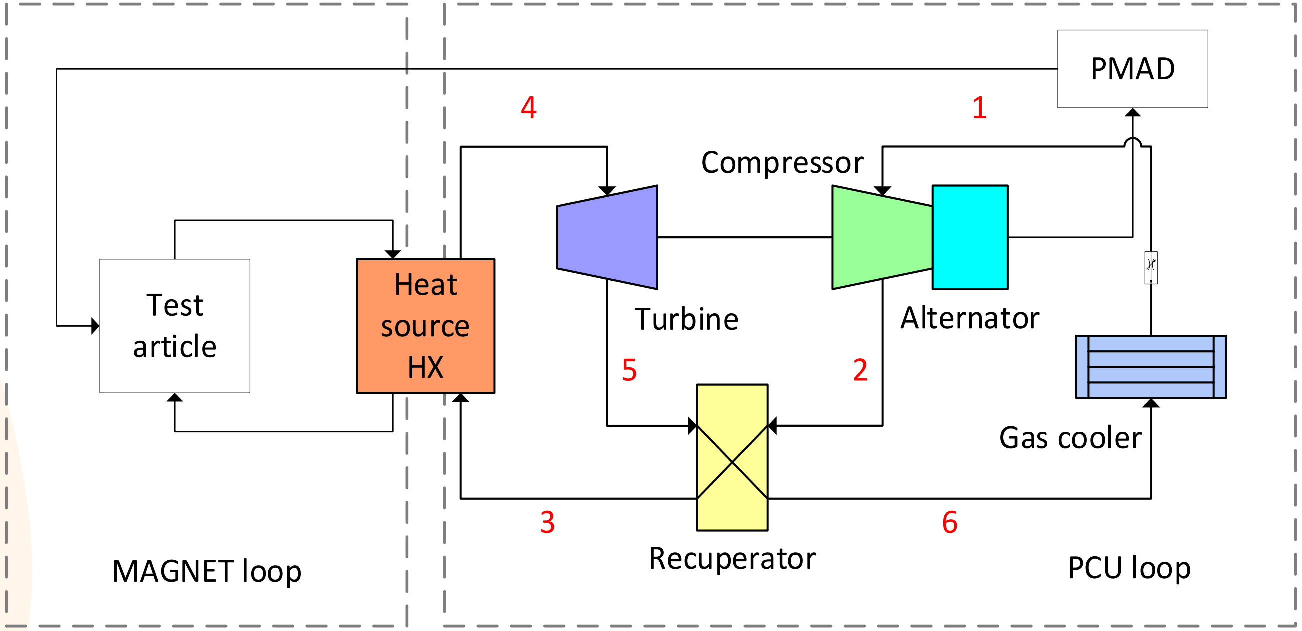
- Demonstrate Initial Startup (Shakedown Testing)
- Single HP Test Article
- Complete engineering design for PCU integration in MAGNET

Microreactor Power Conversion Integration and Testing

- Integration of a modified Capstone C30 turbine-alternator-compressor unit into MAGNET
  - Will provide researchers with the ability to evaluate the test article heat transfer under representative operating conditions with the transient system behavior associated with a closed Brayton cycle PCU
  - Eng'g design for installation underway







