INL/MIS-25-83577

MARVEL Microreactor Project Update

2025 Microreactor Annual Review

March 2025

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

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

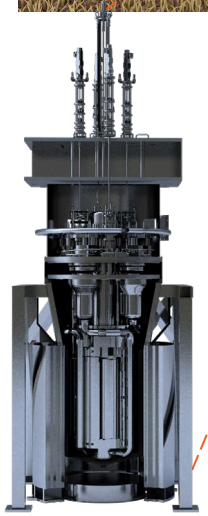
Maturation of commercial microreactor designs

Publication acceptance of microreactor technology

Novel control paradigms for microreactors

Commercial deployment of nuclear-power microgrids

Commercial deployment of nuclear for industrial applications

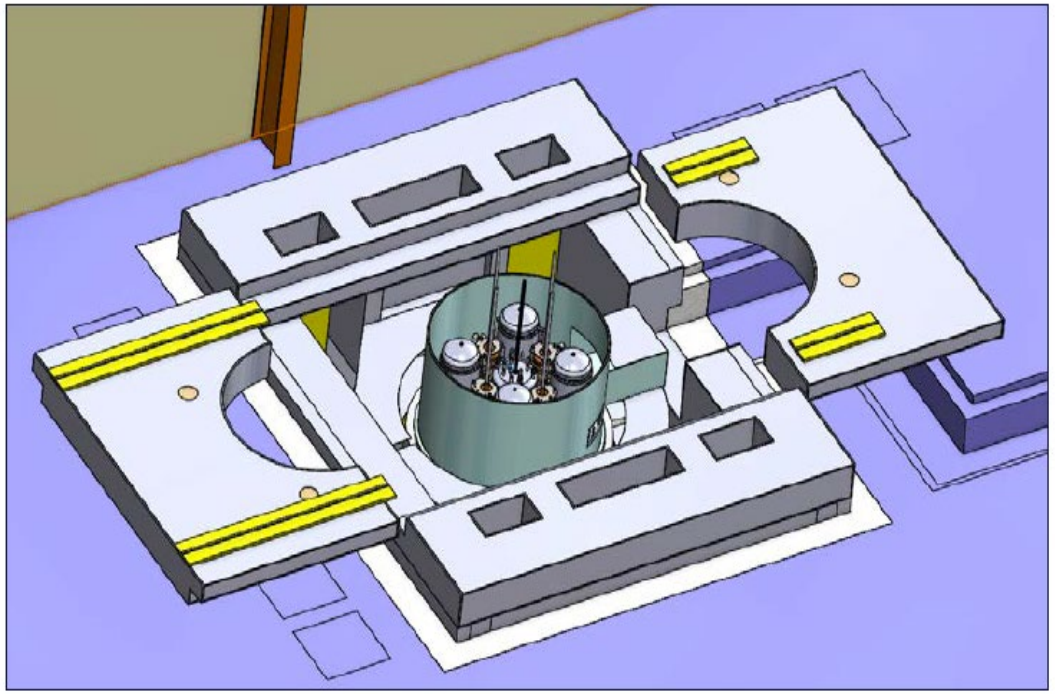


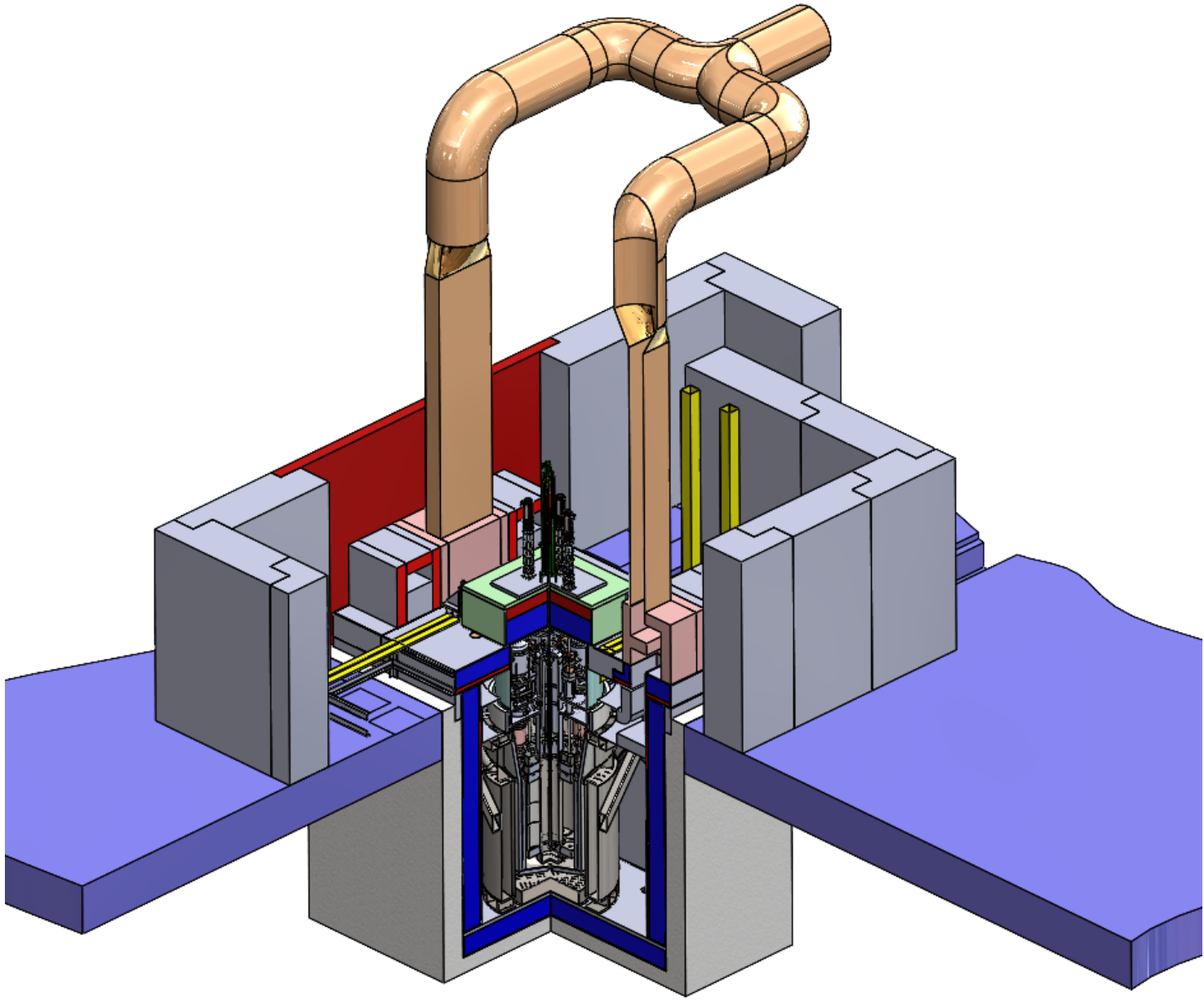
- 85 kW-thermal
- <20 kW-electric
- ~15 feet tall, <10 tons
- NaK primary coolant, natural circulation
- TRIGA fuel
- Radial control drums
- Graphite, Be and BeO reflector
- 2 operators
- Self-regulating

MRP Microreactor Program

TREAT- Reactor Experiment Cell (T-REXC)

- Multi-use facility
- MARVEL is the first experiment
- All components are general purpose



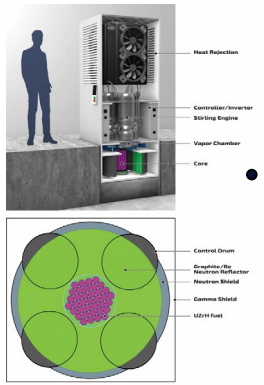


MARVEL Design History

May, 2020

Pre-conceptual

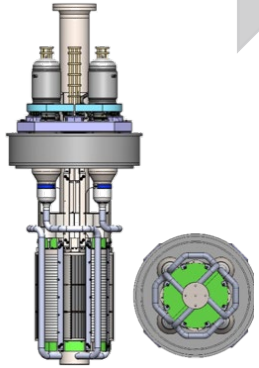
- No operations funding, no D&D funding
- Fuel produced in 2-3 months
- No integral effects test



Dec, 2021
April, 2022

Interim design

