The DOE Microreactor Program

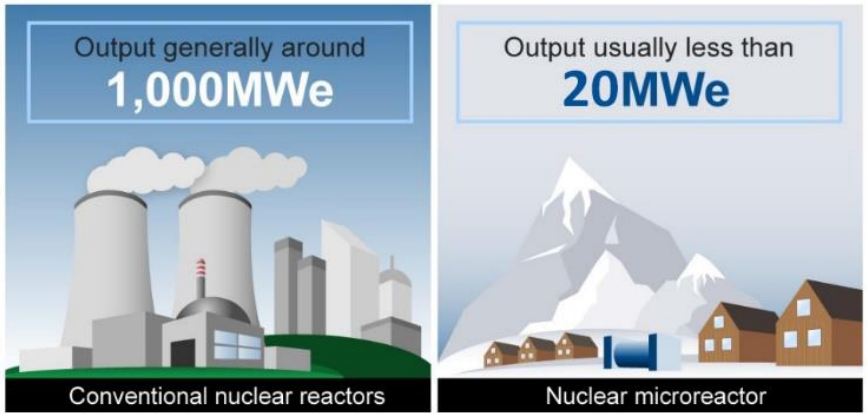
Technology development and demonstration

NSUF Workshop

May 20, 2024

Abdalla Abou-Jaoude, Ph.D.| MARVEL Testing & Experiment Interface

What are Microreactors?



Source: GAO. | GAO-20-380SP







- Much smaller and simpler than traditional nuclear power reactors.
- Technologies evolving from advances in materials, space reactor technologies, advanced nuclear fuels, and modeling & simulation.

- Minimum site preparation
- Flexible operation
- Enhanced safety
- Refueling (every 2-10 years)
- Operational lifetime: 5 – 20 years.

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

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	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	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	XENITH	HTGR	5 MWe/10 MWth	TRISO	Helium	graphite	3+ years	Open air Brayton Cycle

MRP Microreactor Program

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



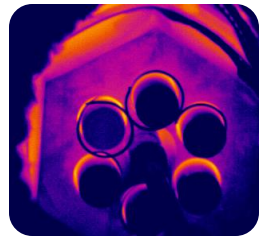
Microreactor Application

- Integrated Nuclear Testing
- Applied R&D



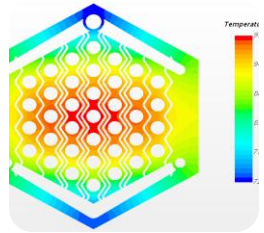
Demonstration Support Capabilities

- 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

MRP Microreactor Program

System Integration and Analysis

Research Area	Task	Description
Analysis Tools	Development of a CRAB/MELCOR framework	(1) perform an assessment of potential microreactor safety analysis scenarios and (2) investigate CRAB tools for the identified scenarios highlighting any potential development needs, coupling challenges between CRAB and MELCOR
Efficient Regulations	Emergency Planning for Transportation	Identify and describe challenges associated with microreactor emergency planning during transportation
Economic Viability	Emerging markets for microreactors	Assess barriers and opportunities for microreactors with an initial focus on Alaska (AK) and Wyoming (WY) energy markets
	Cost Efficient-by-Design Microreactors	Evaluate functional containment aspects for microreactors and how this could result in economic optimizations

Technology Maturation – structural health monitoring

Development of **acoustic monitoring** techniques that can be coupled with **embedded sensors** for **in-situ structural monitoring** of an inaccessible microreactor core block

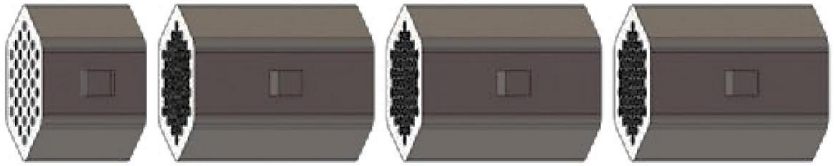
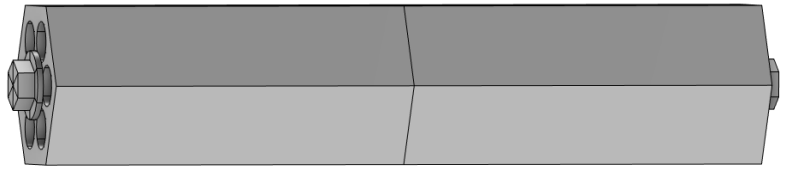


