Microreactor Program FY2022

Winter Program Review – March 3-4th, 2022

John Jackson, Ph.D.
National Technical Director

Meeting Objectives

- Primary purpose for the meeting is to review mid-year progress and focus on known and potential issues for FY22
- Introduce changes to the program
- Hear from developers and other stakeholders
- This is a self assessment so it’s “open season” for any suggested changes/updates

Instructions for Presentations

- Each Technical Area (TA) is provided time on agenda for discussion at the TA level and work package level
- Discussion should be focused on:
  - Progress made so far (Fiscal Year 2022)
  - Each FY22 milestone should be discussed with emphasis on any that may be facing issues or delayed
  - Connectivity with FY2023
- Each Technical Area Lead (TAL) will lead a session focused on their TA and related NEUP projects
- Presenters will adhere to their time slot

MRP Microreactor Program

DOE Microreactor Program

Dr. John Jackson (INL), National Technical Director

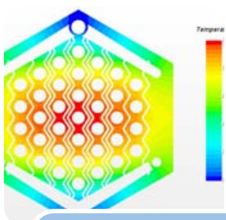
Program Vision

Through cross-cutting research and development and technology demonstration support, by 2025 the Microreactor Program will:

- Achieve technological breakthroughs for key features of microreactors
- Empower initial demonstration of the next advanced reactor in the US
- Enable successful demonstrations of multiple domestic commercial microreactors.

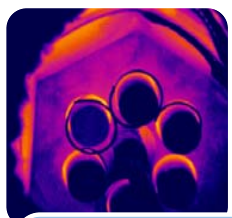
Program Objectives

- Address critical cross cutting R&D needs that require unique laboratory/university capability or expertise
- Develop R&D infrastructure to support design, demonstration, regulatory issue resolution, and M&S code validation
- Develop advanced technologies that enable improvements in microreactor viability



System Integration & Analyses

- Economics & Market Analysis
- Integrated Systems Analysis
- Applications of NEAMS Computational Tools
- Technoeconomic Analyses
- Regulatory Development



Technology Maturation

- Advanced Heat Pipes
- Advanced Moderators
- Heat Exchangers
- Instrumentation & Sensors
- Advanced Materials and Material Code cases

Demonstration Support Capabilities

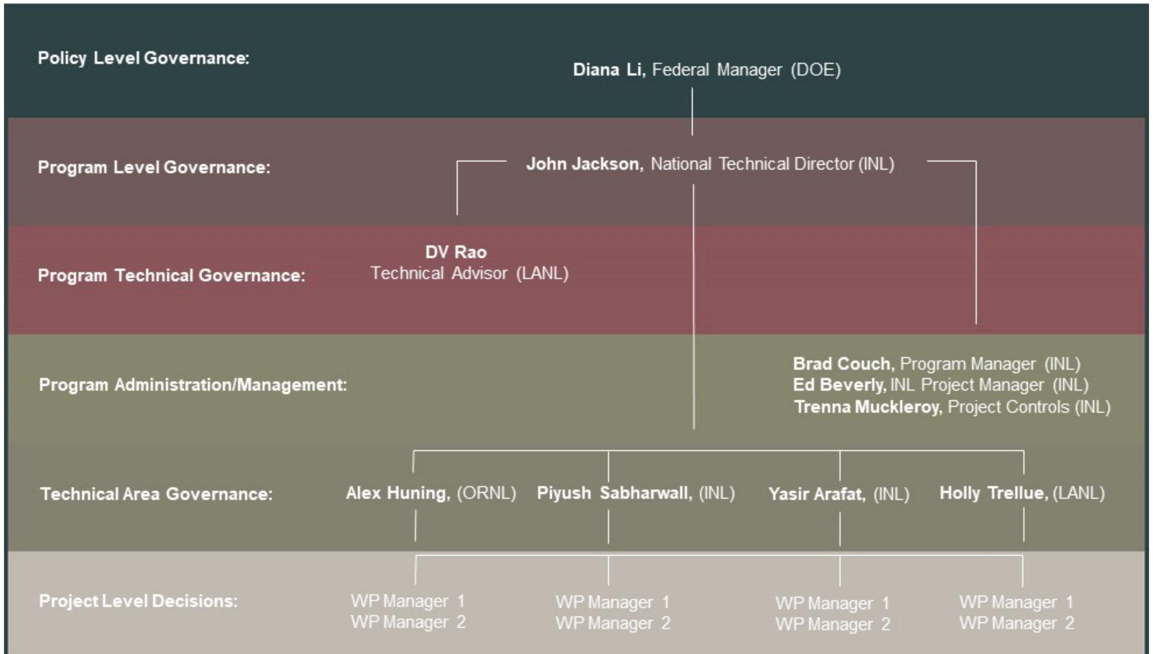
- Single Primary Heat Extraction & Removal Emulator (SPHERE)
- Microreactor Agile Non-nuclear Experimental Testbed (MAGNET)
- Primary Coolant Apparatus Test (PCAT)
- Validation of NEAMS tools

