INL/MIS-25-85727

MARVEL Microreactor Expression of Interest (EOI)

MARVEL Utilization

July 2025

Abdalla Abou-Jaoude

Webinar Agenda

1. Welcome from the DOE Federal Manager and the INL National Technical Director
2. MARVEL Introduction and Expression of Interest (EOI)
3. Use Cases Discussion:
    1. I&C Utilization
    2. Microreactor Microgrid
    3. Nuclear heat for industrial applications
4. Q&A

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

National Impact:

Train staff and exercise processes at labs to

Share data and lessons learned to

Demonstrate passive safety and self-regulation to

Provide an instrumentation platform to

Generate electricity to

Provide heat for stakeholders to

ENABLE

Follow-on demonstrations within DOE system

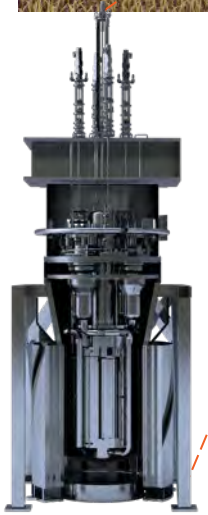
Maturation of commercial microreactor designs

Publication acceptance of microreactor technology

Novel control paradigms for microreactors

Commercial deployment of nuclear-power microgrids

Commercial deployment of nuclear for industrial applications



- 85 kW-thermal
- <20 kW-electric
- ~15 feet tall, <10 tons
- NaK primary coolant, natural circulation
- TRIGA fuel
- Radial control drums
- Graphite, Be and BeO reflector
- 2 operators
- Self-regulating

MRP Microreactor Program

How MARVEL is Helping Unleash Advanced Nuclear Energy

Environmental Assessment

- First EA for an advanced reactor in history
- Pathfinder for streamlined NEPA approvals and training staff on submission process
- Process being leveraged by DOME, MCRE, VALKRE

Design Analysis

- Trained INL staff to perform key safety analyses (e.g., structural analysis, transient simulations)
- Benefiting Pele, MCRE, VALKRE and Westinghouse + Radiant demonstrations

Safety Review

- First new reactor PDSA submission to DOE in history
- Novel approach using risk-informed methodology for reactor safety
- Submittal paved the path for other DOE-authorized reactors (e.g., Pele, MCRE, eVinci)

Guard Vessel Fabrication

- First time in history that a nuclear vessel manufactured by a non-'N' stamp supplier
- Broadening the supply chain by enabling non-nuclear vendors to compete
- Helped identify errors in ASME code that will accelerate future advance reactor manufacturing

Reactivity Control System

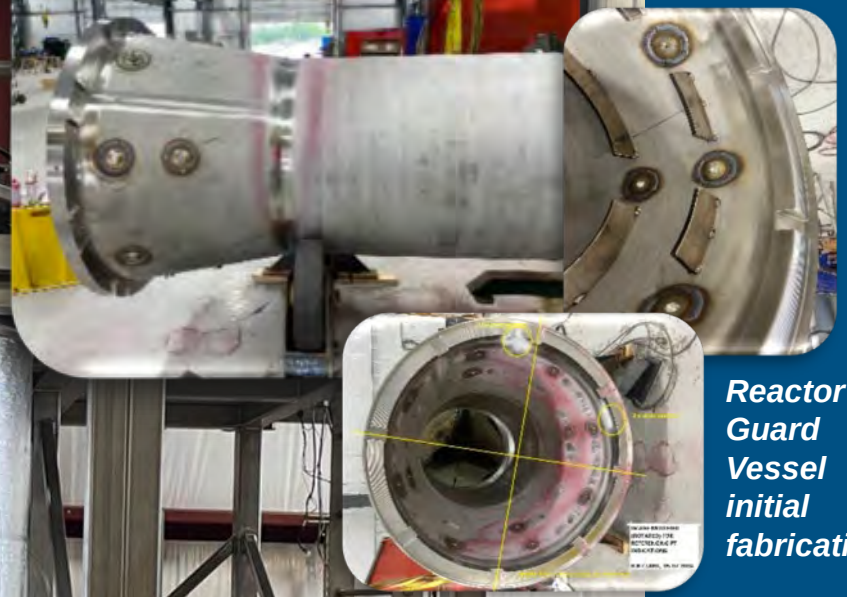
- Established a complete design/fabrication package for microreactor control systems
- Being directly leveraged by VALKRE - under evaluation by commercial vendors (e.g., Antares)

2025 Executive Orders

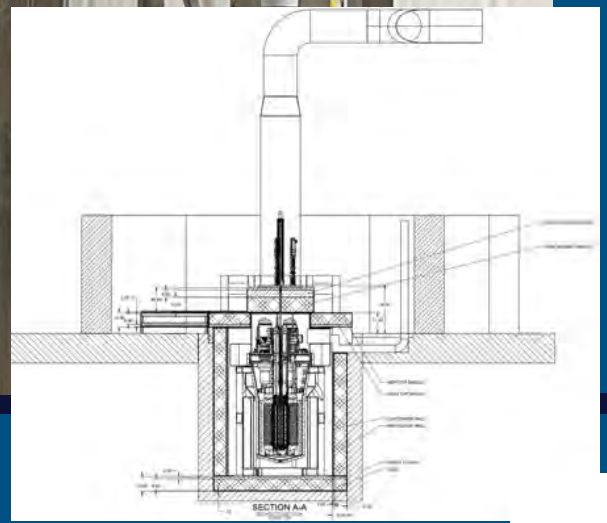
- Using regulatory pathways laid out by MARVEL and Pele to support responses to Executive Orders for expediting the review, approval, and deployment of advanced reactor

MRP Microreactor Program

Key Accomplishments to Date



Reactor Guard Vessel initial fabrication



Overall schematic for MARVEL as part of the 90% Design Completion

90% Final Design: 247 engineering documents, including 35+ Engineering Calculation Analysis Reports (ECARs), addressed 520 comments in two design reviews

Primary Coolant Apparatus Test- PCAT: Electrically heated replica with 36 heating elements. Data used to validate models, per NQA-1. Initial startup on September 19th, 2023

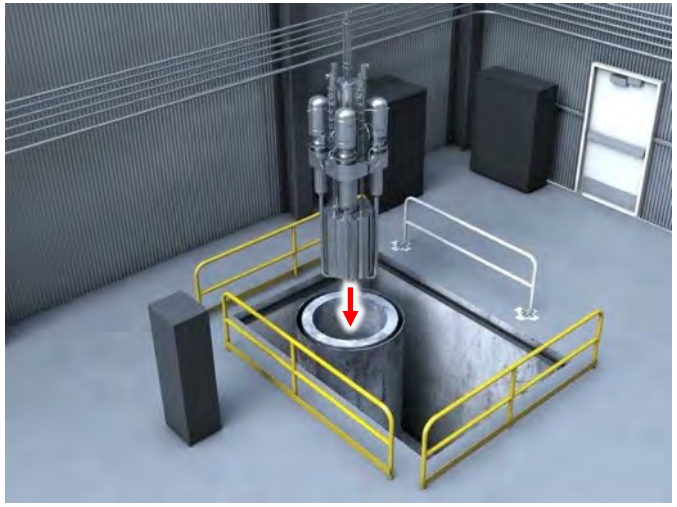
Long-Lead Procurement: Fuel fabrication contract with TRIGA International signed. Material procurement & fabrication of 316H SS structures, systems, and components