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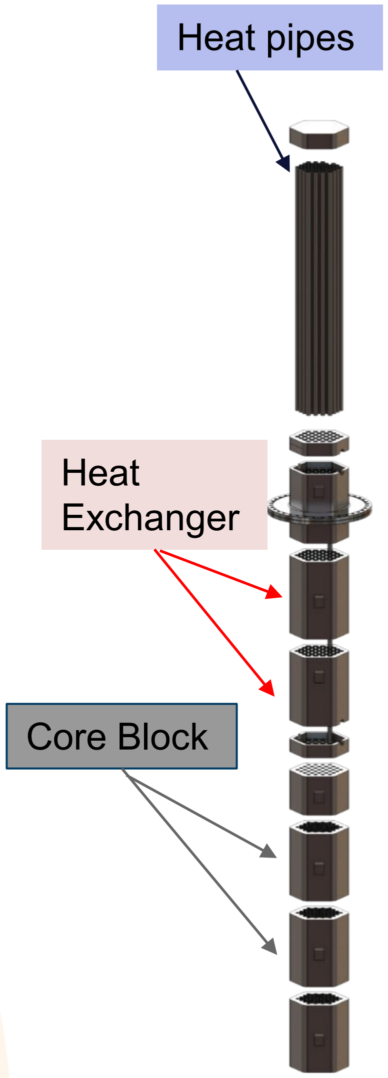
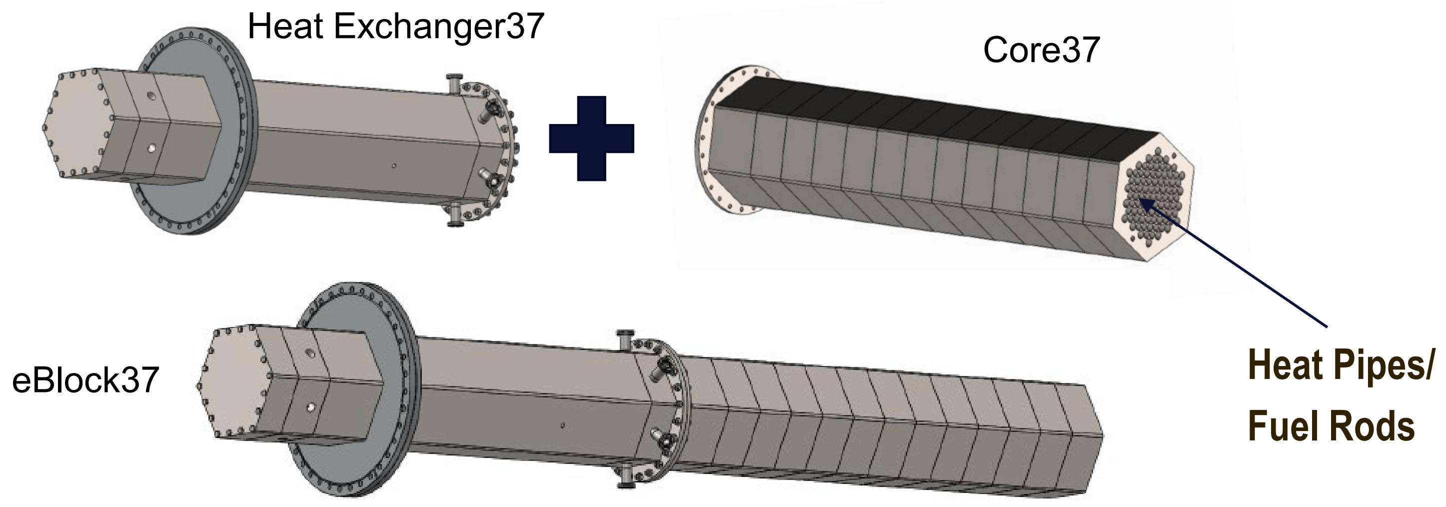
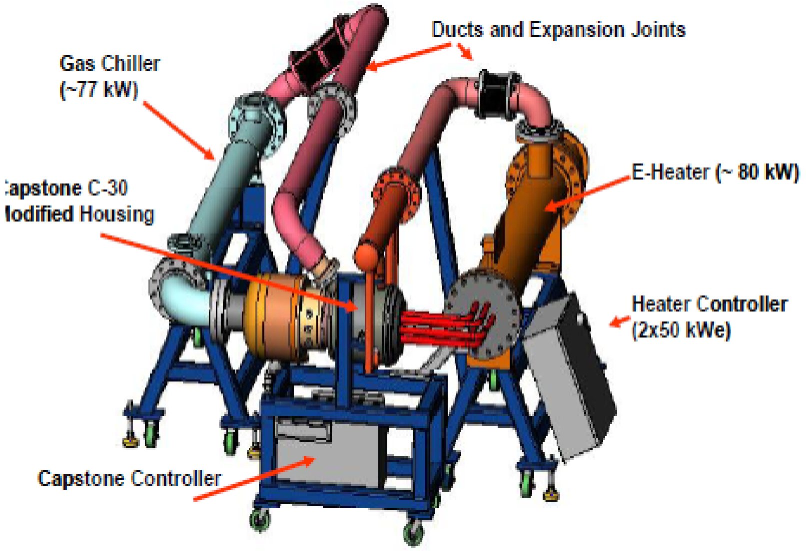
37 Heat Pipe Test Article Will Allow Us to Understand Heat Pipe to Heat Exchanger Interface