Microreactor Application

- Applied R&D
- Microreactor Applications Research, Validation and Evaluation (MARVEL)

MRP Microreactor Program

Current Microreactor Program Org Chart



Key program roles and responsibilities shown in the organization structure are defined below:

DOE Federal Manager – Provides program direction, guidance, and priorities through coordination with NE senior leadership, Congressional direction, other federal program managers, other relevant federal agencies, and program NTD.

National Technical Director (NTD) – Provides overall technical leadership of the program by performing program planning, directing technical work through the Technical Area Leads, reviewing work performed, and communicating with key stakeholders and other program directors.

Technical Area Leads (TALs) – Provides leadership over a specific technical program scope area (see Program Scope section), supports program planning, provides technical direction and oversight to work package managers in their technical area, and reviews work performed.

Work Package Managers (WPM) – Leads and performs a specific technical work scope in support of program milestones and objectives. Provides oversight on work being performed within their work package and is responsible for delivery of assigned milestones within their work scope.

MRP Microreactor Program

Microreactor Program FY22 Budget scenarios

Microreactor R&D	FY22 Planned Target	FY22 Over Target
Project Management	$550K	$550K
Directed Research	$2,769K	$8,070K
Total	**$3,322K**	**$8,620K**

MARVEL	FY22 Planned Target	FY22 Over Target
Project Management	$1,145K	$1,145K
Directed Research	$4,557K	$7,355K
Total	**$5,702K**	**$8,500K**

Preliminary FY22 Program Outcomes

1) Complete MARVEL design and initiate procurement of fuel and major components
2) Perform testing on MARVEL Primary Coolant Apparatus Test
3) Complete MARVEL Preliminary Safety Analysis Report
4) Complete YH PIE and investigate other advanced moderator technologies (e.g. encapsulation)
5) Complete initial integrated YH handbook with both TCR and MRP data (including all PIE).
6) Complete legacy metallic fuel data qualification
7) Complete assembly of the 37 heat pipe microreactor test article.
8) Complete MAGNET procurements and modifications to enable power cycle testing such as 37 heat pipe test article
9) Embed structural health monitoring equipment into a test object during fabrication and evaluate results
10) Support NRIC He-CTF modifications to MAGNET and conceptualize high temp/high pressure (~9 MPa) SPHERE adaptation
11) Guidance for manufacturing license and recommendations to NRC
12) Investigate appropriate automation in MR control systems for inherent safety using MAGNET and with an eye toward MARVEL