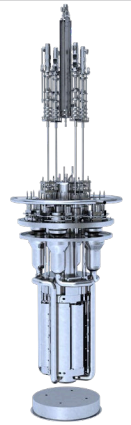
- Includes all three phases (design/construction, operation, D&D)
- Integral effects test (PCAT)
- Fuel procurement
- Much higher complexity (>2,800 parts compared to <30 parts)



September, 2023

90 % Final Design

- Full resource loaded schedule
- Inclusion of management reserve and contingency
- 90% Final Design comprehensively lays out technical path
- Additional engineering required
- Ops support for 24 hour operation
- Full fabrication and construction estimates



MRP Microreactor Program

MARVEL Status: System Overview

Systems	Design Status	Procurement Status
MARVEL Reactor		
Core/Fuel Design	Completed	Fabrication contract awarded
PCS Design	Completed	Fabrication contract awarded
Guard Vessel	Completed	Fabrication complete
I&C Design	90% (excluding heat extraction)	Some parts procured
RCS Design	90-95%	Prototype completed, final system under fabrication
Reflector Support Structure Design	Completed	Contract awarded
MARVEL Balance of Plant		
IHX Design	In progress (80%) tied to Heat Extraction	Scoping options
Heat Extraction System	In progress (20%)	Quotes being procured
TES	In progress (5%)	Scoping options
Power conversion system	In progress (5 to 50% -- sCO2 vs. Stirling)	Quotes being procured

