The DOE Microreactor Program

MARVEL Microreactor

2024 MARVEL Technology Review

March 7th, 2024

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DOE Microreactor Program

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

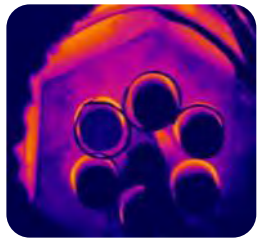
Technology Readiness Level

Microreactor Application

- Integrated Nuclear Testing
- Applied R&D

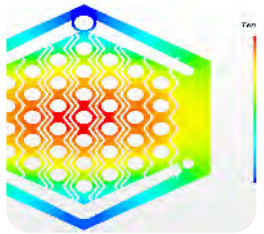
Demonstration Support Capabilities

- Non-nuclear Testing
- Test-beds for developers/regulators



Technology Maturation

- Matures fundamental microreactor enabling technologies and capabilities



System Integration & Analyses

- Identification of technology and regulatory gaps for Microreactors

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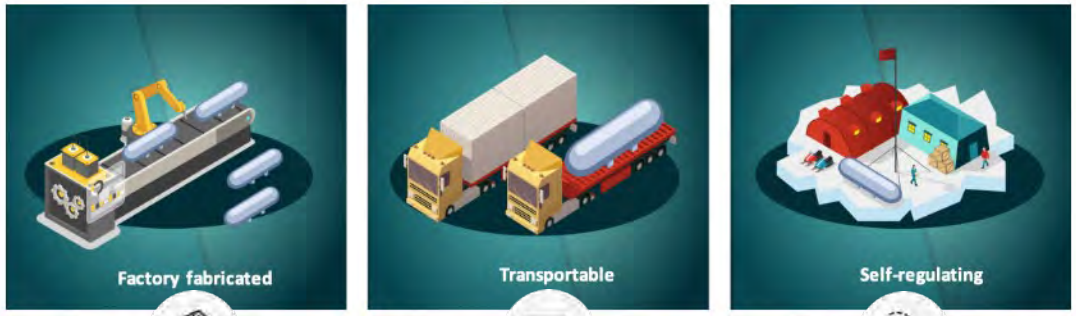
Microreactors
Megawatt-scale Advanced Nuclear Reactors



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

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
Aalo Atomics	Aalo One	STR	7 MWe/20MWth	U-Zr-H	Sodium	H	3-5 years	Steam Rankine
Alpha Tech Research Corp	ARC Nuclear Generator	MSR	12 Mwe/30 MWth	LEU	Flouride salt		intermittent	
Antares Industries		Heat Pipe	1.2 MWth		sodium	graphite		Brayton Cycle
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/Odin	HTGR/MSR	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	15 MWe	metallic (U-Zr)	Sodium		10+ years	Steam Rankine
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	5 MWe/10 MWth	TRISO	Helium	graphite	3+ years	Open air Brayton Cycle

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Demonstration Support - SPHERE and MAGNET testbeds

SPHERE - Single Primary Heat Extraction and Removal Emulator

- Single heat pipe coupled to forced convection cooling, surrounded by 6 electrical heaters
- Designed to quantify operational temperatures and heat rejection from of a single heat pipe
- Highly instrumented to measure temperature and strain distributions in a miniature monolithic core block

MAGNET – Microreactor AGile Non-nuclear Experimental Test Bed

- Engineering scale test bed for testing large sections of a monolithic core block with an array (e.g., 37) of heat pipes and electrical heaters
- Capable of testing advanced heat rejection systems or integral effects such as the potential for cascading failures of multiple heat pipes
- Helium component testing

Increasing complexity

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MARVEL Can Enable a New Class of Nuclear Reactors

(Microreactor Applications Research, Validation & EvaLuation)

Project Goals:

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

Primary Objectives:

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

U.S. DOE Sponsor Program:

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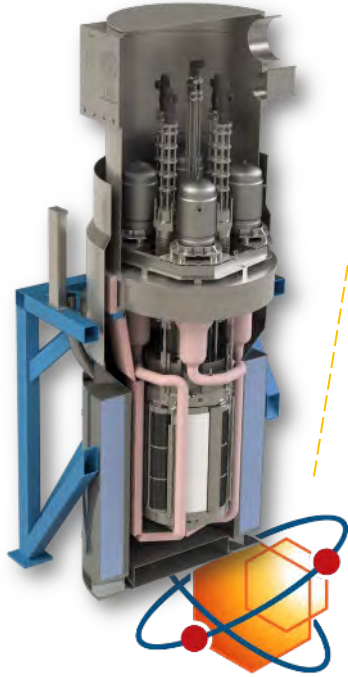
Create momentum,
Champion rapid technology maturation to de-risk industry
Collaborate and engage microreactor end-user companies