MRP Microreactor Program

US Microreactor Concepts Under Development

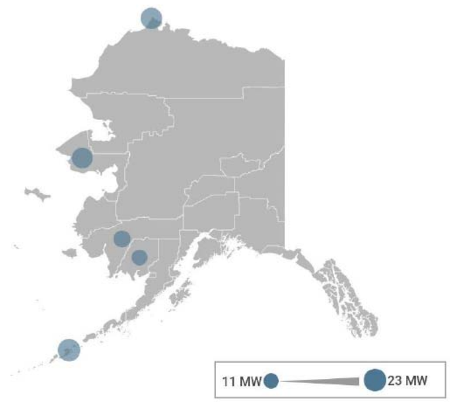
- Concepts that we're aware of:

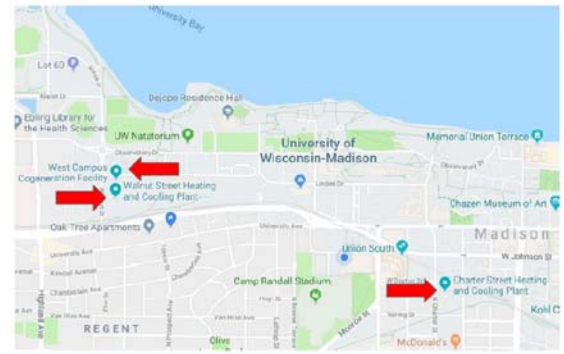
Developer	Name	Type	Power Output (MWe/MWth)	Fuel	Coolant	moderator	refueling interval
Alpha Tech Research Corp	ARC Nuclear Generator	MSR	12 MWe	LEU	Flouride salt	YH	
BWXT	BANR	HTGR	17 MWe/50 MWth	TRISO	Helium	graphite	5 years
General Atomics	GA Micro	HTGR	1-10 MWe		gas		
HolosGen	HolosQuad	HTGR	13 MWe	TRISO	Helium/CO2		10 years
Micro Nuclear, LLC	Micro Scale Nuclear Battery	MSR/heat pipe	10 MWe	UF4	FLiBe		10 years
NuGen, LLC	NuGen Engine	HTGR	2-4 MWe	TRISO	Helium		
NuScale Power	NuScale Microreactor	LMTM/heat pipe	<20 MWe	metallic	Liquid Metal	Liquid Metal	10 years
Oklo	Aurora	SFR/heat pipe	1.5 MWe	metallic	Sodium		10+ years
Radiant Nuclear	Kaleidos Battery	HTGR	1.2 MWe	TRISO	Helium	graphite	4-6 years
Ultra Safe Nuclear	MicroModular Reactor	HTGR	5 MWe/15 MWth	TRISO	Helium	graphite	20 years
Westinghouse	eVINCI	heat pipe	1 - 5 MWe	TRISO	Sodium	graphite	3+ years
X-Energy	Xe-Mobile	HTGR	7.4 MWe/20 MWth	TRISO (PB)	Helium	graphite	

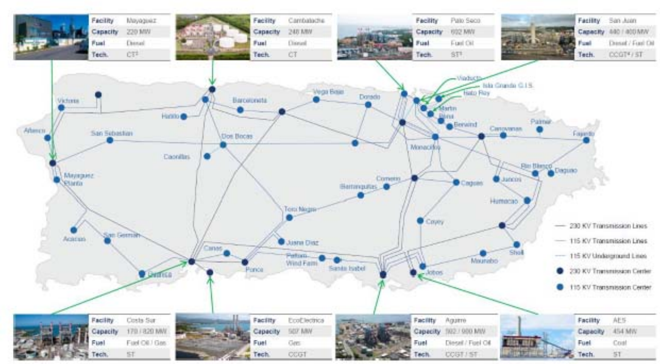
MRP Microreactor Program

Microreactor Economic Analysis - Overview

- Scope overview. This work supports the understanding of the market and economic potential for microreactors in the U.S. and internationally.
- Why? Economic Performance and Market Analysis provides a techno-economic basis for support to industrial microreactor deployment and operation.
- How? Three studies managed by INL were independently conducted
  - U Alaska-Anchorage, U Wisconsin-Madison, and the Nuclear Alternatives Project in Puerto Rico.
  - INL summarized 3 studies and added international perspective in global market report. https://www.osti.gov/biblio/1806274