Assembly of Article is Underway





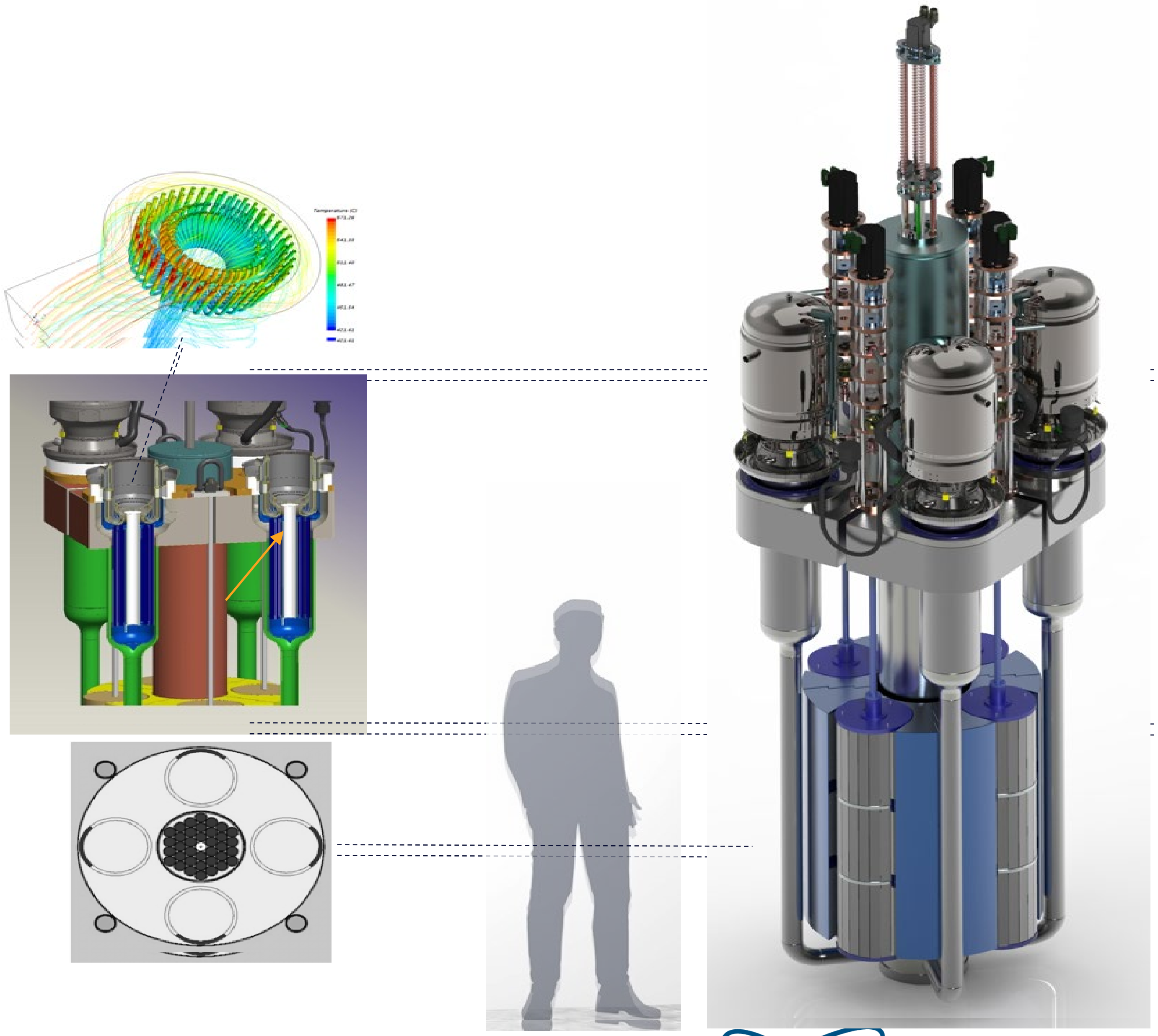
Modified Capstone C30 Power Conversion Unit

