Microreactor Program FY2023

Winter Program Review – March 8-9th, 2023

John Jackson, Ph.D.
National Technical Director

Meeting Logistics and Objectives

- Please mute your microphone and turn your camera off
  - Ask questions during Q&A by raising your hand or using chat during the discussion
  - Speakers will turn on their cameras
- Primary purpose for the meeting is to review mid-year progress and focus on known and potential issues for FY23
- Introduce changes to the program
- Share with developers and other stakeholders
- This is a self assessment so it's "open season" for any suggested changes/updates

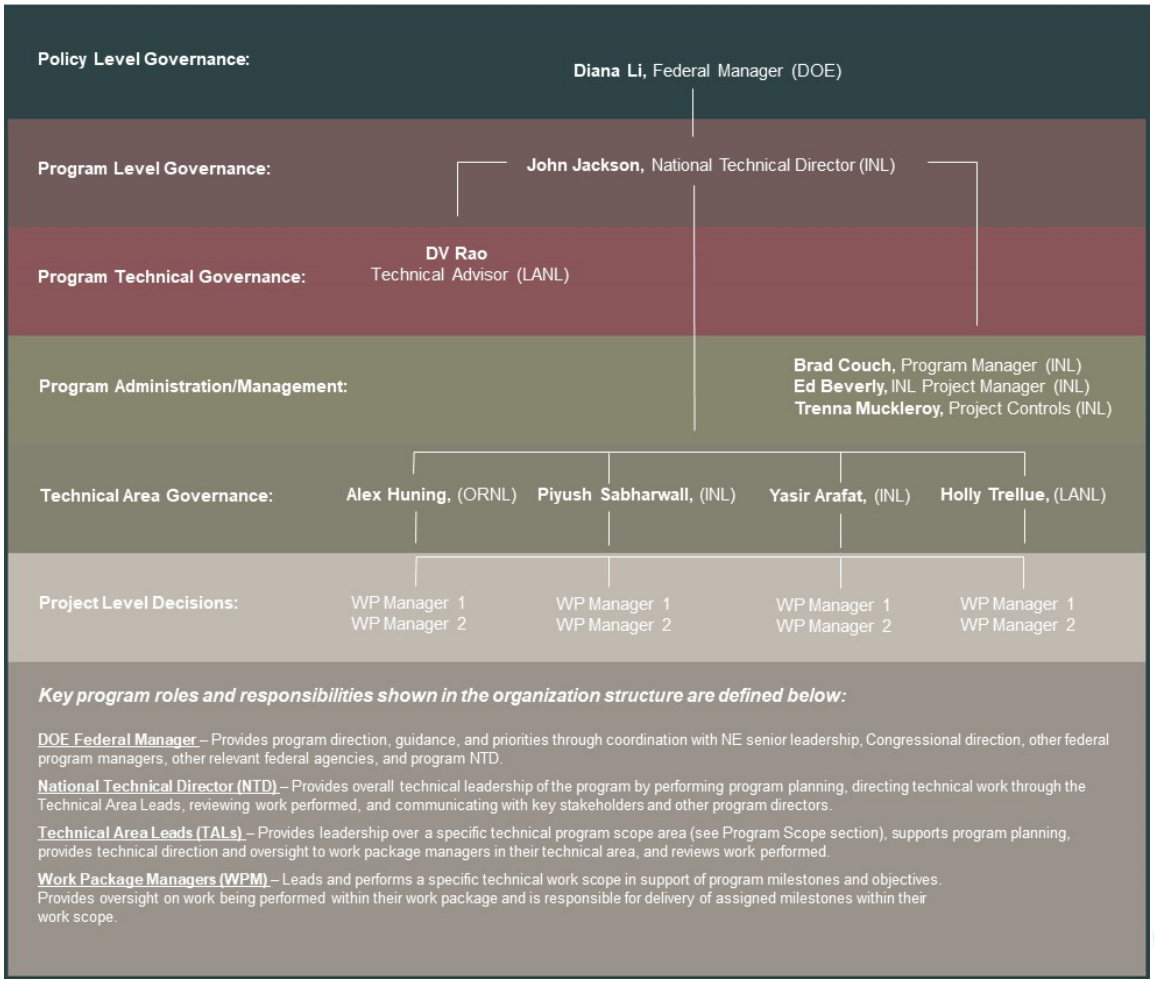
MRP Microreactor Program

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 2023)
  - Major FY23 milestones should be discussed with emphasis on any that may be facing issues or delayed
  - Connectivity with FY2024
- 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