MRP Microreactor Program

FY22 Activities: Manufacturing Licenses and Transportation

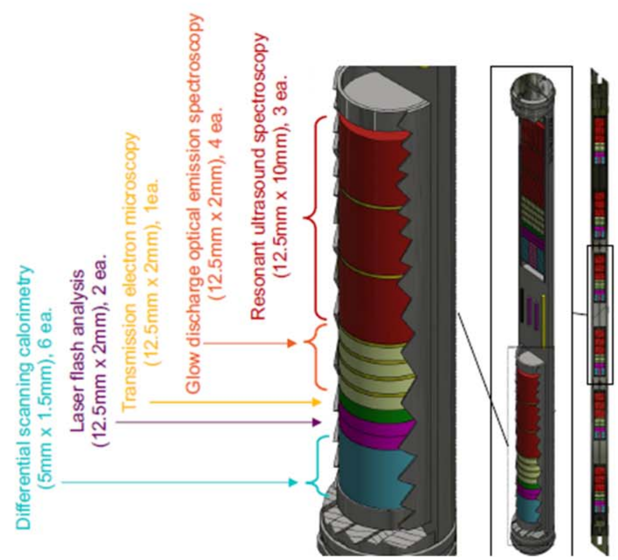
- Some microreactor vendors have stated the desire to construct their entire reactor in a factory setting under a manufacturing license (some including factory fueling)
  - Reduces complexity of on-site assembly and construction
  - These microreactors would then be shipped (fueled or unfueled) to an operating site licensed under 10CFR Part 50/52/53
- Currently, the draft regulation for 10CFR Part 53 Subpart E addresses traditional manufacturing licenses but does not address Part 70 (SNM possession and use), Part 71 (transportation), or Part 72 (spent fuel storage)
- NEI White Paper from July 2021 provided recommendations to NRC staff on how to address these needs
- INL report (due February 2022) will provide a recommendation from INL/ORNL staff on how to address these needs
  - INL/ORNL staff will then draft a report (due September 2022) that discusses and provides recommendations for transportation of a fueled or unfueled microreactor from the factory to the operational site

MRP Microreactor Program

DOE-NE Microreactor Technology Maturation

- Main focus of FY22 work is:
  - High Temperature Moderator Material (yttrium hydride)
    - Post irradiation examination (PIE) of samples irradiated in the Advanced Test Reactor (ATR) – see picture to right for PIE starting soon.
    - Hydrogen diffusion analyses using neutron imaging
  - Fabrication of a Heat Pipe Test Article for non nuclear testing at MAGNET
- Instrumentation and Sensors for testing at MAGNET