Diagram from LA-UR-20-20824

Goals

Demonstrate acoustic sensitivity to the **stress state** and **structural integrity** of joints between sections of a modular microreactor core-block-like object

- Use **nonlinear elasticity** to detect changes in material properties and joint integrity



- Apply **machine learning** to identify state-of-stress and the data features to prioritize in future embedded sensor deployments

MRP Microreactor Program

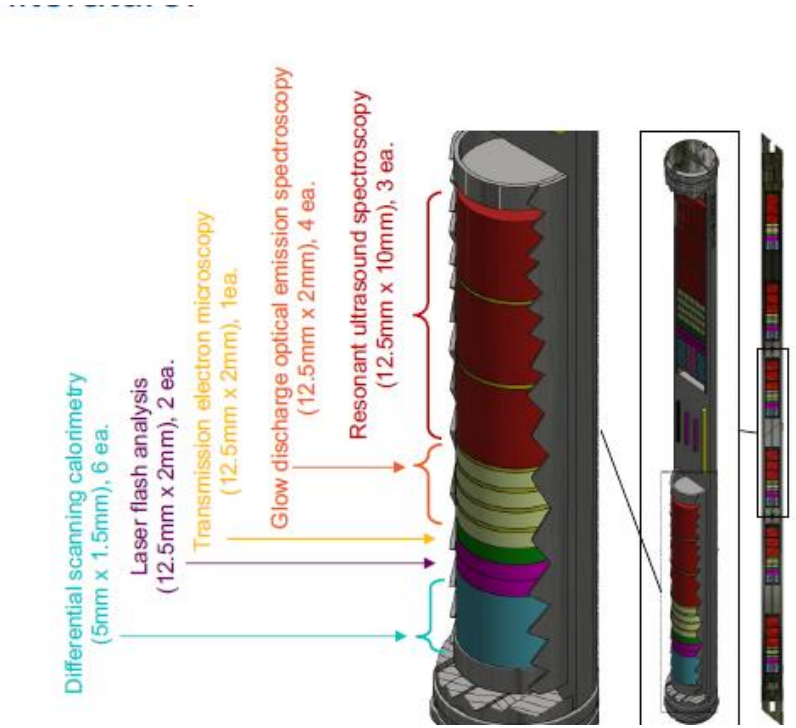
Technology Maturation – solid moderators



Yttrium hydride samples were irradiated in ATR

Neutron radiography of irradiated YH



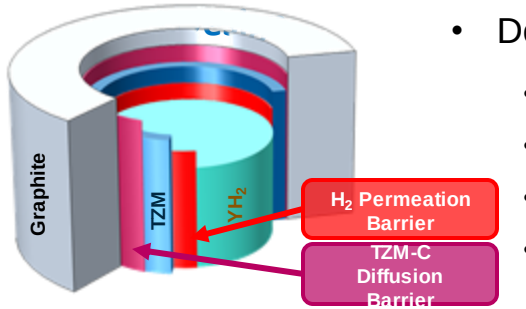


- Most important:
  - Hydrogen stability with temperature and fluence.
  - General integrity of samples.
- Determine thermophysical/ mechanical properties
  - Swelling
  - Elastic properties
  - Heat capacity
  - Thermal diffusivity
  - Microstructure
  - Thermal expansion
  - Hardness

MRP Microreactor Program

Technology Maturation – solid moderators (ANL)