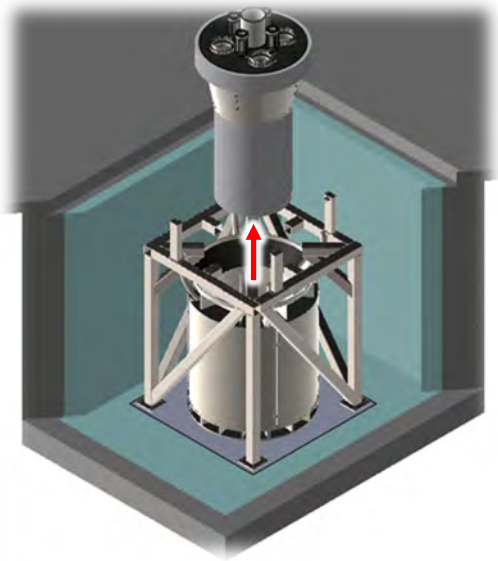
MARVEL Status: System Overview

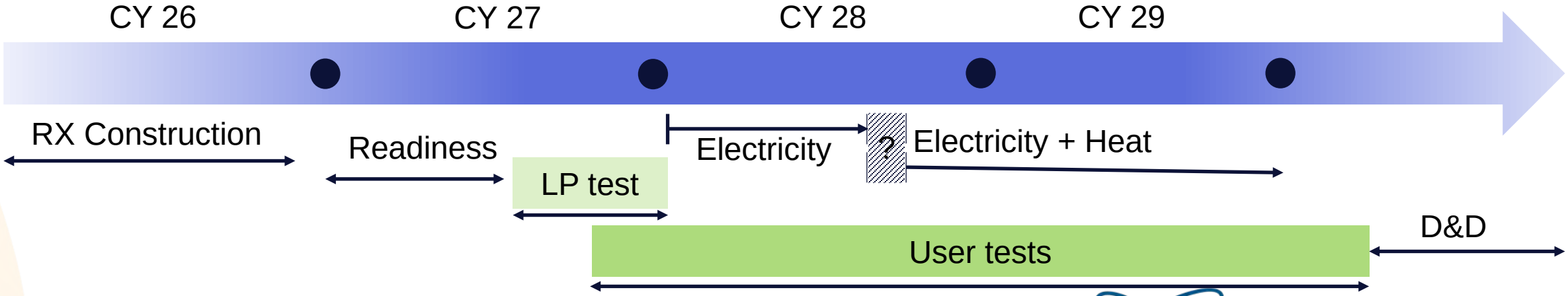
Systems	Design Status	Procurement Status
MARVEL Reactor		
Core/Fuel Design	Completed	Fabrication contract awarded
PCS Design	Completed	Fabrication underway
Guard Vessel	Completed	Fabrication complete
I&C Design	90% (excluding heat extraction)	Some parts procured
RCS Design	90-95%	Fabrication underway
Reflector Support Frame (RSF) Design	Completed	Fabrication Contract awarded
MARVEL Balance of Plant		
IHX Design	In progress (25%) tied to Heat Extraction	Conceptual design
Heat Extraction System	In progress (35%)	Conceptual design complete
Process heat system	In progress (5%)	Scoping options
Power conversion system	In progress (20%)	Conceptual design

MRP Microreactor Program

MARVEL HIGH-LEVEL TIMELINE (TENTATIVE)

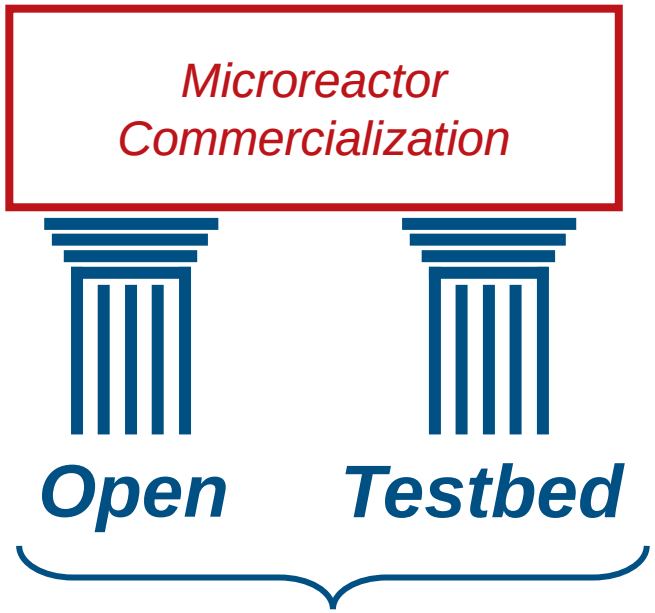






MARVEL Value Proposition

- First-of-a-kind demonstration that will proliferate ‘know-how’ and provide opportunity to test novel features of microreactors
- Key attributes:
  - **Open**: Design & operational data access
  - **Testbed**: Platform for testing new technologies & nuclear applications
- Opportunities for collaboration:
  - **Vendors**: Design, technology testing, validation data
  - **Industry users**: New ways to leverage nuclear
  - **DOE programs**: Demonstrating new technology/applications
  - **Universities**: Furthering nuclear R&D
  - **Regulator**: Building confidence in adv. reactor ops



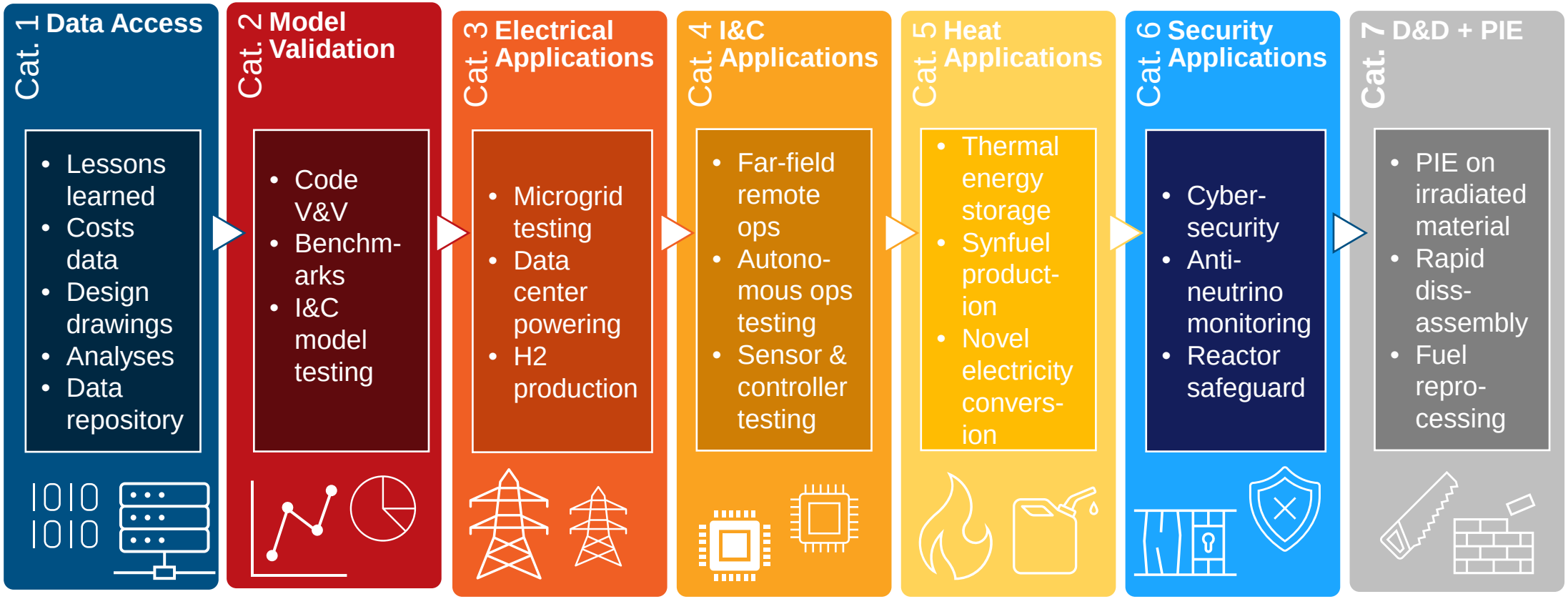
Key MARVEL Differentiation

MARVEL Value: *Open Platform for Testing, Data Generation, and Technology/ Application Demonstration*

MRP Microreactor Program

And many more possibilities!