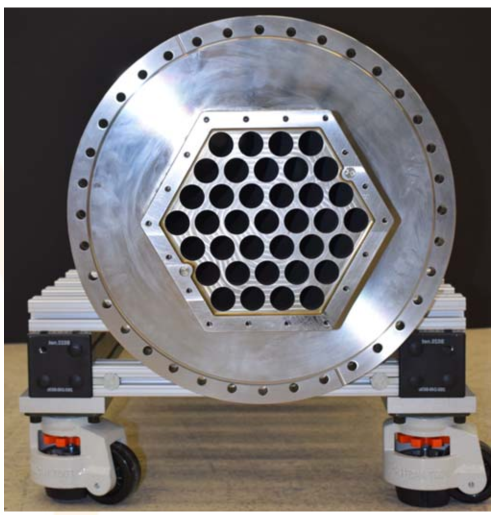
Neutron radiography of irradiated YH

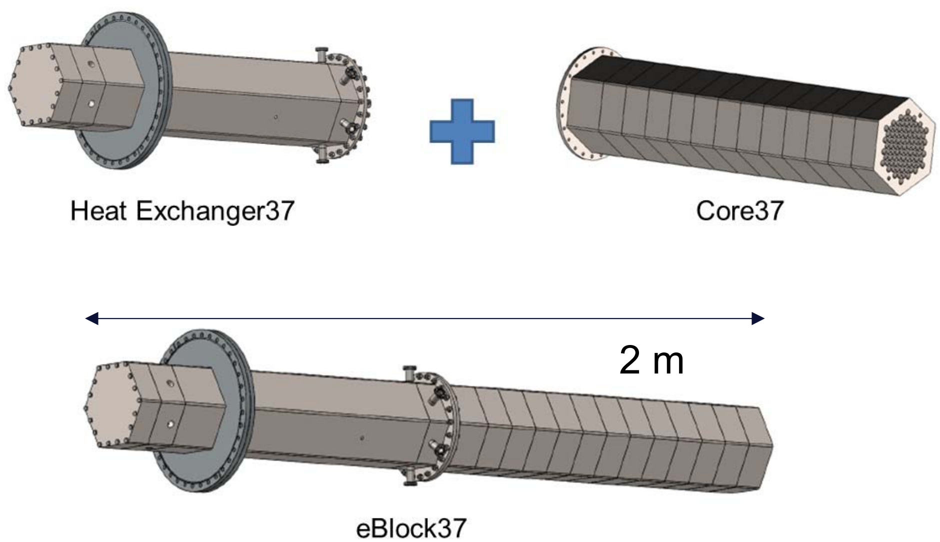


- Most important:
  - Hydrogen stability with temperature and fluence.
  - General integrity of samples.
- Determine thermophysical/ mechanical properties
  - Swelling
  - Elastic properties
  - Heat capacity
  - Thermal diffusivity
  - Microstructure
  - Thermal expansion
  - Hardness

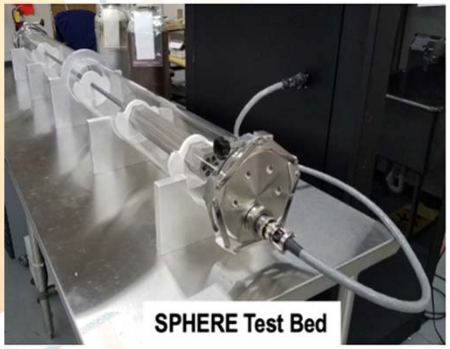
37 Heat Pipe Test Article

- 91 holes: 37 of these holes house sodium heat pipes linked to a heat exchanger; 54 holes are intended for electrical cartridge heater installation. Three-inch sections are still in the process of being joined (see picture to right where they are assembled on a cart).
- Heat exchanger consists of a main body containing holes through which the heat pipe array passes (see picture to left).
- High fidelity wicks in heat pipe array will be filled with sodium in the latter part of 2022.

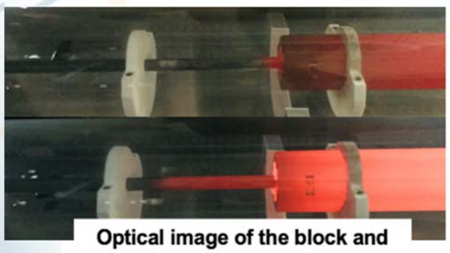




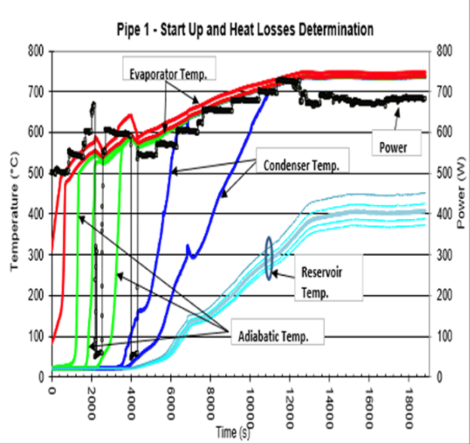
Single Primary Heat Extraction and Removal Emulator (SPHERE)