Current Microreactor Program Org Chart



MRP Microreactor Program

DOE Microreactor Program – 2019-2022

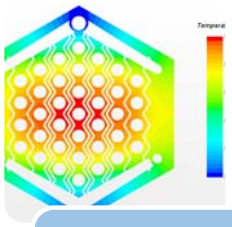
Program Vision

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

DOE Microreactor Program – 2023!

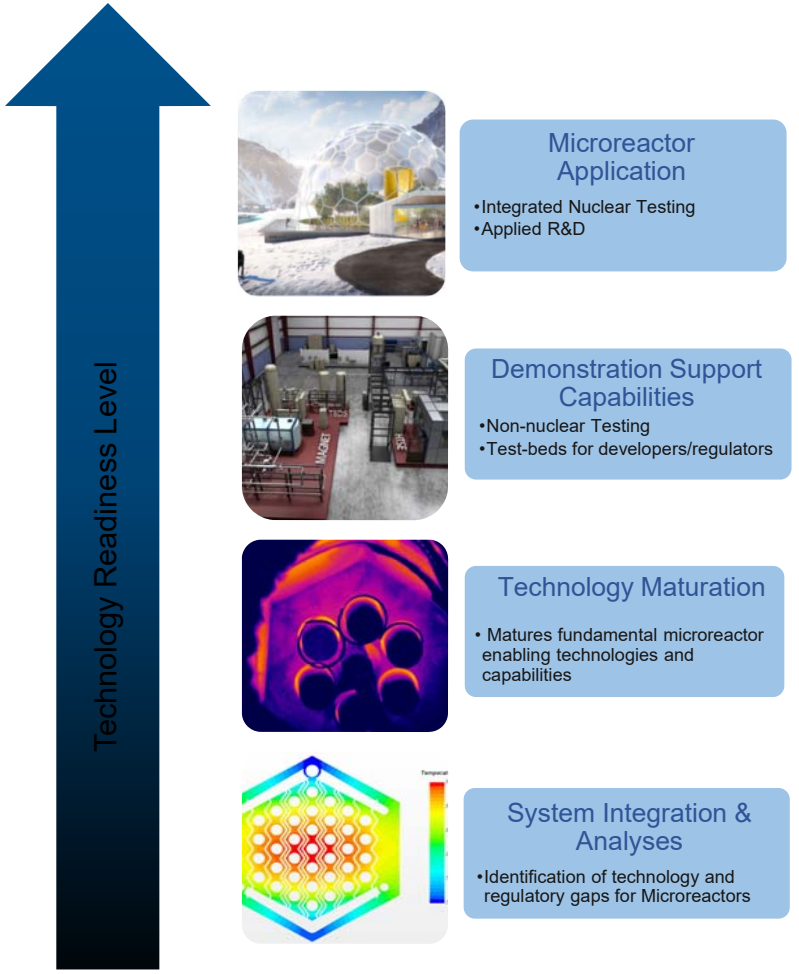
Program Vision

Through cross-cutting research and development and technology demonstration support, the Microreactor Program will enable broad deployment of microreactor technology by:

- Achieving technological breakthroughs for key features of microreactors
- Identifying and addressing technology solutions to improve the economic viability and licensing readiness of microreactors.
- Enabling 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



MRP Microreactor Program

Nuclear Energy University Program (NEUP)