Potential MARVEL Applications



MRP Microreactor Program

MARVEL End User Utilization – Expression of Interest

- DOE and INL released an Expression of Interest (EOI) request to industry providers to suggest potential tests and experiments leveraging the Microreactor Application Research Validation and Evaluation (MARVEL) demonstration. This will consist of a two-step process starting with a feasibility assessment, then a physical implementation.
- The EOI was released on sam.gov on 06.16.2025 and will close on 08.30.2025
- The EOI is targeting the following types of applications leveraging the MARVEL reactor:
  - Demonstrating novel nuclear-generated electricity applications (e.g., nuclear-powered microgrids, or nuclear-powered data-centers)
  - Demonstrate novel nuclear heat applications (e.g., chemical processing, synfuel production, novel power conversion systems)
  - Requesting data access (e.g., analyses conducted, documentations, engineering drawings)
  - Operating the reactor in specific modes to validate models (e.g., conducting a specific transient to benchmark codes)
  - Deploy advanced instrumentation and control paradigm to nuclear reactors (e.g., semi-autonomous operations, far-field remote operations)
  - Demonstrate novel safeguards and security paradigms for nuclear technology (e.g., cyber-secure communications, novel safeguard techniques for microreactors)

DOE social media announcement of the MARVEL EOI

Link: https://sam.gov/opp/36dd4ccf93bb43cca53ab9244eeb2135/view
Additional information: https://inl.gov/marvel/marvel-eoi/

MRP Microreactor Program

How to Engage?

Timeline | Engagement

- **Notice of Opportunity**
  - Expression of Interest: ~June, 2025
  - Requesting Responses: ~Aug 2025
  - Invitation to submit response to Notice of Opportunity (NO): ~Sep 2025
  - Responses to NO due: ~Oct 2025
  - Awards for feasibility assessment: ~Dec 2025
  - Contract signed: ~Q1 2026
- **Anticipated timing of tests by type**
  - ~CY27 Q4: Startup testing & benchmarks
  - ~CY28 Q1: Microgrid applications
  - ~CY28 Q3: I&C and HMI
  - ~CY28 Q4 & beyond: Heat applications

Report:
A. Abou-Jaoude, M. W. Patterson, "MARVEL Utilization Plan", Idaho National Laboratory, INL/RPT-24-78261, June 2024, https://www.osti.gov/biblio/2371820

Expression of Interest

- **Overview**
  - Targeting private sector companies – cross-collaborations encouraged
  - 2 – 4 projects anticipated – cost sharing
  - GAIN-like system: directed research at labs
  - Submission: 1-2 page high-level explanation of how end user can leverage MARVEL
  - First step: feasibility assessment and preliminary design of proposed option (e.g., scope demonstration specifications and cost, evaluate safety basis)
- **Other potential funding avenues:**
  - Subcontract: CRADA, SPP
  - GAIN vouchers
  - DOE-sponsored programs
  - Lab Directed Research and Development (LDRDs)
  - CINR/NEUP/IRP

MRP Microreactor Program

Frequently Asked Questions (1)

What ARE suitable example of EOI responses?

- Requesting access to MARVEL data under appropriate controls
- Requesting to connect a specific electrical appliance to the system
- Conducting specific transients that do not impact the safety basis of the reactor
- Requesting to connect a specific chemical skid that can leverage MARVLE heat
- Demonstrating novel energy conversion system (e.g., sCO2 Brayton Cycle)
- Connecting self-sustaining instrumentation to monitor the reactor (if they do not require design modifications)

What are NOT suitable examples for EOI responses?

- Requests to move MARVEL
- Requests to change the fuel or key design features
- Requests to insert something in the core (please refer to NSUF capabilities for irradiation)
- Any changes to finalized parts of the reactor (especially parts already under fabrication)
- Any modifications that negatively impact the safety basis of the reactor

MRP Microreactor Program

Frequently Asked Questions (2)

- *How does DOE define "novel" applications? What does this mean?*
  - Novel applications consist of use cases that have never been previously demonstrated with a nuclear reactor or proven applications with limited data. For instance, nuclear energy has never been previously shown to power a data center directly, or to provide heat for chemical processes. Preference will be giving to applications that have never been previously coupled to a nuclear reactor, but applications which have seen limited demonstration time but lack data are also encouraged. Potential use cases that are eligible include connecting an electrical application to the reactor, connecting a thermal storage system to the process heat system, coupling the process heat system to a chemical process, conducting a specific transient within the allowed safety basis with the reactor, or demonstrating novel controls paradigm.
- *Who is eligible to apply?*
  - Responses must be led by the private sector and be a U.S. based company. Preference will be given to end-users of nuclear energy. Specifically, interested parties who can leverage the energy produced by a reactor. University or national labs can be listed as supporting entities.
- *Do interested parties need to reply to the EOI to be eligible for the subsequent notice of opportunity?*
  - Failure to respond to the EOI will not disqualify eligibility to the subsequent notice of opportunity, however respondents to the EOI will be favored.
- *When will the MARVEL notice of opportunity be issued?*
  - The notice of opportunity is expected to be issued in calendar year 2026, following the review of EOI submissions. It will be made publicly available on SAM.gov.
- *Does DOE anticipate any funding tied to the notice of opportunity?*
  - While there are no direct financial awards related to the anticipated notice of opportunity, funding may be provided in the form of a cost-share with the end user. The majority of funds provided by DOE will be leveraged to cover national laboratory staff hours in support of the end user application.
- *If there is no direct financial award tied to the future notice of opportunity, why should industry be interested? What is the benefit of participating in a self-funded MARVEL application test case?*
  - Stakeholders who are self-funded can greatly benefit from the demonstration of novel nuclear applications that can be commercialized in the future. Tests conducted with MARVEL can result in substantial experimental data that can prove to be invaluable for scale-up commercial demonstrations in the future. Applications can significantly de-risk novel technologies and help secure follow-on funding in the future. Furthermore, proprietary intellectual property (IP) generated as part of these demonstrations can be protected subject to contractual agreements between the different stakeholders.
- *What are the anticipated steps towards ultimate demonstration of a novel MARVEL application?*
  - Following the response to the EOI and to the subsequent notice of opportunity, successful end users will conduct a feasibility assessment of their proposed application in collaboration with a DOE national laboratory. This will then form the basis for any follow-up notice of opportunity to then deploy the physical demonstration within the 2027 to 2030 timeline.

MRP Microreactor Program

SAM.gov posting

Information page and registration for Webinar

Questions?

MRP Microreactor Program

INL/MIS-25-85990

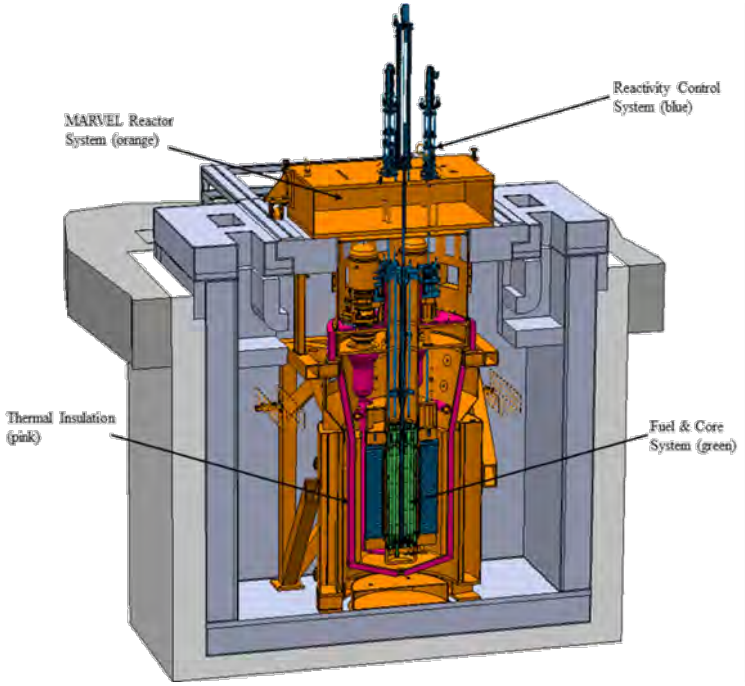
MARVEL Utilization:
Instrumentations & Controls