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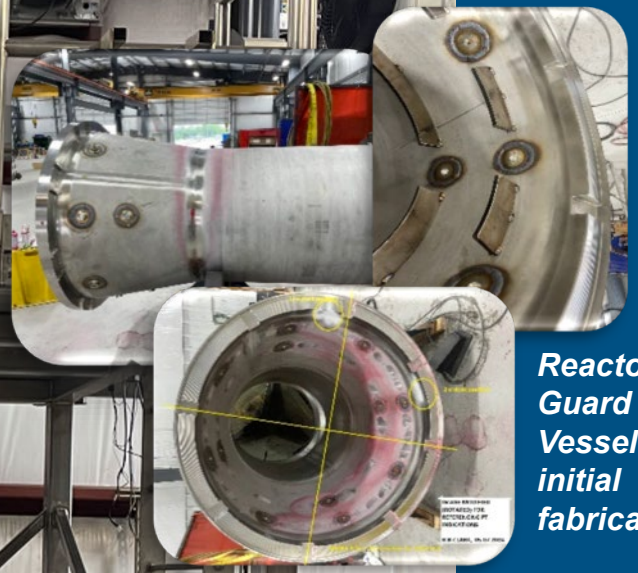
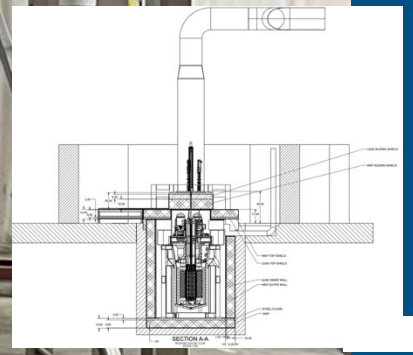
Key Accomplishments to Date



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

Summary of Recent Developments

MARVEL is the first DOE reactor to achieve 90% final design.

MAJOR FY23 MILESTONES

- 90% final design completed September 2023
- Started operations at Primary Coolant Apparatus Test (PCAT)
- Fuel fabrication contract with TRIGA International signed

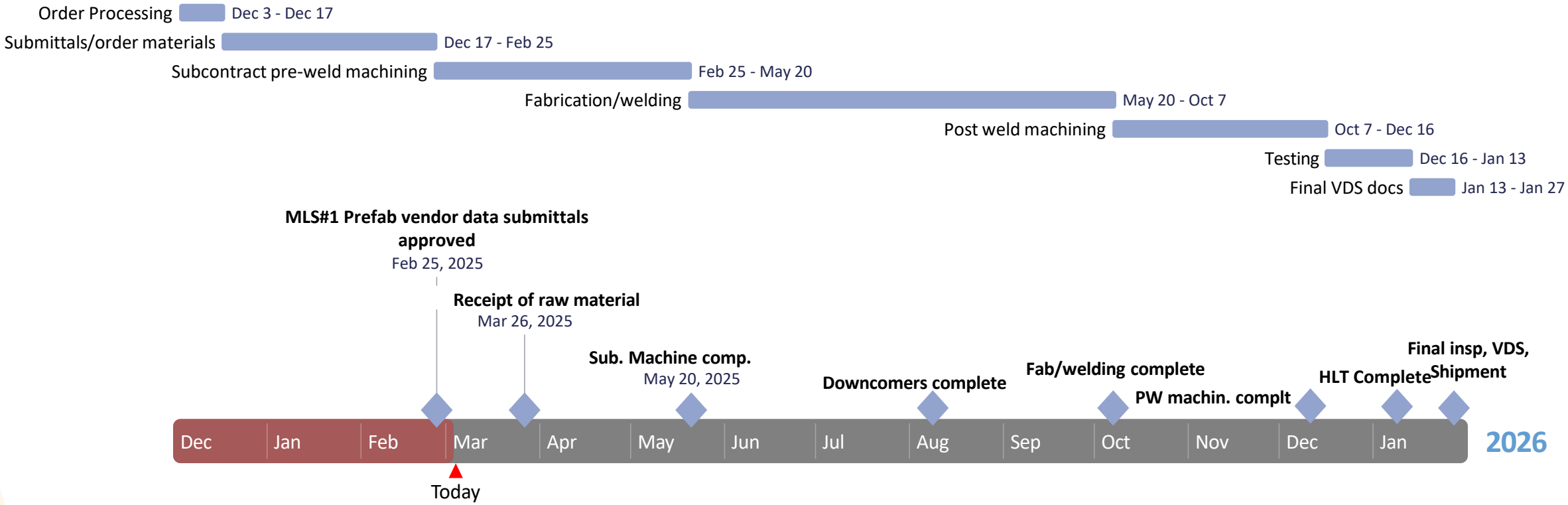
MAJOR FY24 DELIVERABLES

- Submit preliminary documented system analyses (PDSA) to DOE-ID in July 2024
- Fuel fabrication started in February 2024; delivery planned for March 2025
- Guard vessel fabrication started in December 2023
- Control Drum qualification testing completed. Fabrication initiated, expected complete by September 2024

MRP Microreactor Program

FY25 Priorities: Construction of Primary Coolant System (PCS)