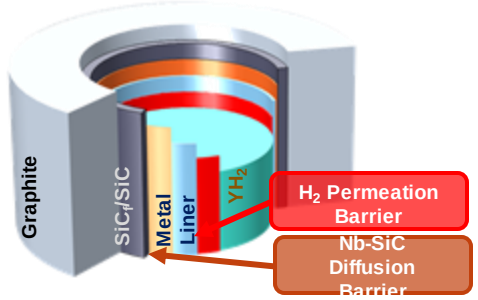
Current Moderator



Containment: TZM alloy

- Design of H_2 permeation barrier for TZM
  - Selection of **compatible materials (optimized)**
  - Permeation barrier **architecture (optimized)**
  - Resistant to H.T. **thermal cycling**
  - Resistant to **radiation damages**

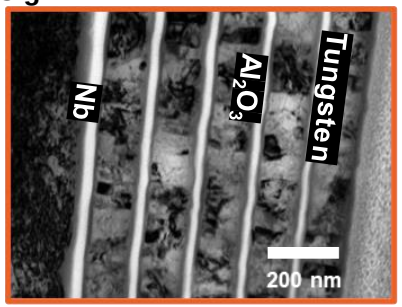
Advanced Moderator Design



Containment: Nb liner + SiC

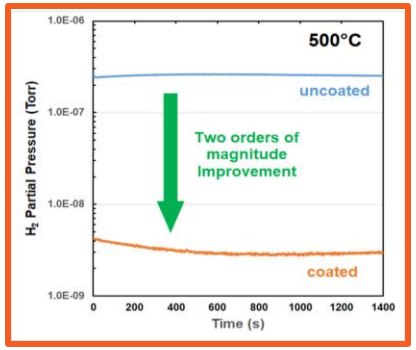
- Design & Development of tube coating technologies (*Primarily Internal tube surface*)
  - **Identification of parameters** to implement metal coating internally with plasma sputtering technique.
  - Verification of developed **film quality**

Based on our previous Barrier Design



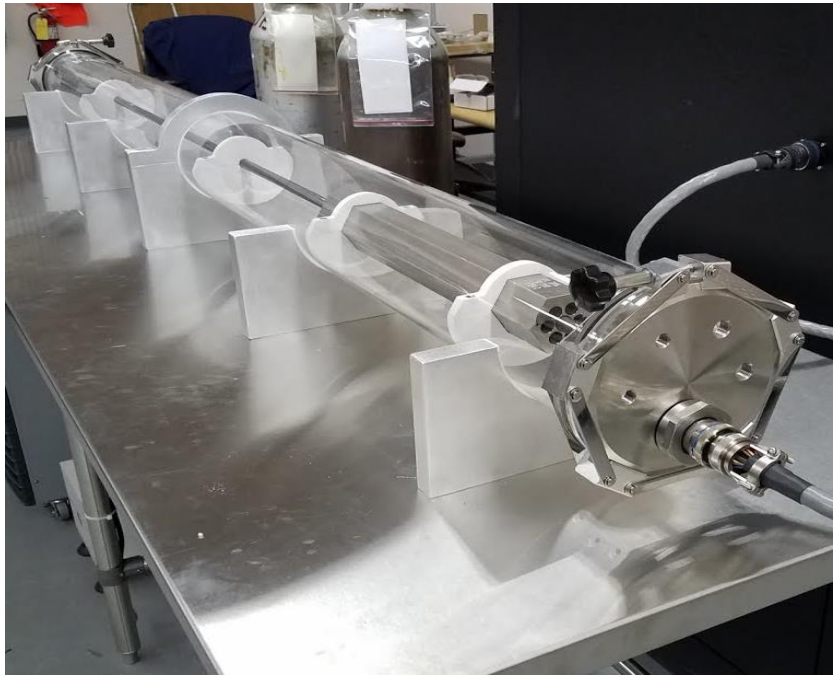
PVD/ALD technique

Significant reduction in H_2 Permeation



MRP Microreactor Program

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

MRP Microreactor Program

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:

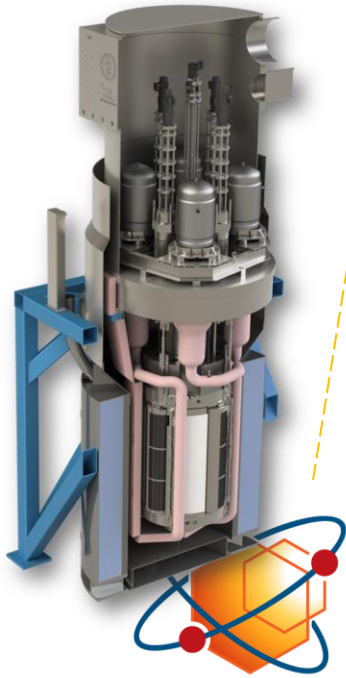
- **Operational** microreactor
- Produce **combined heat and power (CHP)** to a functional **microgrid**
- **Share lessons learned** with commercial developers
- **Train** future operators

U.S. DOE Sponsor Program:

MRP Microreactor Program

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



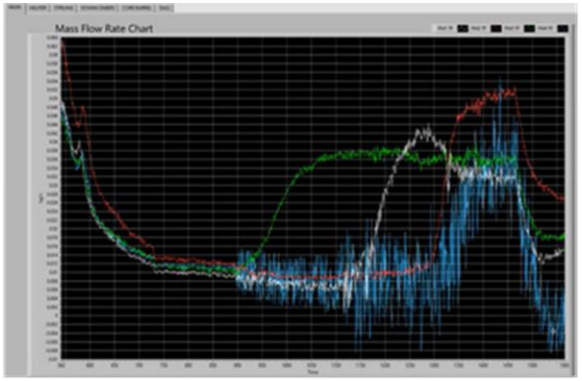


- 85 kW-thermal
- 20 kW-electric
- ~10 feet tall
- < 12 tons
- 2 operators
- Self-regulating