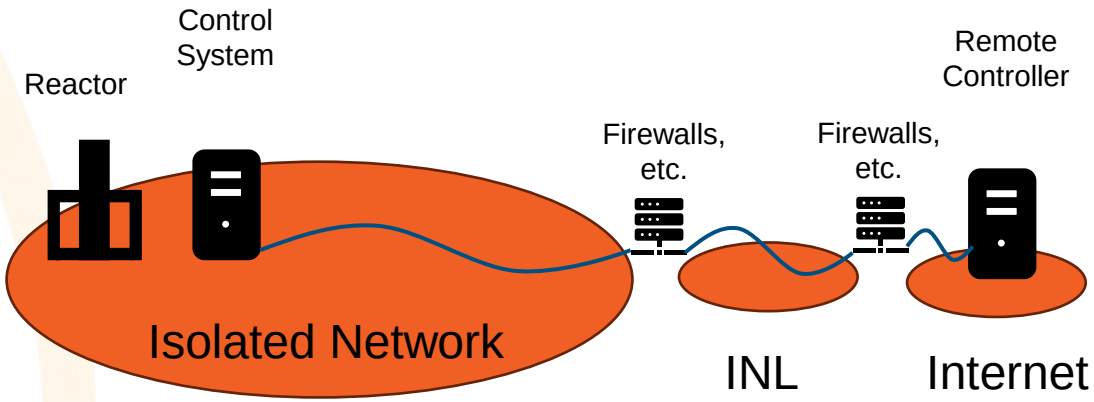
Benjamin Baker, Andrew Heim, Anthony Crawford

July 2025

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

MARVEL I&C Utilization: Semi-Autonomous & Remote

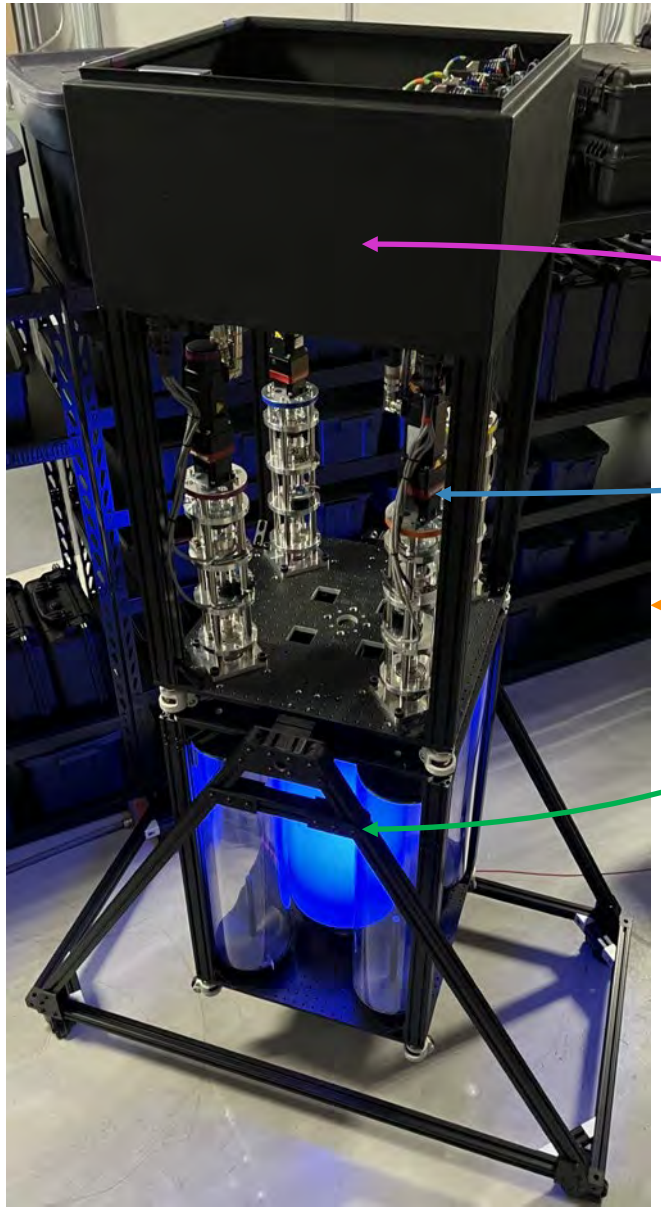


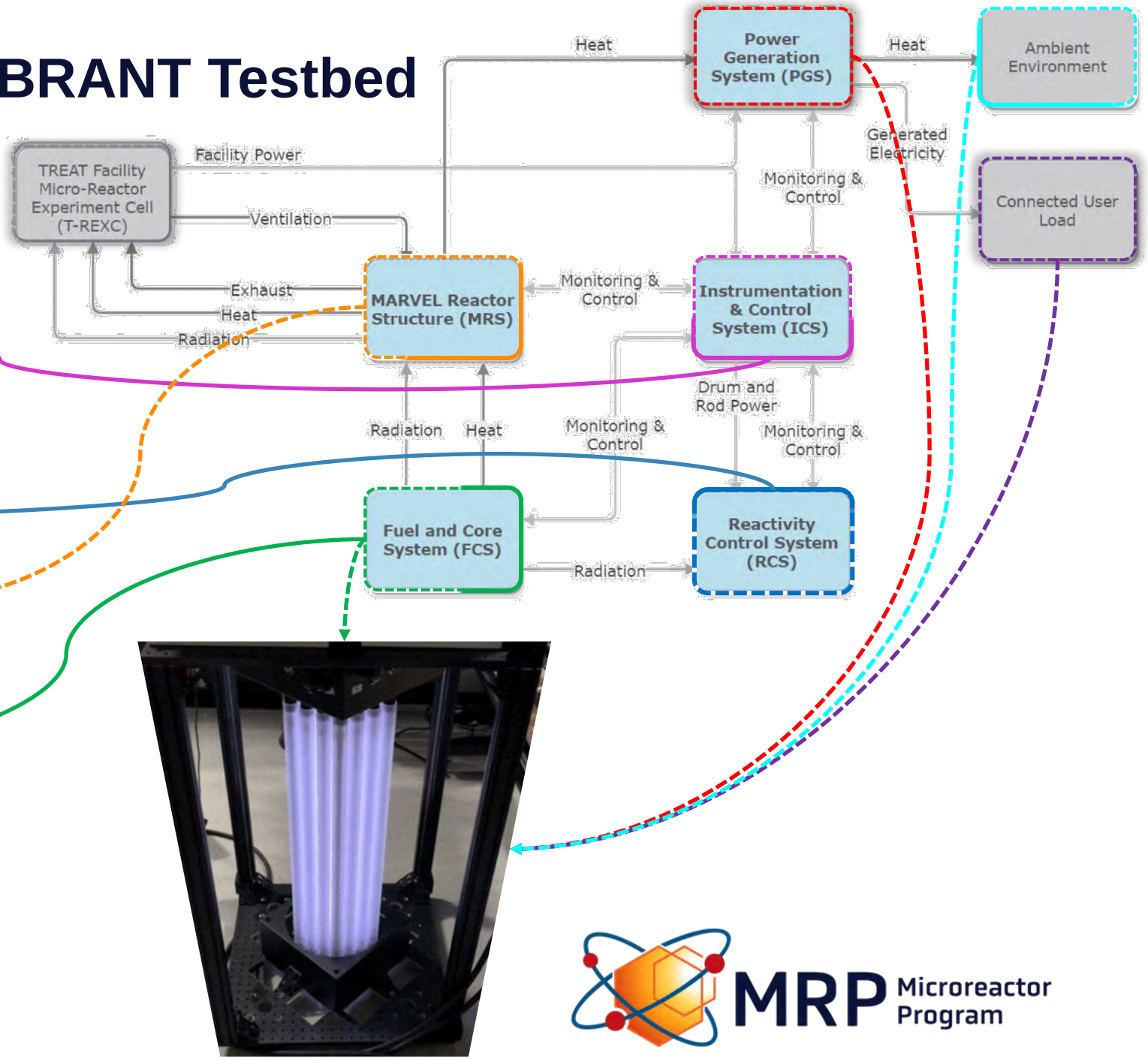


- ***MARVEL I&C design philosophy***:
  - Safety basis supports advanced use cases
  - Most MARVEL I&C non-safety related
  - Opportunity to develop novel operational paradigms
- ***Connect & control peripheral systems to a real reactor:***
  - E.g., microgrid, data center racks, process heat
- ***Semi-autonomous controls:***
  - Anticipating operator presence for monitoring
  - Opportunity to test control algorithms with supervision
- ***Remote operations:***
  - Remote monitoring
  - Remote controlling: more challenging cybersecurity considerations **but possible**