- (Project 19-16802) Evaluation of Semi-Autonomous Passive Control Systems for HTGR Type Special Purpose Reactors – U of Michigan
- (Project 19-16980) Determining the Effects of Neutron Irradiation on the Structural Integrity of Additively Manufactured Heat Exchangers for Very Small Modular Reactor Applications – Auburn U
- (Project 19-17185) Demonstrating Reactor Autonomous Control Framework Using Graphite Exponential Pile – MIT
- (Project 19-17416) Experiments and computations to address the safety case of heat pipe failures in Special Purpose Reactors – U of Michigan
- (Project 20-19042) Flexible Siting Criteria and Staff Minimization for Micro-Reactors – MIT
- (Project 20-19693) Evaluation of micro-reactor requirements and performance in an existing well-characterized micro-grid – UIUC
- (Project 20-19735) Experiments for Modeling and Validation of Liquid-Metal Heat Pipe Simulation Tools for Micro-Reactor – Texas A&M
- (Project 21-24152) Direct heating of chemical catalysts for hydrogen and fertilizer production using Microreactors – Kansas State
- (Project 21-24226) Cost Reduction of Advanced Integration Heat Exchanger Technology for Micro-Reactors – U of Wisconsin
- (Project 22-26910) Demonstrating Autonomous Control, Remote Operation, and Human Factors for Microreactors Under Prototypic Conditions in PUR-1 – Purdue
- (Project 22-27123) Development of Hydrogen Transport Models for High Temperature Metal Hydride Moderators – CSM

MRP Microreactor Program

Microreactors
Megawatt-scale Advanced Nuclear Reactors

ENABLING TECHNOLOGIES

Fuel & Moderator

- Small Core,
- Long life,
- HALEU
- High-T Moderator

Reactor Controls

- Automation
- Compact, in-core sensors
- AI/ ML
- Remote Control

Power Conversion

- Skid mounted
- High Temp.
- Robust
- Flexible operation

Structural Material

- Creep resistance
- ASME Sec III, Div. 5 compliant
- NQA-1 supply chain

Neutron Reflector

- Low cost
- Manufacturability
- High moderating ratio
- High temperature

Transport & Siting

- NEPA
- Vibration isolation
- Transport shielding
- Licensing modernization

Input from microreactor developers (Westinghouse example)

- **MAGNET/SPHERE**
  - Planning and execution of testing (SPHERE and MAGNET) for code validation and electrical demonstrations
- **High-Temperature Moderator Materials**
  - Beryllium Oxide (BeO) Advanced Manufacturing Techniques for near-net shape consolidation and Improved Economics
  - Extend Yttrium Hydride Moderator Irradiation Testing
- **Integrated Modeling and Simulation of Microreactors**
  - Transient and Irradiation Testing of TRISO Fuel
  - Neutronics Benchmarking and Criticality Testing
  - TRISO Pd-SiC Interaction Margin Improvement
  - Microreactor and Heat Pipe Microreactor Startup Modeling
- **Licensing and Regulatory**
  - Safeguards Licensing Development
- **Heat Transfer and Power Conversion**
  - Mechanical Seals for High Temperature Helium Environment
- **Advanced Structural Material Manufacturing and Testing**
  - Graphite and Carbon-Carbon Composite Thermal Coupling Material

MRP Microreactor Program

Microreactor Program FY23 Budget scenarios

Microreactor base R&D	FY23 Planned Target	FY23 Over Target
Project Management	$700K	$750K
Directed Research	$4,600K	$8,250K
Total	**$5,300K**	**$9,000K**

MARVEL	FY23 Planned Target	FY23 Over Target
Project Management	$1,750K	$1,750K
Directed Research	$13,250K	$16,250K
Total	**$15,000K**	**$17,000K**

MRP Microreactor Program

FY23 Program Planned Outcome Highlights

1) Complete MARVEL final design and procure 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 MRP data (including all PIE from ATR exp).
6) Complete assembly of the 37 heat pipe microreactor test article.
7) Complete MAGNET design for Power Conversion Unit addition (air Brayton cycle)
8) Demonstrate use of Resonant Ultrasound Spectroscopy for detection of flaws
9) Design and initiate fabrication of a high temp, high pressure He component test capability
10) Investigate emergency planning for transportation of microreactors
11) Evaluate a framework for CRAB/MELCORE model for mechanistic source term
12) Demonstrate hardware in the loop interaction with digital twin for Microreactor Automatic Control system
13) Assess fuel system options for microreactors
14) Progress on structural materials – 316H SS and refractory metal mfg