MRP Microreactor Program

MARVEL Thermal Hydraulic Prototype – PCAT

- 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

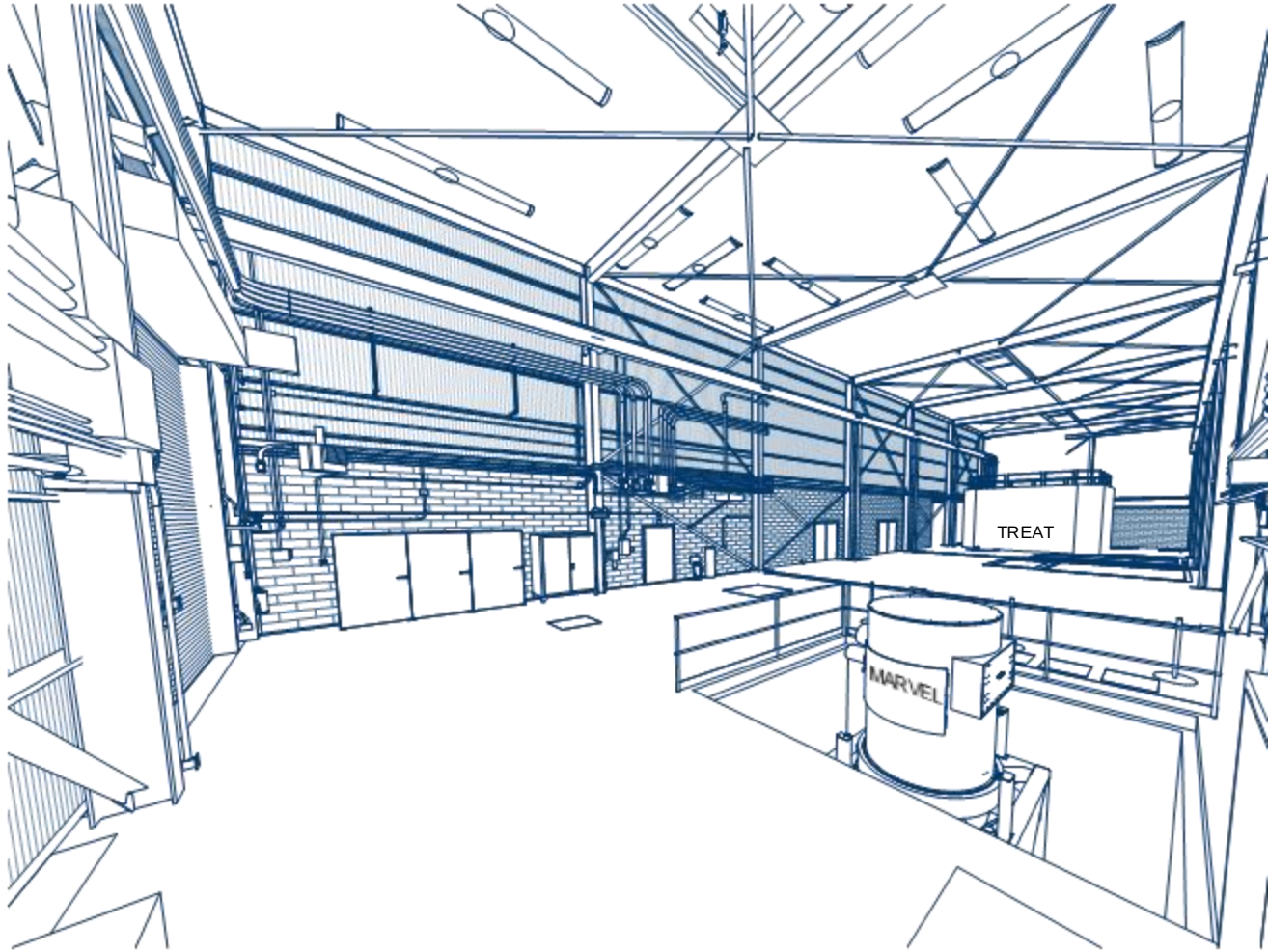


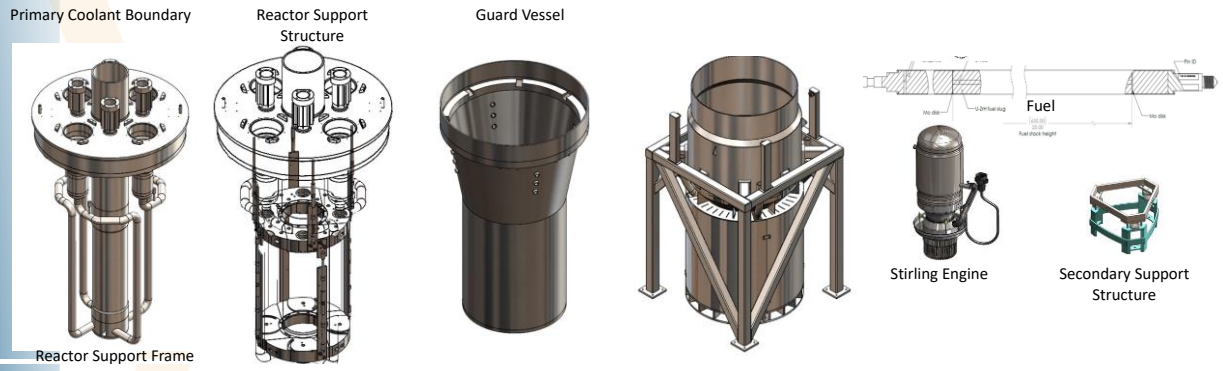
NaK flow measurements through 4 loops



Initiation of MARVEL Construction 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 construction phase**
  - Purchased materials, LLP#1 (completed)
  - Fabrication, LLP#2 (initiated)
  - RCS, LLP#3 (initiated)