MRP Microreactor Program

MARVEL Diagram and Relationship to ViBRANT Testbed

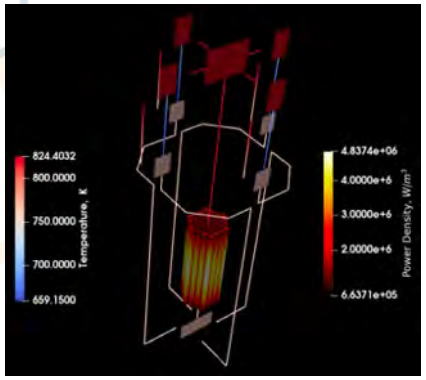




MRP Microreactor Program

MARVEL Beyond the Reactor: Non-Nuclear Integration and Controls as a Stepping-Stone

Virtual simulation of MARVEL core physics



Electric heat output and outlet temperatures

MAGNET
(non-nuclear heat source with test article integrated power conversion unit)

Drum position and core response

Electricity generation and dispatch

Mobile Data Center

Nuclear-powered data center demonstration

Demonstrate Autonomous & remote operation in non-nuclear system first, prior to testing in MARVEL

MACS Hardware
(non-nuclear surrogate for MARVEL controls)

RAPID MIB
(Microgrid in a box)

MRP Microreactor Program

Tim McJunkin
Kurt Myers
Aaron Epiney

July 14, 2025

Microgrid and Grid Edge Applications: Capabilities and Planned Demonstration

MARVEL Expression of Interest Informational Webinar

INL/MIS-25-86151

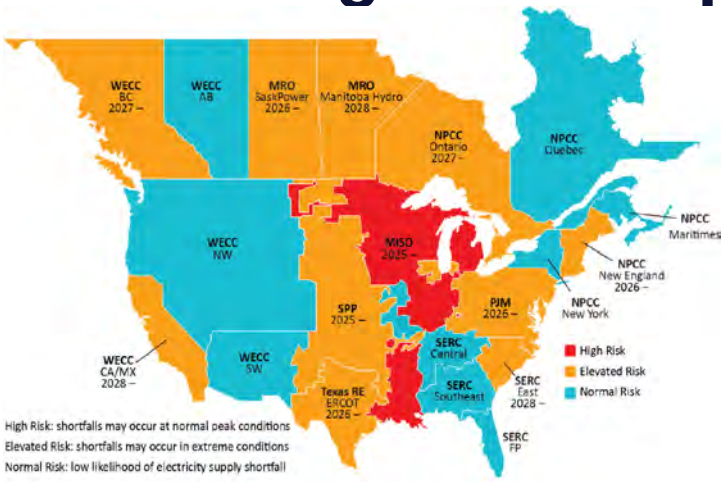
Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

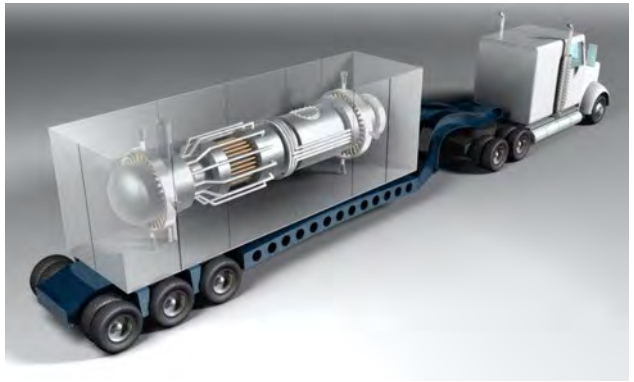
Idaho National Laboratory

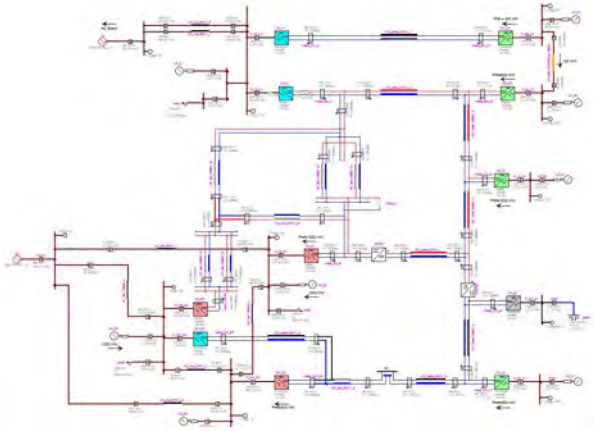
Small Nuclear Reactors in Microgrid Consortium (SNRMC): Formative – DOE Office of Electricity Microgrid Program

- A consortium of DOE national laboratories, industry, and academia will focus on energy system design and management.
- **The grand challenge is to demonstrate the deployability, affordability, security, and resilience of nuclear-powered microgrid and grid edge applications.**
- Address gaps in electricity resource adequacy and support for key assets under stress from unusual weather and malicious attacks.
  - The goal is to utilize existing and new nuclear power resources for affordable, feasible, and resilient electricity provision in the U.S.
  - Significant demand growth in North America's power system is due to data centers, heat pumps, electric vehicles, and retirements of coal and older gas plants.
  - Near-term solutions include placing new energy generation near loads or locating new loads near existing power plants.
  - The new paradigm of locally sourced power will include nuclear power, thermal storage, and inverter-based resources, creating new management challenges.
  - Digital engineering and standardized models can reduce microgrid deployment costs, supported by DOE programs and the Small Nuclear Reactor Microgrid Consortium.
- Alignment of DOE-OE and NE into cooperative objectives over FY26-28

Data Centers (and other applications) in Microgrids Review: Challenges and Opportunities







Microgrids for Data Centers

- Grid resource inadequacy
- Stringent reliability and power quality needs
- Relatively stable demand

Modular microgrid solutions with nuclear present an excellent opportunity

Barriers to Implementation

- Load characteristics/ variability
- Frequency and voltage controls with large load
- Harmonics and power factor issues due to DC inverter loads
- Sub-synchronous oscillations
- Impact of voltage-frequency drive (VFD) interfaced motor cooling system

Recommended Analysis

- Accurate demand modeling
- Strategies to collocate generators and data centers
- Ride-through and ramping capabilities
- Power quality and stability evaluation through EMT studies
- Harmonic filters and power factor corrections
- System protection