- 85 kW-thermal
- 20 kW-electric
- ~15 feet tall
- < 12 tons
- 2 operators
- Self-regulating

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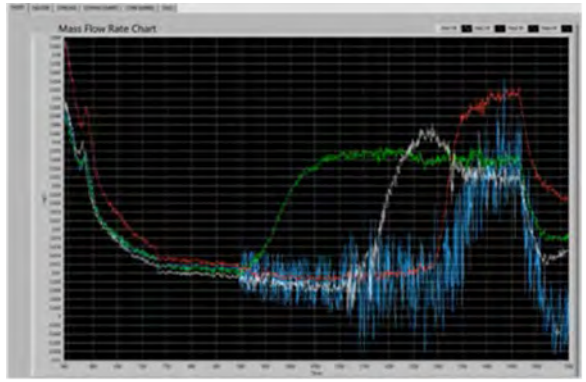
MARVEL Thermal Hydraulic Prototype

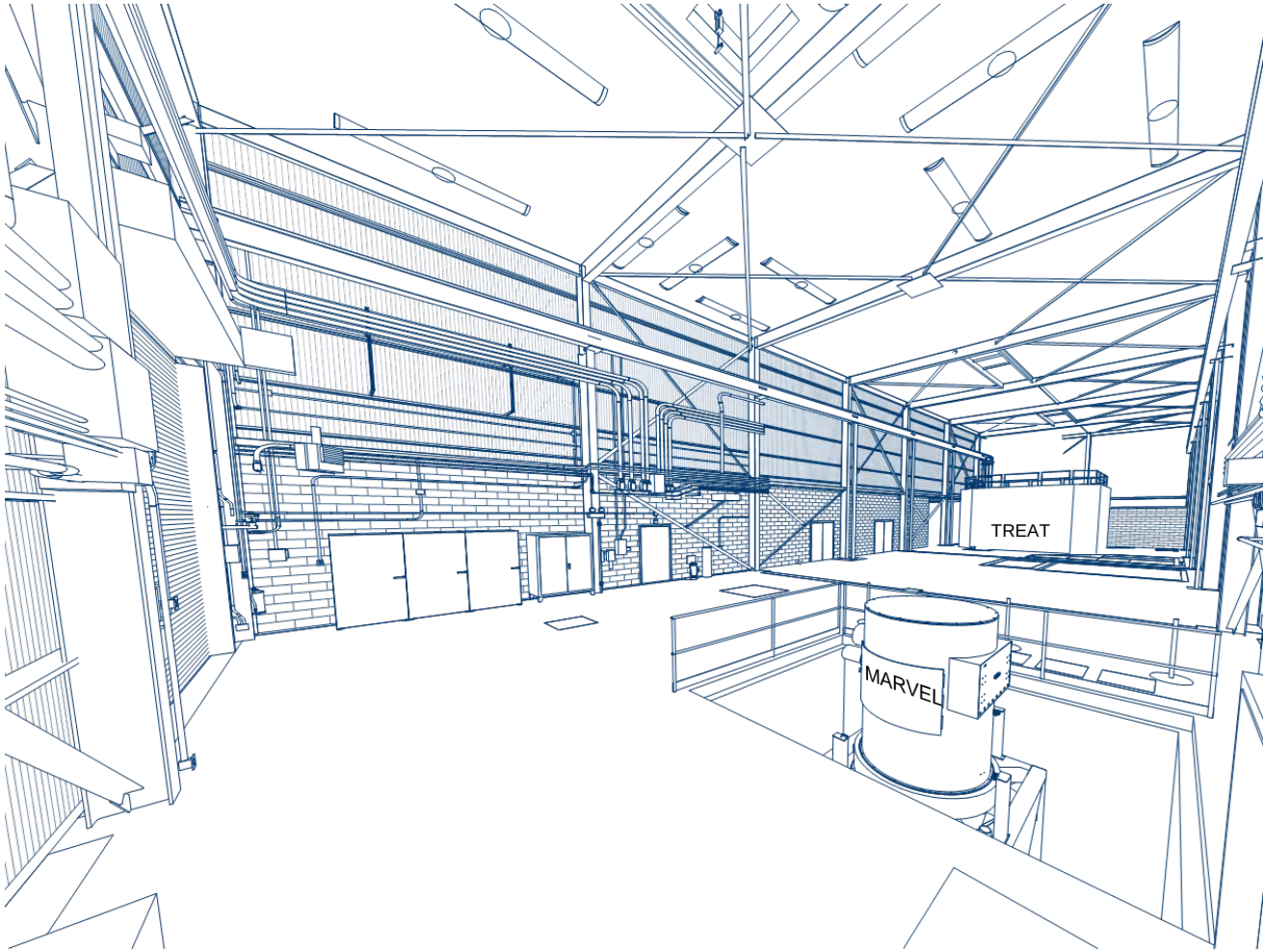
- Thermophysical twin of MARVEL
- Full-scale, electrically heated
- Data used to validate models, per NQA-1
- Initial startup on September 19th, 2023 with demonstration of natural circulation and power generation