MRP Microreactor Program

Microreactor Concepts Under Development in the U.S. (that we're aware of)

Developer	Name	Type	Power Output (MWe/MWth)	Fuel	Coolant	moderator	refueling interval	PCU
Alpha Tech Research Corp	ARC Nuclear Generator	MSR	12 Mwe/30 MWth	LEU	Flouride salt		intermittent	
BWXT	BANR	HTGR	17 MWe/50 MWth	TRISO	Helium	graphite	5 years	Brayton Cycle
General Atomics	GA Micro	HTGR	1-10 MWe		gas			?
HolosGen	HolosQuad	HTGR	13 MWe	TRISO	Helium/CO2		10 years	Brayton Cycle
Micro Nuclear, LLC	Micro Scale Nuclear Battery	MSR/heat pipe	10 MWe	UF4	FLiBe	YH	10 years	
Nano Nuclear	Zeus	FR/HTGR	1.0 MWe/2.5 MWth	UO2	Helium			Brayton Cycle
NuGen, LLC	NuGen Engine	HTGR	2-4 MWe	TRISO	Helium			Integral direct cycle
NuScale Power	NuScale Microreactor	LMTM/heat pipe	<10 MWe	metallic	Liquid Metal	Liquid Metal	10 years	TPV
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	Rankine
Westinghouse	eVINCI	heat pipe	5 MWe/15 MWth	TRISO	Sodium	graphite	8 years	Brayton Cycle
X-Energy	Xe-Mobile	HTGR	7.4 MWe/20 MWth	TRISO	Helium	graphite	3 years	Brayton Cycle

MRP Microreactor Program

MARVEL Can Enable a New Class of Nuclear Reactors

(Microreactor Applications Research, Validation & EvaLuation)

Project Goals:

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

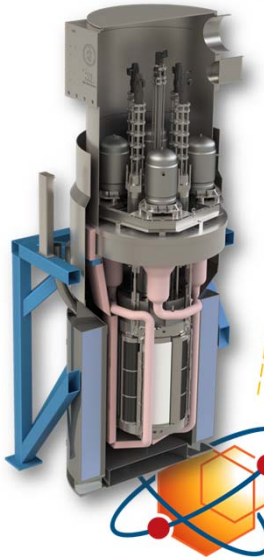
Primary Objectives:

- Operational microreactor in the most **accelerated timeline** possible
- Produce **combined heat and power (CHP)** to a functional **microgrid**
- **Share lessons learned** with commercial developers
- **Train** future operators

U.S. DOE Sponsor Program:

MRP Microreactor Program

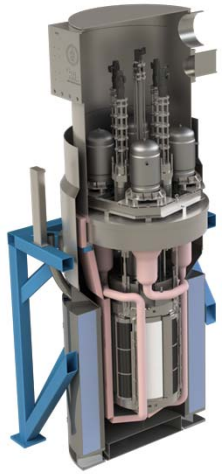
Create momentum,
Champion rapid technology maturation to de-risk industry
Collaborate and engage microreactor end-user companies

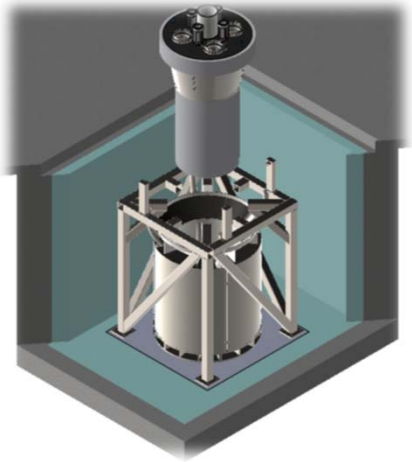


- 100 kW-thermal
- 20 kW-electric
- ~10 feet tall
- < 12 tons
- 2 operators
- Self-regulating

MRP Microreactor Program

Opportunity- MARVEL Utilization





CY 23 CY 24 CY 25 CY 26

RX Construction

Readiness

ZP test

Electricity

?

Electricity + Heat

User tests

D&D

Where do you fit in?

How do you fit in?

MRP Microreactor Program