MRP Microreactor Program

RAPID-MIB, i.e. Microgrid-in-a-Box

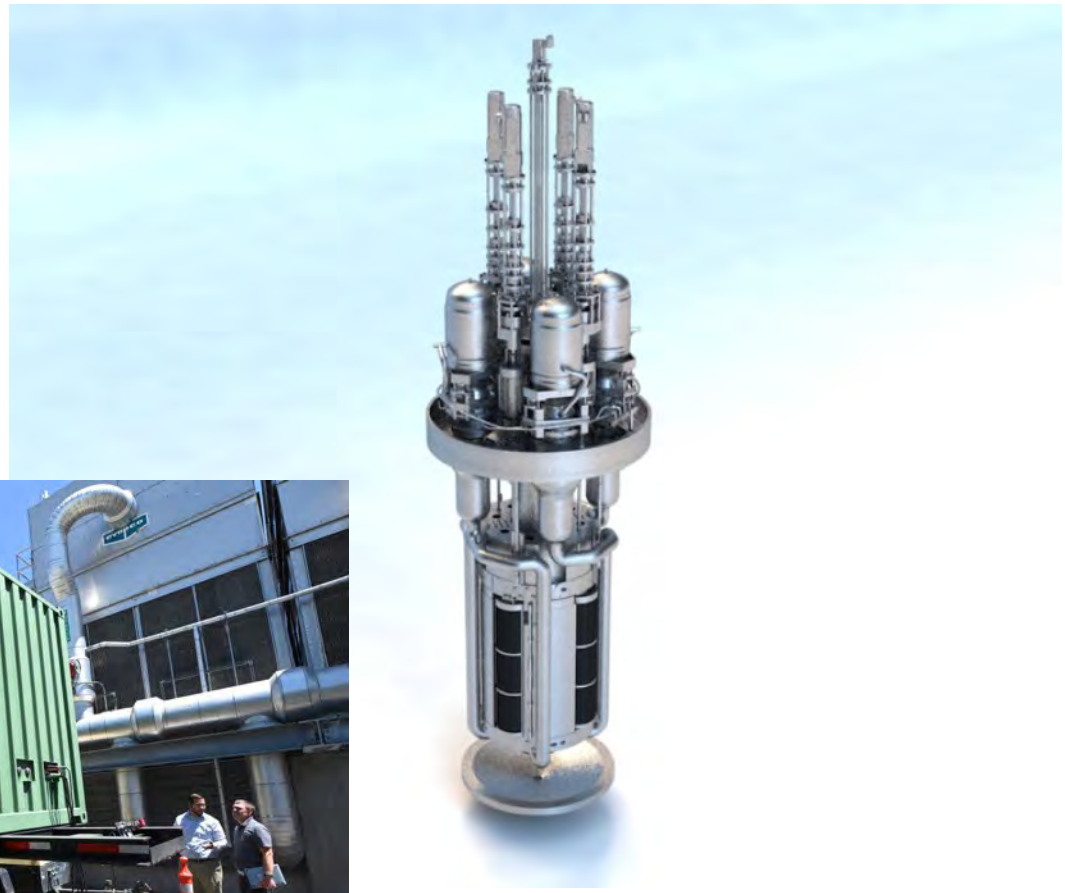
- **Relocatable/ Resiliency Alternative Power Improvement for Distribution** – Microgrid In a Box (RAPID-MIB)

- First-of-kind portable high energy density compatible with domestic and foreign electricity systems
  - 60hz 480/277VAC
  - 50hz 415/230VA
- Advanced controls for grid tied and islanded operation
- Frequency and Voltage control in multiple modes
- Plug and play energy resources, e.g. solar, wind, diesel, hydrogen, **small nuclear!**

More information: kurt.myers@inl.gov

MRP Microreactor Program

Demonstration: MIB/MARVEL/Data Center in a Box in 2028



MRP Microreactor Program

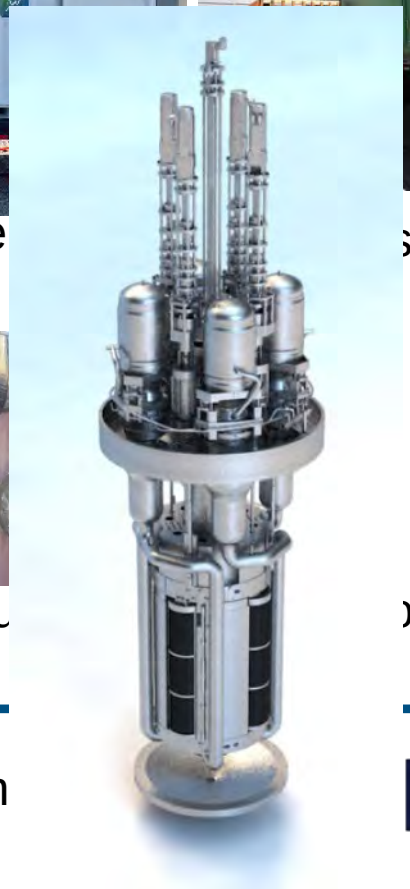
Buying down Risk with successive validation of modeling, grid emulation and introduction of physical systems

Control System Hardware

Physical Storage
Microgrid control

sical application

MAGNET – not nu



on of reactor

Energy Generation, Storage and Application Models

Real-world compon
and systems

MRP Microreactor Program

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

Rami M. Saeed, Ph.D.
Christopher T. Wright, PhD

Nuclear & Industrial Heat at INL

MARVEL and the Energy Technology Proving Ground

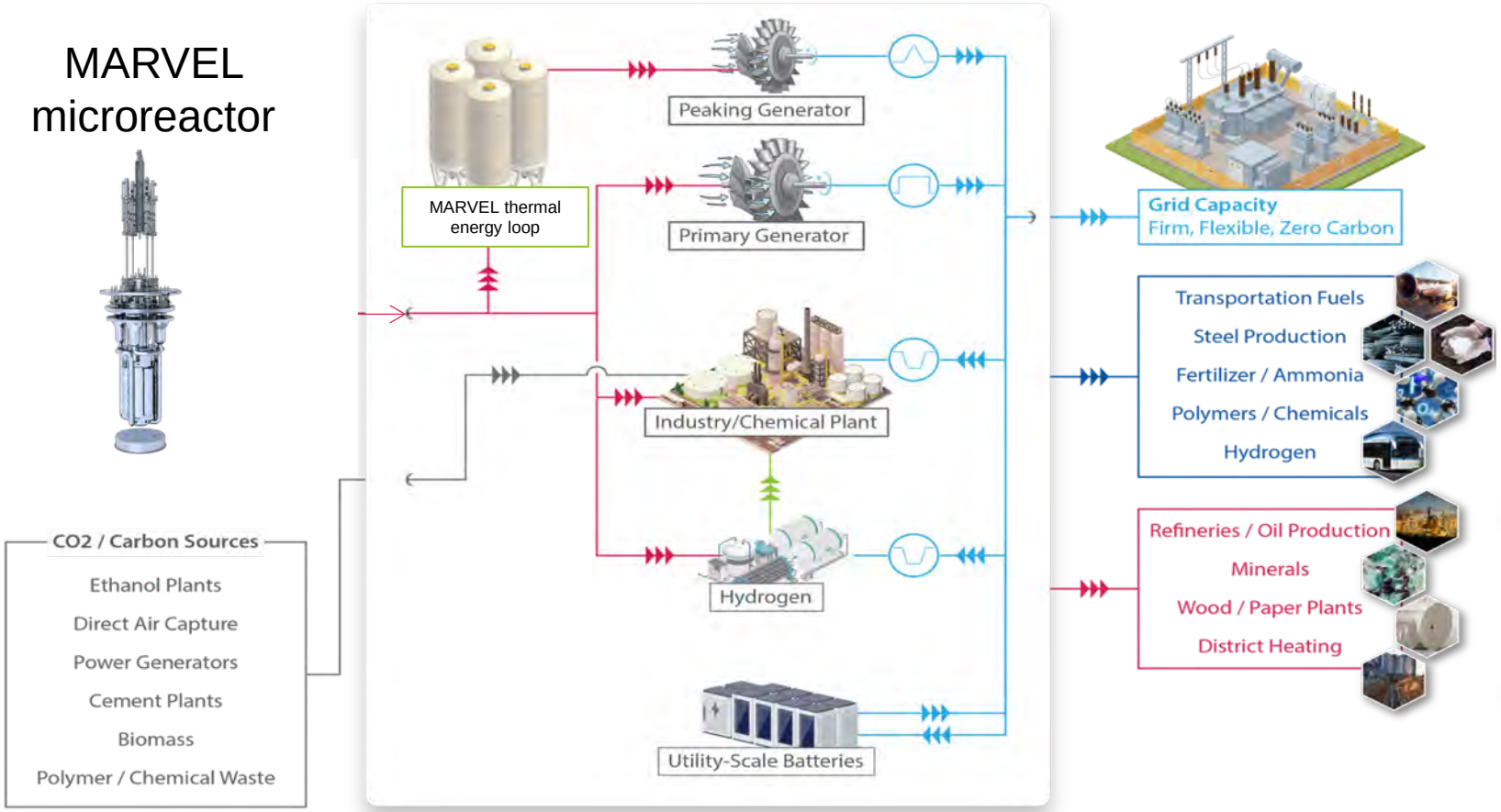
Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