NaK flow measurements through 4 loops

Initiation of MARVEL Fabrication Phase

- **Final Design Review (completed)**
  - Live Review- Sept 2022
  - 440+ comments received
  - Final comments resolution meeting, Aug 2023
  - **90% Design Completion, per DOE-STD-1189** September 29, 2023!
  - Release of 260+ documents
- **MARVEL officially in fabrication phase**
  - Purchased materials, Long Lead Procurement #1 (completed)
  - Fabrication, LLP#2 (initiated)
  - RCS, LLP#3 (initiated)



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MARVEL Value Statement for Public/End Users

- Nuclear Energy is new to microreactor entry market
  - Operation complexity
  - Fear of colocation
  - Training needs
  - Reliability
- Customers reluctant to adopt microreactor technology unless they “see one” first (not willing to be the first in their backyard)
- Having no real test reactor is a barrier to market entry
  - End users deem it necessary to “interact” with a microreactor prior to providing customer requirements
  - End users unsure of technology potential prior to interaction

MARVEL will be the first microreactor to achieve criticality to demonstrate end user applications

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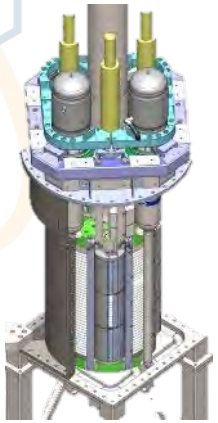
MARVEL Value Statement for Developers

OKLO | Westinghouse | BWXT (BWX Technologies, Inc.) | X-energy | RADIANT | GENERAL ATOMICS | LOCKHEED MARTIN



"With many companies working on microreactor concepts behind closed doors, I see unique value in having a system that can be shared and discussed across teams "

Fuel

Reactor Controls

NEPA

Fuel Loading

Power Conversion

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Net-Zero

Assets
By INL $$

IES

Assets
by Public $$

GAIN

Public-
Private $$

TBD

Private
Incubator $$

Industry

Private $$

TRL

Microreactor Developers

R&D by
Private $$

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R&D by
Public $$

NEUP

R&D by
Public $$

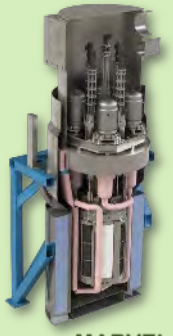
Renewables

Solar

Wind

Battery

Microreactor-Microgrid



MARVEL
reactor

Microgrid
Inverter

Electricity

HGHES

High grade
heat

Low grade
heat

Hydrogen

H2 electrolyzer

H2 storage

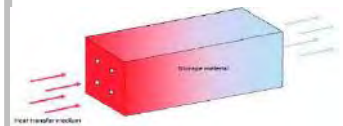
H2 generation
from heat

Generation

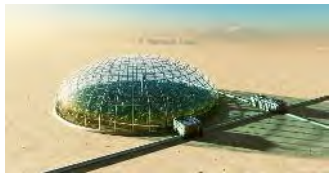
Electricity Users

Containerized
Supercomputer

Heat Users



Thermal
Storage



Bio dome

Consumption

Assets
By public $$

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Conceptual MARVEL utilization model

Questions?

https://gain.inl.gov/SitePages/MicroreactorProgram.aspx

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