PCS Timeline and Schedule Overview



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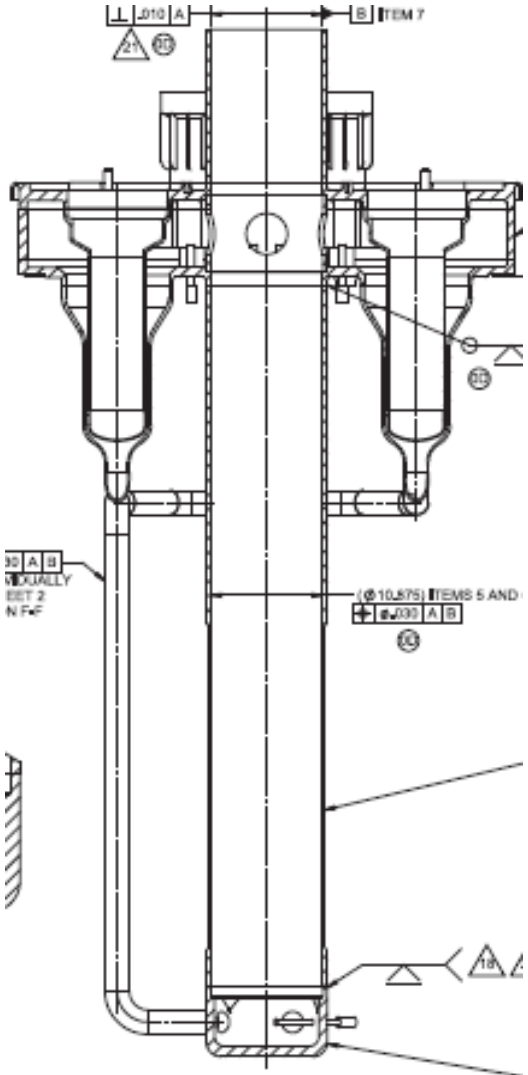
PCS Fabrication Plan

Fabrication Key Phases:

- PHASE 1: Pre-Fab operations (order processing, submittals, Material Procurement, initial material processing)
  - CFI to procure materials, process materials, receive components in Group 3&4 difficulty machining categories
- PHASE 2: Subcontract pre-welding machining operations
  - CFI to manage group 2 machining vendors via on-site surveillance, kickoffs, regular meetings, etc.
  - Key operation of core-barrel machining to be performed by Sawyer Manufacturing
- PHASE 3: Welding operations withing CFI
  - Risk mitigation plan includes use of multiple Bluco fixtures, tables, rings, etc. to assist with alignment, positioning, and weld distortion minimization.
- PHASE 4: Post Weld Machining Operations
  - CFI to ship weldments to group 1 vendor for PW machining at Metalex (on-site surveillance, kickoffs, regular meetings, support offered by Bluco/CFI)
- PHASE 5: Testing, Final Inspections, Shipping
  - Return weldments to CFI following machining for final inspections, pressure testing, and Helium Leak Testing to be performed by ATS at our facility



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FY25 Priorities: Reactor Control System Fabrication

RCS Fabrication Work Control:

- WO 359037 MARVEL Control Drums
  - All metallic components for the drums, excludes BeO and B4C components.
  - Will supply enough for five control drums (four drums plus one spare).
- WO 374089 MARVEL CIA Actuator System
  - Components to assemble two Central Insurance Rod drive mechanisms (one system plus one spare).
  - Two Central Insurance Rod Connecting Rod assemblies.
- WO 374102 MARVEL Control Drum Actuators and Seals
  - Components to fabricate five control drums and drive mechanisms (four systems plus one spare).
  - Components to fabricate five control drum seal assembles (four systems plus one spare).
- WO 374217 MARVEL CD Drive Shafts, Bearings, and Gray Rod
  - Components to fabricate five control drum actuator shaft assemblies (four systems plus one spare).
  - Procurement of five sets of High Temperature Bearings for the reactor structure and fabrication of housings for the spherical bearings
  - Fabrication of two sets of Gray Rods, two of each detail for a total of six.
- WO 374196 MARVEL Black Rod Cladding Assembly
  - Two CIA Black Rod Cladding Assemblies (includes assembly with B4C pellets and ASME Section III welding of Clad Assemblies).
- WO 374011 MARVEL RCS Test Stand and Standoffs
  - Components to fabricate one test stand.
  - Fabricate four testing standoffs.

Control Drum Testing

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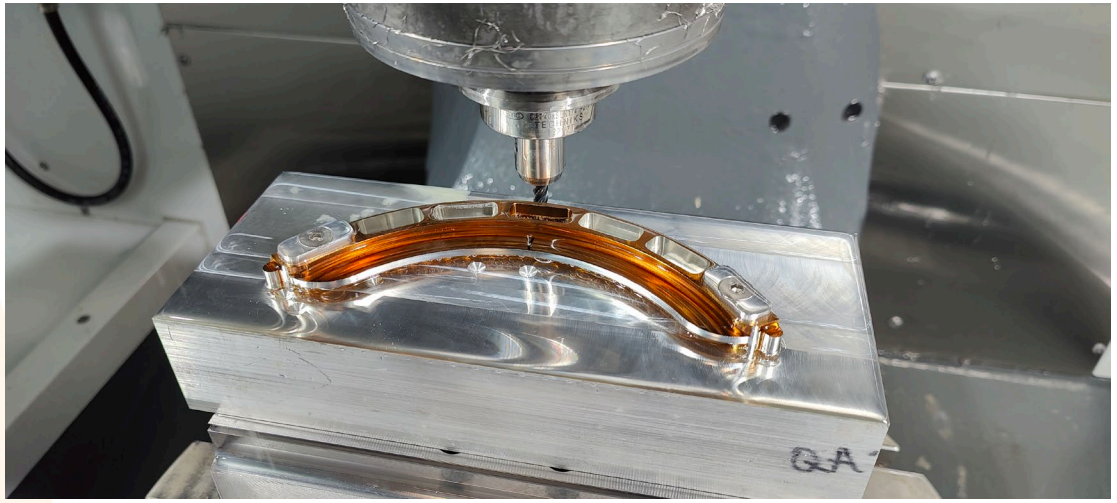
RCS Fabrication Status