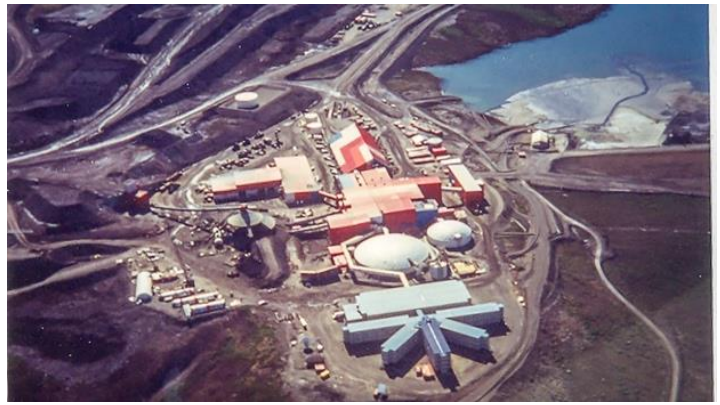




MRP Microreactor Program

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



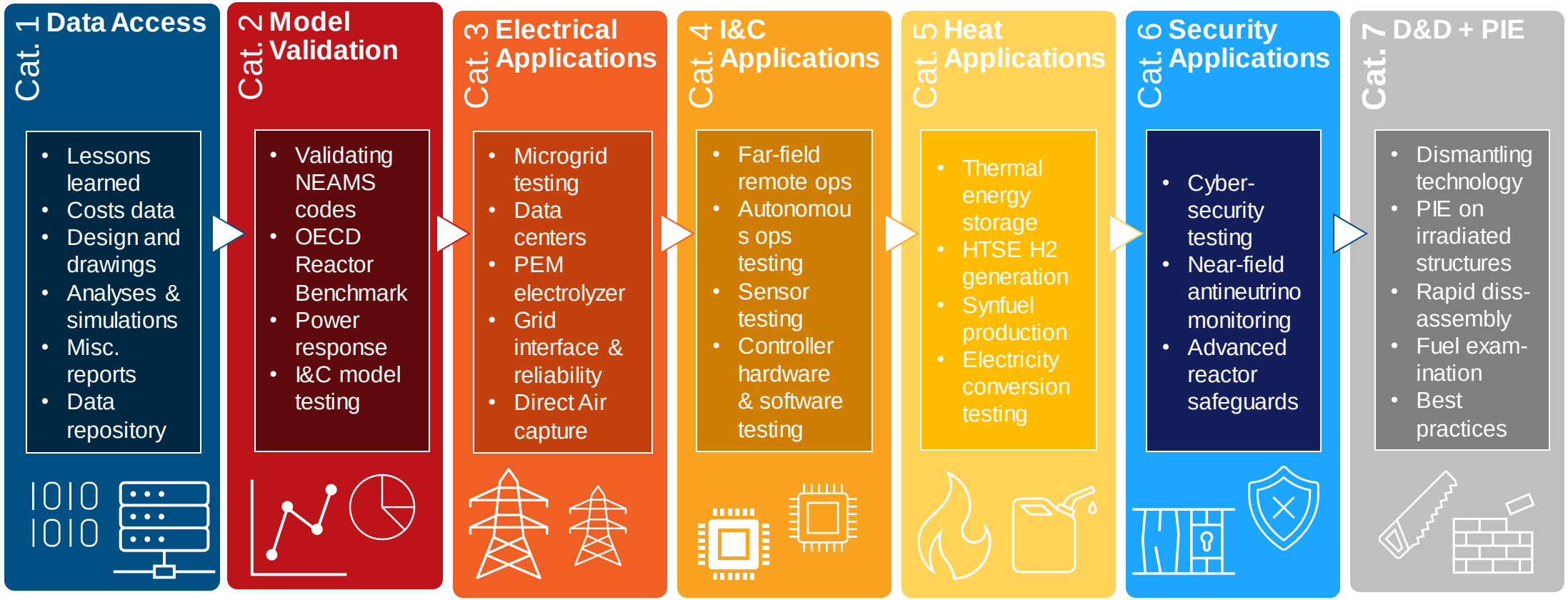


MARVEL will be the first microreactor to achieve criticality to power end user applications → Potential NEUP/NSUF Opportunity