Idaho National Laboratory

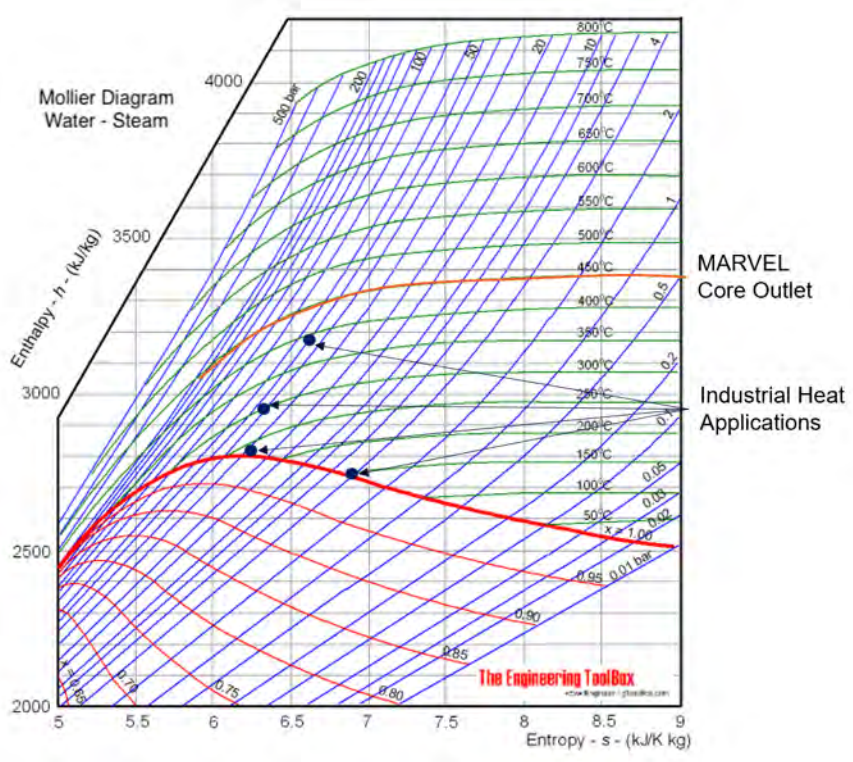
INL/MIS-25-85026

MARVEL can provide power for heat and electric applications

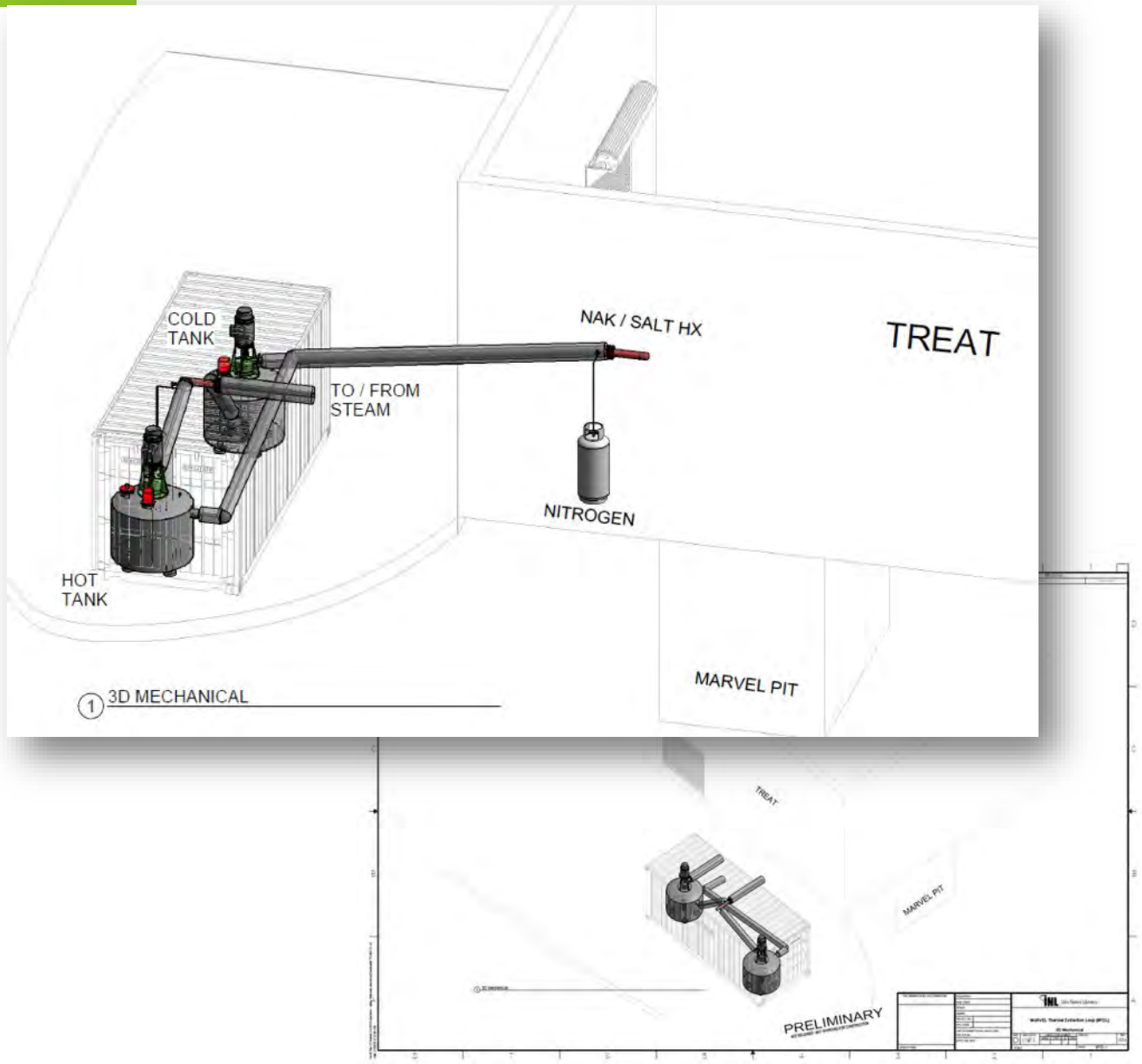
MARVEL microreactor



Relevant industrial heat end-use cases for MARVEL

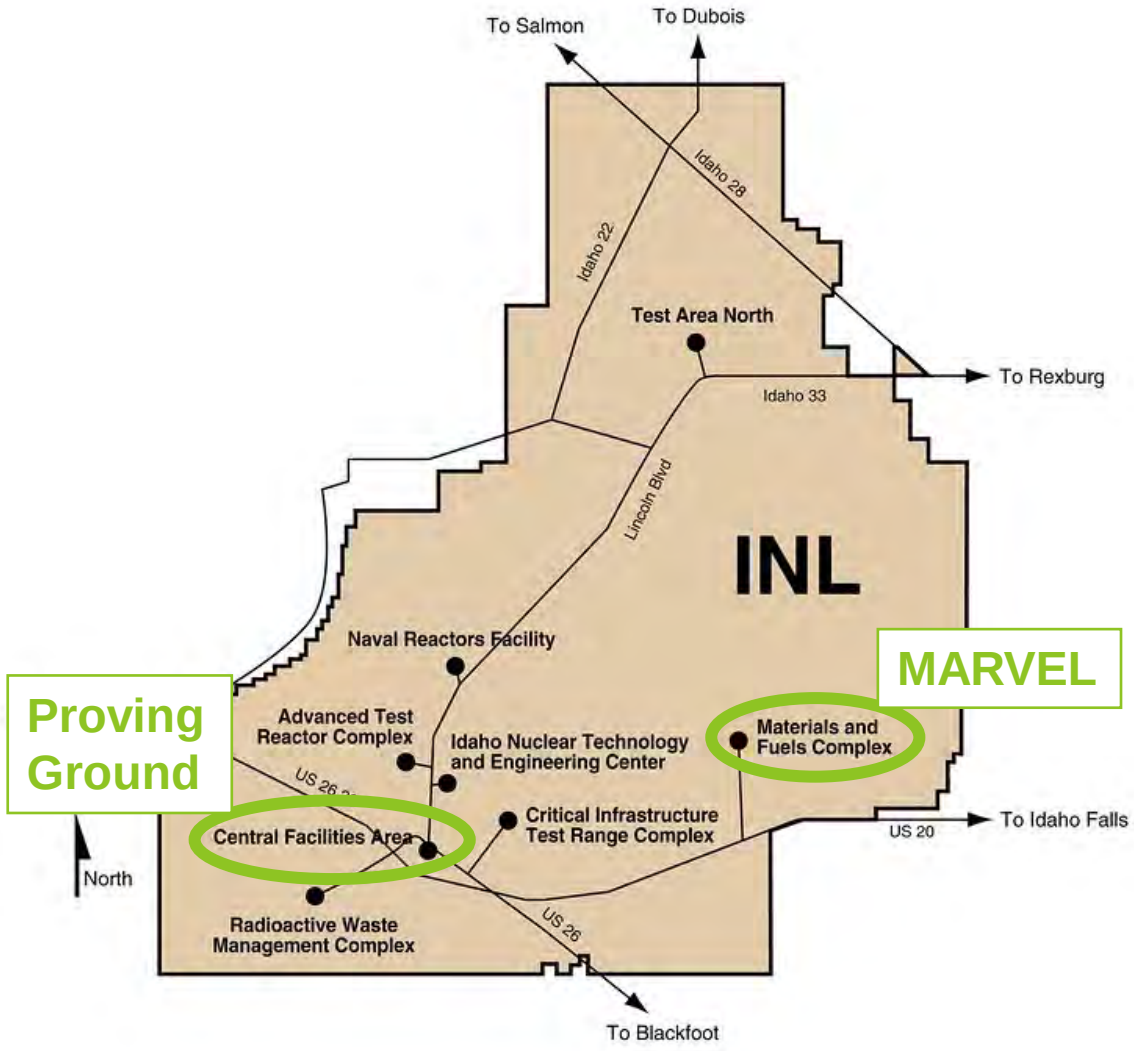


MARVEL Thermal Energy Loop (MTEL)



- Intermediate loop:
  - Secondary NaK → Salt/oil/gas→ steam
- Modular, transportable and scalable
- Thermal Energy Loop Specifications:
  - 85 kWth nominal heat delivery
  - >400°C salt
  - Up to 400°C steam
- Example use cases: Food & beverage skids, petroleum refinery, chemical, pulp & paper, high temperature steam electrolysis (HTSE)
- End user feedback: heat needs, transients, reliability, duration of tests, etc.
- Additional considerations: thermal storage, thermal/heat boosters.

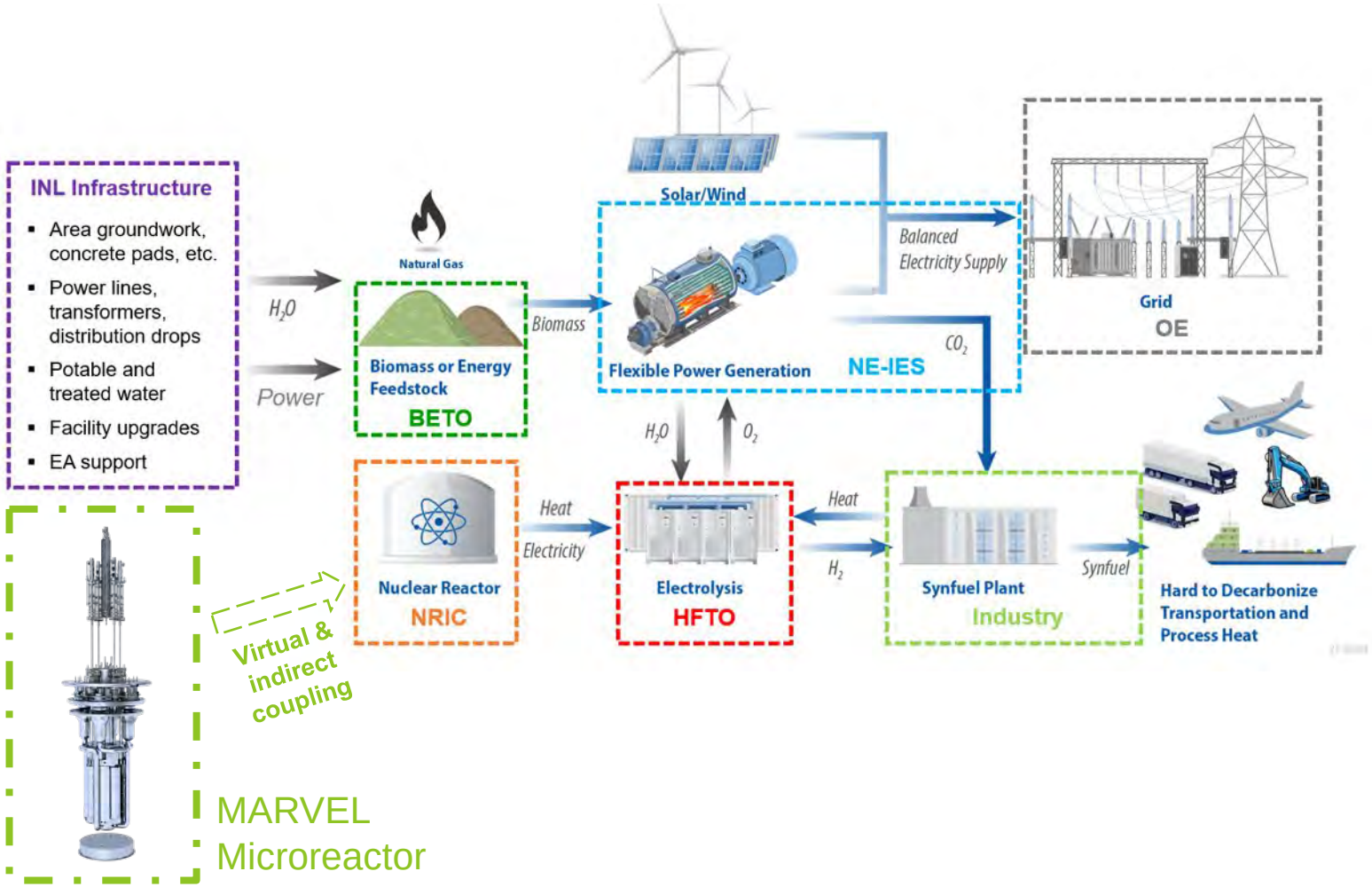
Integrated Energy Systems at INL



- **MARVEL:**
  - Located at the TREAT facility at MFC
  - kW-scale tests and demonstrations
- **Energy Technology Proving Ground:**
  - Separate space from MARVEL, located at INL Central Facilities Area
  - MW-scale tests and demonstrations

Broader INL Effort: Energy Technology Proving Ground

- MARVEL can be used as:
  - Steppingstone for proving ground technologies
  - Earlier coupling with nuclear heat
  - Lower scale users (e.g., food & beverage)
  - Indirect coupling with Proving Ground:
    - early-stage integration
  - Virtual coupling with Proving Ground:
    - emulated heat output



Proving Ground Future Scopes

- Near Term:
  - High Temperature Hydrogen Production (facility construction)
  - Biogenic CO_2 Production, Purification, and Storage (facility design)
  - Electrified Processes for Industrial eXCellence (EPIXC) (consortia driven projects – lead is Arizona State University)
- Medium Term:
  - Synthetic Fuels Production (facility conceptual design)
  - Thermal Energy Management Testbed (facility pre-conceptual design)
- Long Term:
  - Advanced Nuclear Reactor Construction Technology (testing phase design) (Note: not MARVEL)
  - Catalysis Testbed (facility pre-conceptual design)
  - Electric, Hydrogen, and Synfuels Transportation Systems (facility pre-conceptual design)

https://www.epixc.org

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.