- Procurement Progress
  - Over 200 separate items being tracked in procurement.
  - Approximately 150 delivered to MFC as of 2/16
  - Metal rough stock being prioritized in receipt inspection to support fabrication.
- Internal Fabrication Progress
  - Fabrication efforts have started on the stainless steel components of the Control Drums in WO 359037, with successful first article inspections.
  - Successful strategy developed for difficult materials with extremely tight tolerances.



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PCAT Testing Round 3

PCAT fabrication at INL

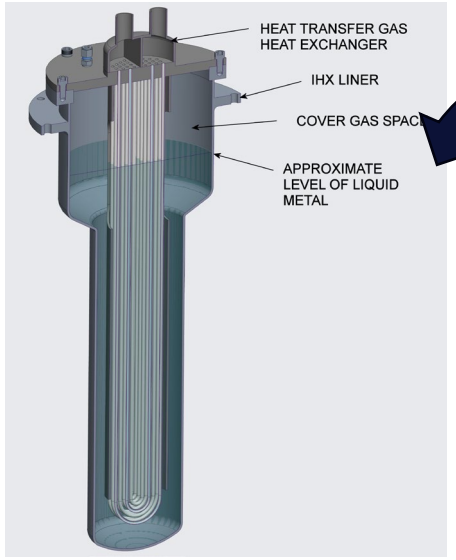
- Moving away from Stirling engines: replacing with fluid circulating in coil
- Finalizing EC/Engineering Paperwork
- Testing planned to restart in March
- Data Validation of RELAP
- Documentation finished April 30.

Stirling engine replacement with heating coils:

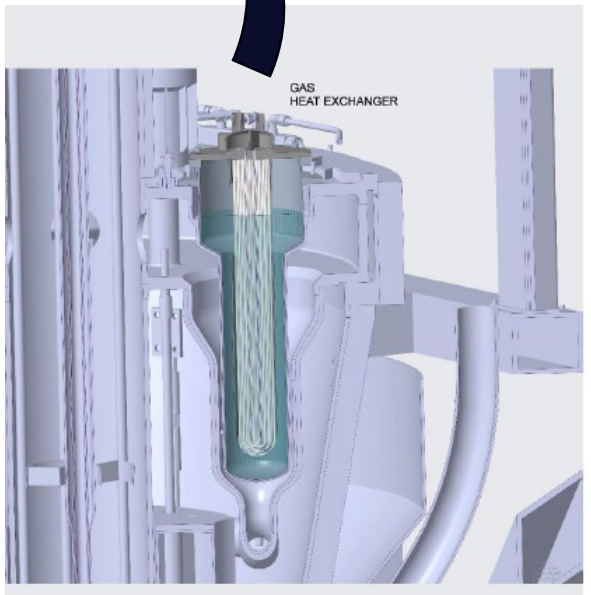
Heat Extraction System: Analysis of Alternatives

Combinations to Consider

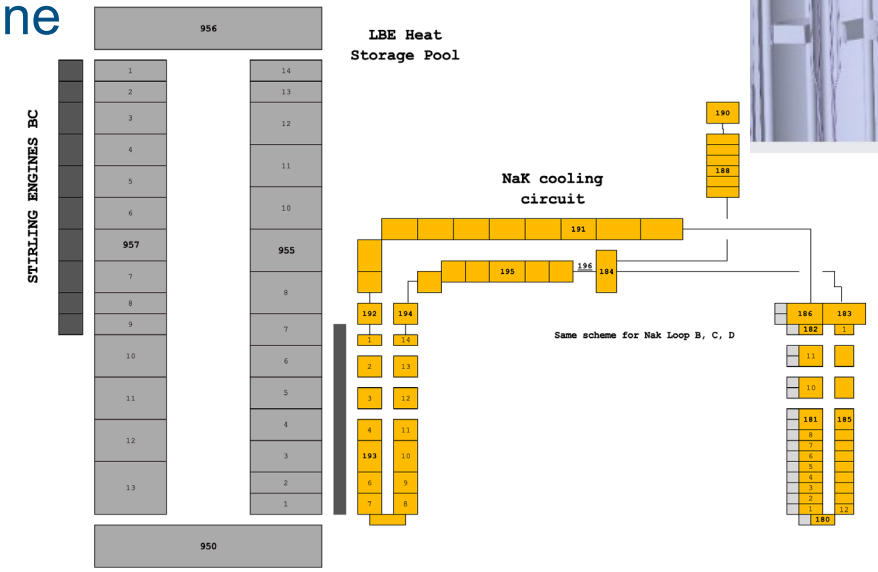
- **Working Fluid**: NaK, NaK+He
- **Interface**:
  - Direct heat exchanger
  - Thermal Energy System (TES):
    - Structure: two tank, one tank, solid (Concrete, PBS)
    - Fluid: None, NaK, Salt, LBE
    - Air Radiator: before, after, or none
- **Power conversion**: sCO2, Stirling Engines, Rankine