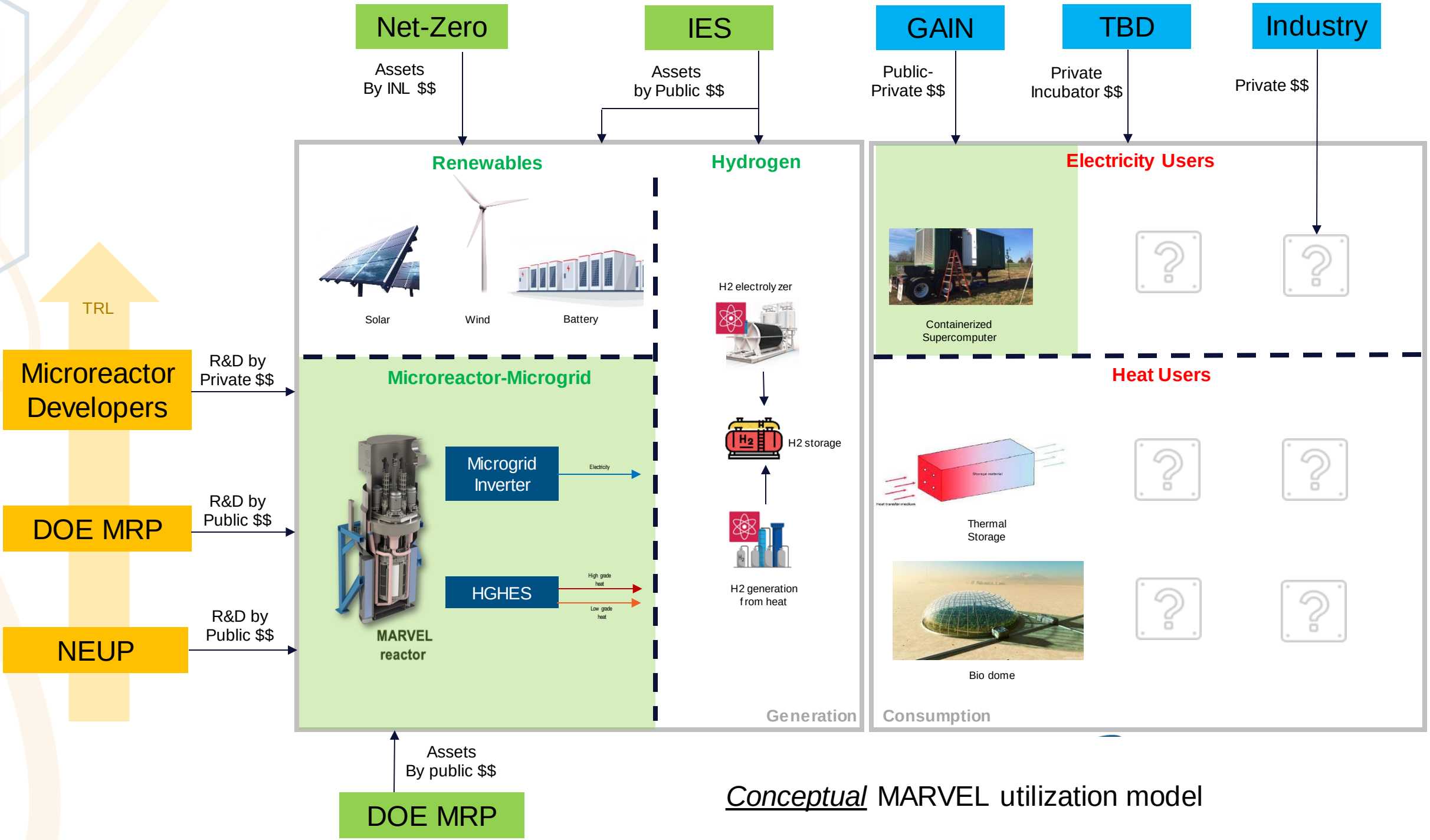
MRP Microreactor Program

And many more possibilities!

Conceptual MARVEL Applications



MRP Microreactor Program



Conceptual MARVEL utilization model

Questions?

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

MRP Microreactor Program