SPHERE Test Bed



Optical image of the block and heat pipe operation



Objectives

- 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**
- **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

Key Accomplishments

- SPHERE Initial Startup and Operation
- Complete Engineering Design of Gap Conductance Test Article

In Progress

- Gap Conductance Testing for NRC
- Working for Industrial Partner on understanding the effect of orientation on heat pipe performance

Challenges

- Testbed chamber is inadequate for accessibility and assembly
- TC routing too tight
- Secondary test article creates additional complexity
- Contact resistances are significant source of model error

External Vendor Testing

- Evaluation of heat pipe performance for external microreactor vendor
- Heat pipe limit testing
- Compare vertical and horizontal performance

MRP Microreactor Program

Microreactor AGile Non-Nuclear Experimental Test Bed (MAGNET)

MRP Microreactor Program

- Completed construction in November 2020
- Pressurized, started, and slightly heated system in January of 2021 for ASME B31.3 pressure testing
- A change in Engineer of Record for design and construction resulted in removal of insulation from all joints for a new B31.3 pressure test
- Final pressure testing of reworked section of piping

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, N_2)
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

Objective

- General-purpose, non-nuclear microreactor test bed
- Thermal-hydraulic and materials performance data for design performance verification and analytical model validation (V&V)
- Expandable design with capability to demonstrate an integrated power conversion unit (PCU)
- Advanced sensors identification, development, and testing for potential autonomous operation

Lessons Learned

- System design in parallel with equipment procurement presents challenges
  - General arrangement drawings sometimes differ from final fabrication drawings
- Include instrumentation and control (I&C) in scope of construction
  - Allows installation contractor to perform complete system commissioning and turn over a fully operational system to INL
- Installation discrepancies with construction drawings resulted in significant re-work not communicated to project
- Near miss while starting up co-located system (thermal energy distribution system (TEDS)) resulted in changes to operations in facility

Thermal expansion loop added to this section

Microreactor Applications, Research, Validation, and Evaluation (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 Program: MRP Microreactor Program

- Create momentum, champion rapid technology maturation, and engage microreactor end-user companies.
- Develop and exercise capabilities to execute reactor demonstration and demonstrate integrated energy systems and non-electric applications.

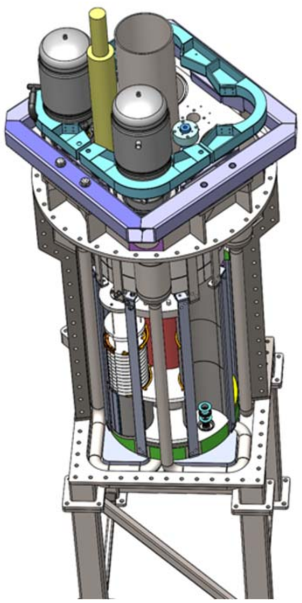
Images by ThirdWay

MARVEL Project Burndown = 1.5 yrs

MRP Microreactor Program

Major Accomplishments

- Completed Conceptual and Interim Design Reports
- Completed at least 7 separate effects tests to increase technology readiness levels
- Completed design, fabrication and assembly of full-scale electrically heated test system (aka PCAT). Next step is to complete installation and testing
- Completed safety analyses on expected performance on normal operation and postulated accident analyses
- All NEPA steps are complete, with final DOE approval of EA and FONSI.
- Completed Independent Interim Design Review
- Fuel Supplier selected



Next Steps

CY 2022
Site Prep,
Final Design,
Reactor Construction
PSAR

CY 2023
FSAR
Fuel Production
Fuel Load,
Criticality,
MARVEL Microgrid

MRP Microreactor Program

MARVEL is <u>on track </u>for construction completion within the next 12 months