IHX + U-tubes



X configuration



RELAP model

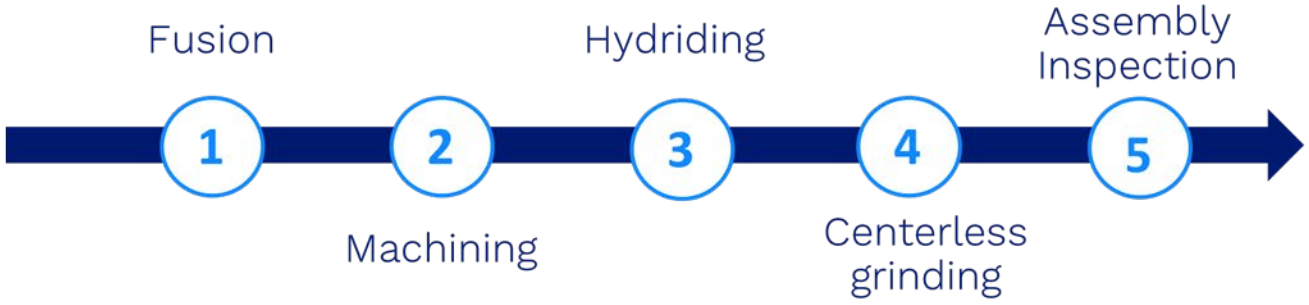
Microreactor Program

Fuel Fabrication

- Current Status: Fuel fabrication delayed until end of CY25, following release 10.
- Expected delivery July/August of 2026
- Maintains 6 months + of float to loading fuel.

U Metal 19.75%

Zirconium sponge



TRIGA Fuel Element

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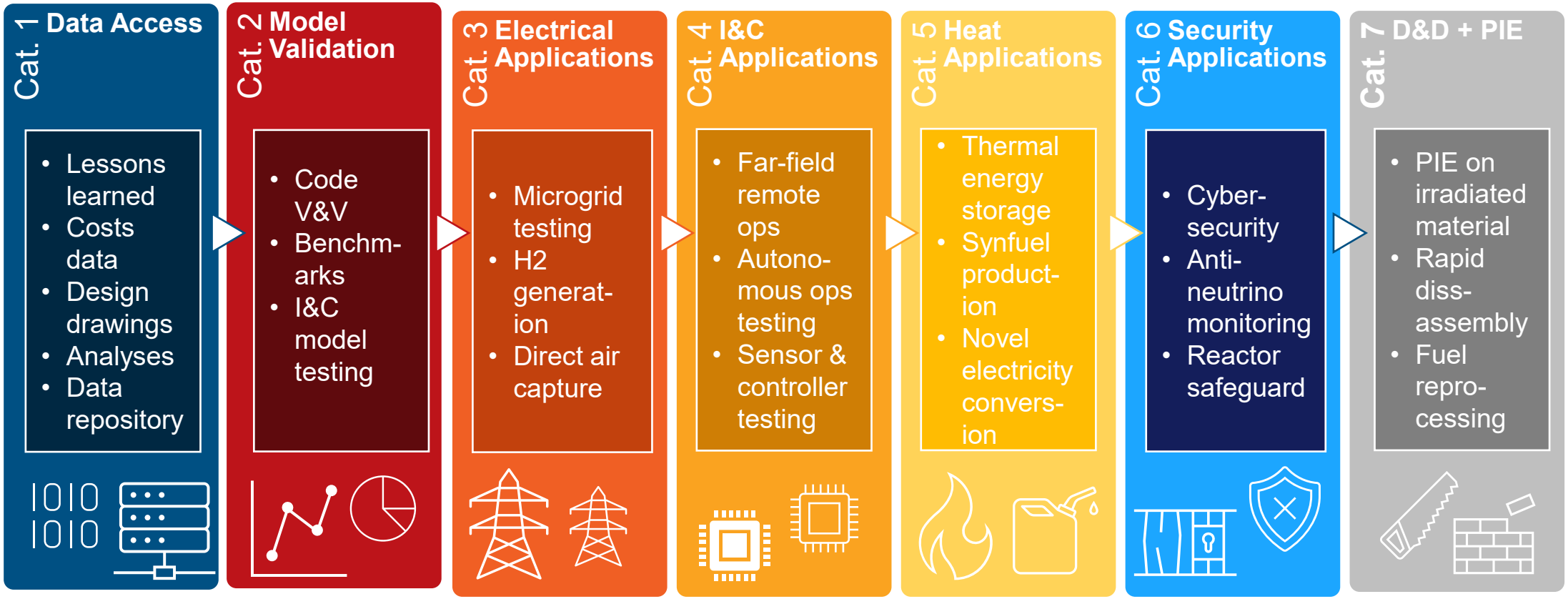
And many more possibilities!