MRP Microreactor Program

Summary of FY-21

MARVEL FY 2021

- PCAT Fabrication
- Preliminary Safety Analyses
- Detailed Design for long lead procurement
- Fuel Fabrication Process Finalization

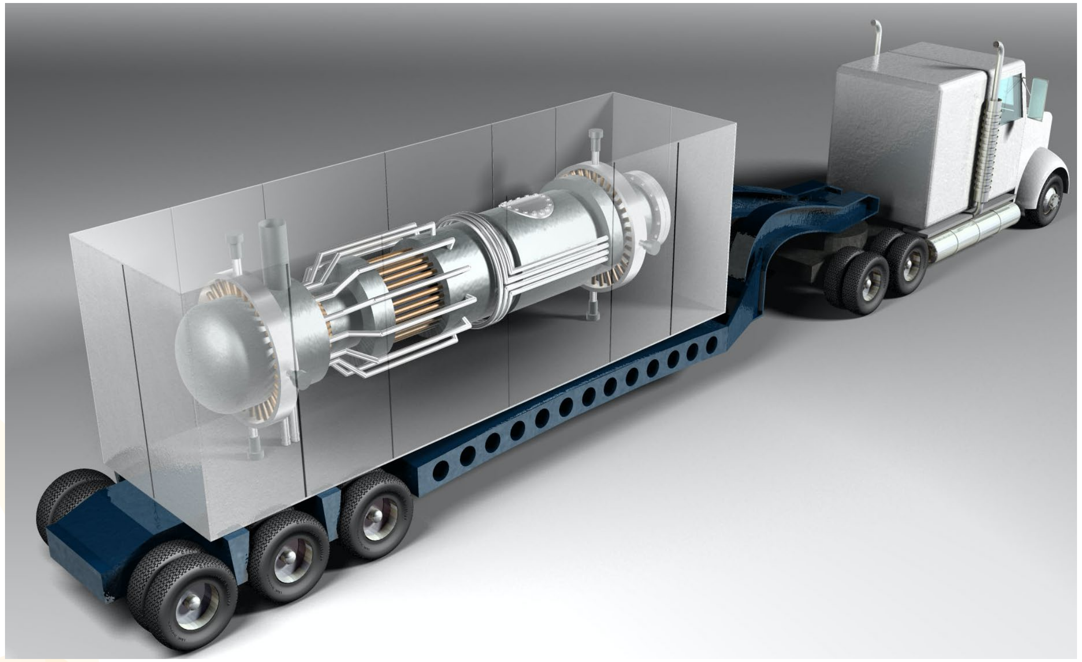


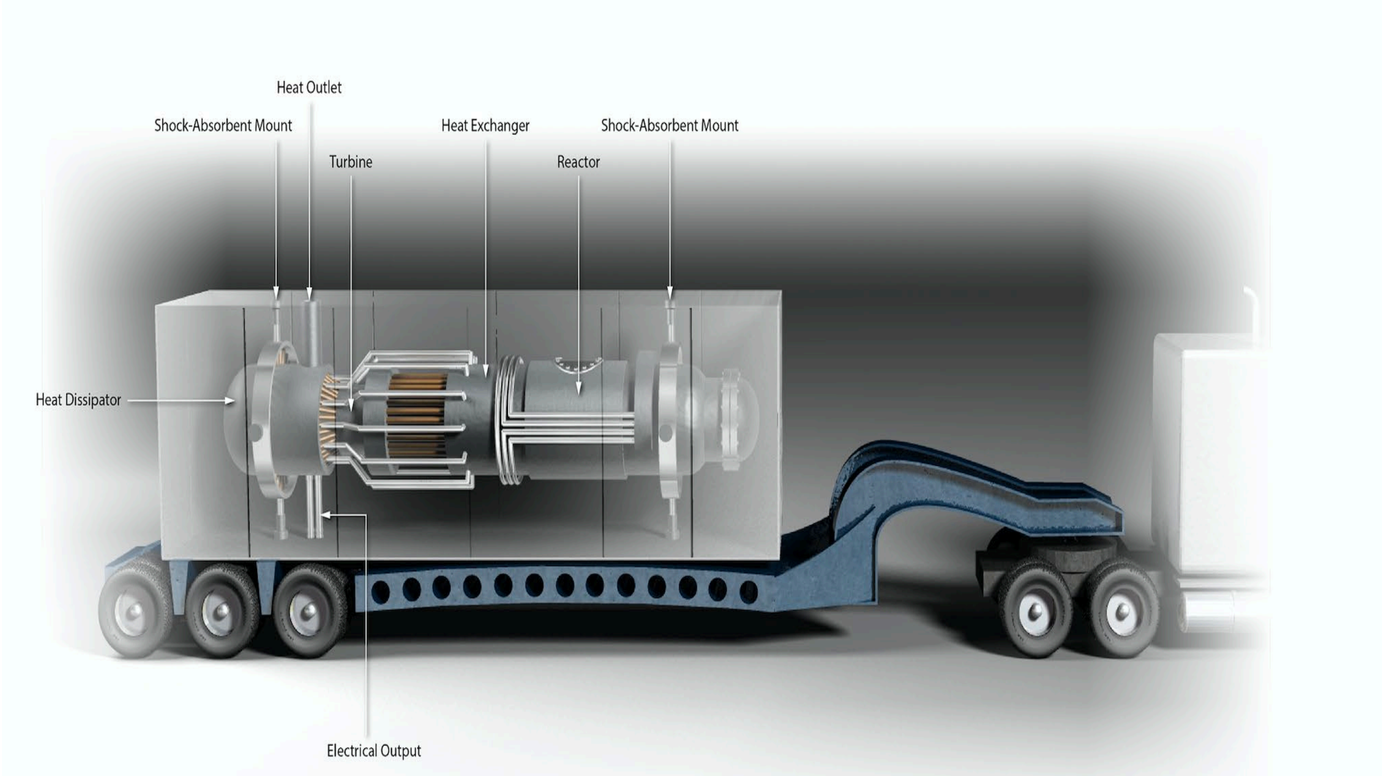
MRP Microreactor Program

Potential Areas Where Industry Can Leverage SPHERE and MAGNET (Non-Nuclear Test Bed)

- Heat Pipe Thermal Performance
  - Startup and Shutdown
- Studying Cascading Failure and Its Effect
- High Temperature and Pressure Testing
  - Prototype microreactor design testing
  - Component Testing
- Instrumentation and Control
  - Advanced Manufactured Test Articles
  - Advanced Manufacturing Sensor Development
- Verification and Validation
  - Concepts with low TRL levels for better understanding
  - Addressing Technical Gaps and Data Requirement
- Interface and Coupling Different Systems
  - Heat Exchanger
  - PCU Integration
- Safety Basis
  - Design Margins

MRP Microreactor Program





MRP Technical Lead: Piyush.Sabharwall@inl.gov

Credit & Acknowledgement

Idaho National Laboratory

Los Alamos National Laboratory EST. 1943

Oak Ridge National Laboratory

Argonne National Laboratory