Conceptual MARVEL Applications



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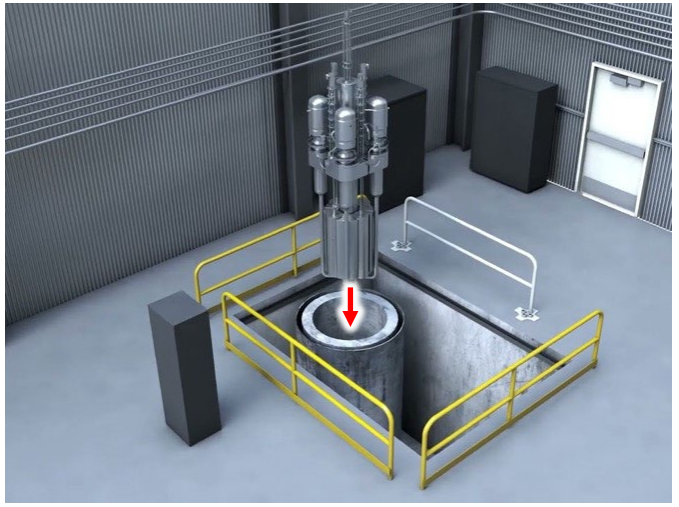
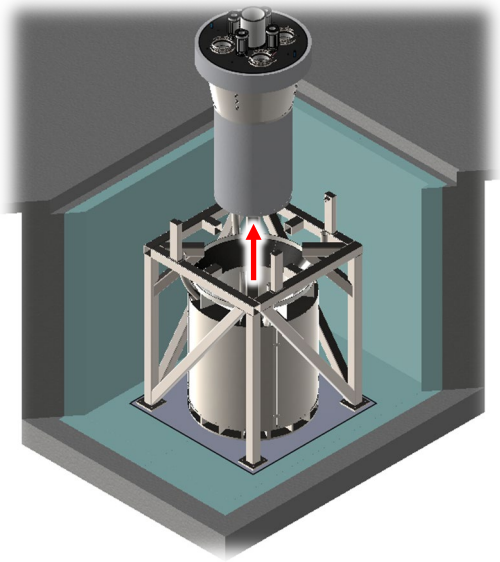
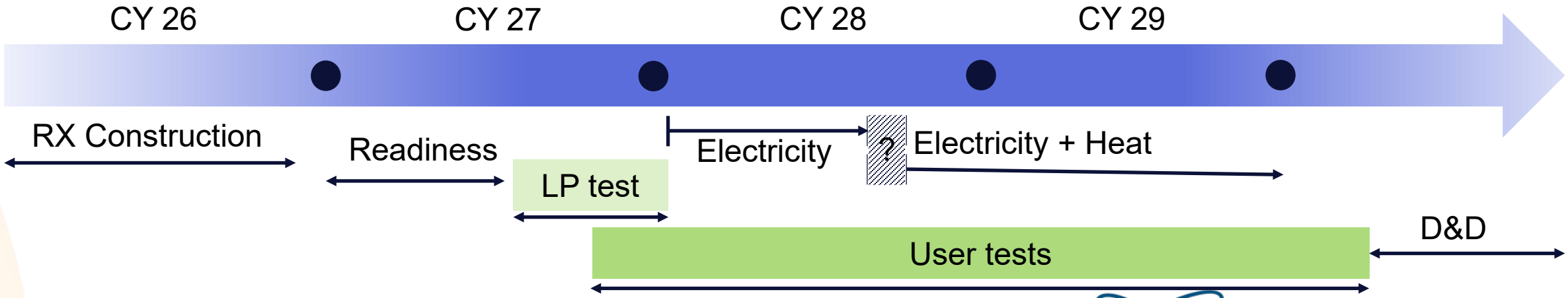
MARVEL HIGH-LEVEL TIMELINE (TENTATIVE)







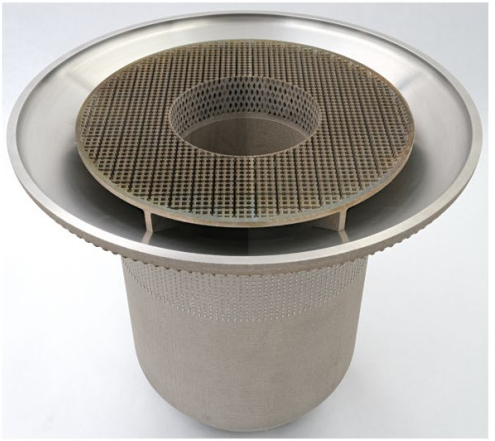
MRP Microreactor Program

Ongoing Collaborations with other DOE Programs

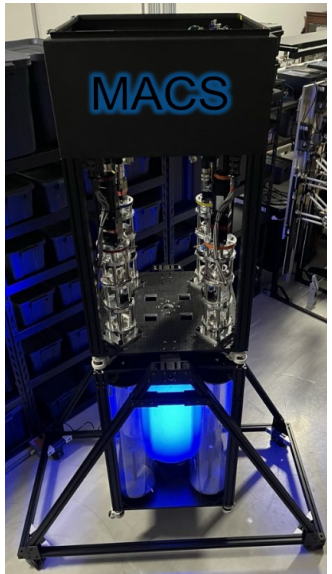
Example Use Cases:

- **IES**: combined nuclear heat & electricity demo
- **DOE-OE**: nuclear microgrid evaluations
- **ASI**: new sensors & controls demo
- **NEAMS**: software V&V
- **ARSS**: nuclear cybersecurity assessments
- **AMMT**: in-service operation of 3-D printing components
- **SA&I**: leveraging MARVEL cost data

AMMT Program: 3D-printed liner for MARVEL



ASI Program: COMMAND control system deployed on MRP's MACS platform in MARVEL configuration



SA&I Program: Economics of microreactor mass production

How to Engage? Some *Suggestions*…

Timeline | Engagement

- **When do you need to perform these tests?**
  - ~CY27 Q3: Startup testing & benchmarks
  - ~CY28 Q1: Microgrid applications
  - ~CY28 Q3: I&C and HMI
  - ~CY28 Q4 & beyond: Heat applications

Fill out the pre-engagement questionnaire

Funding Opportunities

- **Private Sector**
  - Subcontract: CRADA, SPP
  - GAIN vouchers (apply in 2026!)
- **National Labs**
  - DOE-sponsored programs
  - Lab Directed Research and Development (LDRDs)
- **University**
  - NEUPs on harvesting/processing data?
  - IRPs on hardware testing?
  - Submit in 2025 CINR call!
- **Future:** MARVEL FEEED Study?

Report:
A. Abou-Jaoude, M. W. Patterson, "MARVEL Utilization Plan", Idaho National Laboratory, INL/RPT-24-78261, June 2024, https://www.osti.gov/biblio/2371533

MRP Microreactor Program

Questions?

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MRP Microreactor Program

Option 1 for alternative cooling

- He pressure: 20 barg (Aerzen model GM-HP compressor not suitable for p > 25 barg)
- He loop mass flow: 0.0583 kg/s
- Natural circulation in the LBE pool
- Constrains: **keep core outlet temperature ~ 530 ºC** (safety limit from ULOF, could be revised upward..)

Reference case

Parameters	Primary (NaK)	Secondary (NaK)	Tertiary (He)	Pool (LBE)
Maximum temperature, ºC	529	454	425	371
Minimum temperature, ºC	472	421	381	322
ΔT	57	33	44	49
T average	500	437	403	346
Reactor power, kW_{th}	65.0			
Thermal power removed by Stirling engines, kW_{th}	52.3			
Electric power produced, kW_e	~8.9			

Option 2 for alternative cooling

- Reference case run for secondary NaK mass flow: 0.6 kg/s
- Natural circulation in the LBE pool
- Constrains: **keep core outlet temperature ~ 530 ºC** (safety limit from ULOF, could be revised upward..)

Reference case

Parameters	Primary (NaK)	Secondary (NaK)	Pool (LBE)
Maximum temperature, ºC	523	438	403
Minimum temperature, ºC	462	407	350
ΔT	61	31	53
T average	492	422	376
Reactor power, kW_{th}	73.0		
Thermal power removed by Stirling engines, kW_{th}	65.7		
Electric power produced, kW_e	~11.2		

MARVEL Special Issue in *Nuclear Technology* Journal

1. Foreword: Special issue on the MARVEL Project (carlo.parisi@inl.gov)
2. MARVEL project: Mission and system description (john.jackson@inl.gov)
3. MARVEL Planned Applications (justin.johnson@inl.gov)
4. Analysis of hydrogen migration, dissociation, and release behavior in UZrH fuel rods in the MARVEL reactor using the BISON fuel performance code (ryan.sweet@inl.gov).
5. Thermomechanical evaluation of UZrH fuel behavior under transient and non-uniform operating conditions in the MARVELreactor(ryan.sweet@inl.gov).
6. MARVEL core neutronic design and modeling (travis.lange@inl.gov)
7. MARVEL system thermal-hydraulic design and modeling (carlo.parisi@inl.gov)
8. CFD and thermo-mechanical Modeling and Simulation of Sodium-Potassium-Cooled MARVEL Microreactor Core (sujongyoon@gmail.com, carlo.parisi@inl.gov)
9. Large Eddy Simulation of Low Reynolds Number Turbulent Flow of Low Prandtl Number Fluid in a Tight Lattice Bundle for Assessment of Reynolds-Averaged Navier Stoke Turbulence Model (sujongyoon@gmail.com, carlo.parisi@inl.gov)
10. Structural design and modeling of MARVEL Primary Coolant System using ASME Sec. III Div. 5 code (messner@anl.gov)
11. MARVEL Safety analysis strategy and main results (doug.gerstner@inl.gov)
12. MARVEL Instrumentation, Control, & Software Considerations (Andrew.Heim@inl.gov)
13. Marvel Reactor Control System design (anthony.crawford@inl.gov)
14. PCAT (Primary Coolant Apparatus Test) design (carlo.parisi@inl.gov)
15. PCAT first test results (? Pending ?)
16. MARVEL Authorization process (doug.gerstner@inl.gov)
17. MARVEL Microreactor economics (Abdalla.AbouJaoude@inl.gov)

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