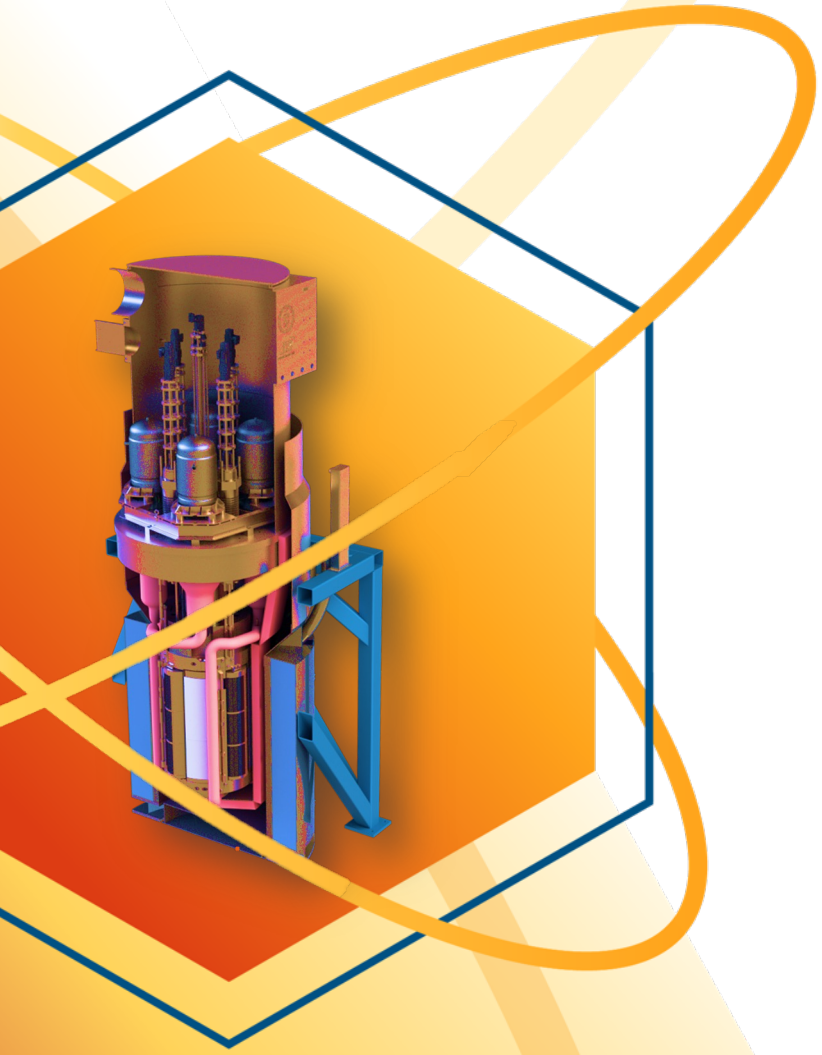


(Microreactor Applications Research, Validation & EvaLuation),
June 2023

MARVEL

Project Update: Final Engineering & Construction

Yasir Arafat

MARVEL Chief Designer & Project Lead

Idaho National Laboratory, USA

the global challenge

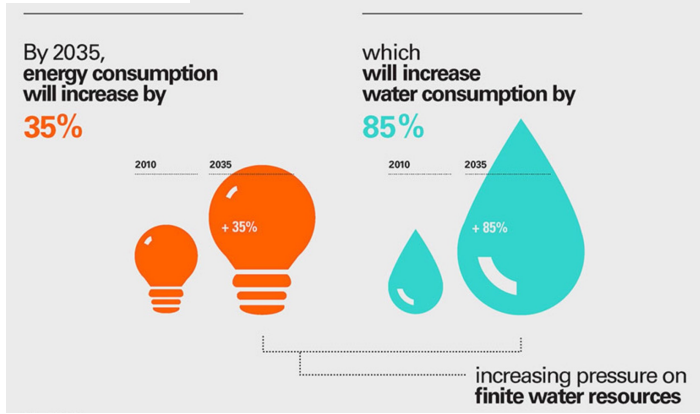
of the
7 Billion people on Earth today,

legend

= 100 Million

2.5 Billion
have unreliable or no access to electricity
Source: EIA, 2012

2.8 Billion
live in areas of high water stress
Source: WWAP, 2012



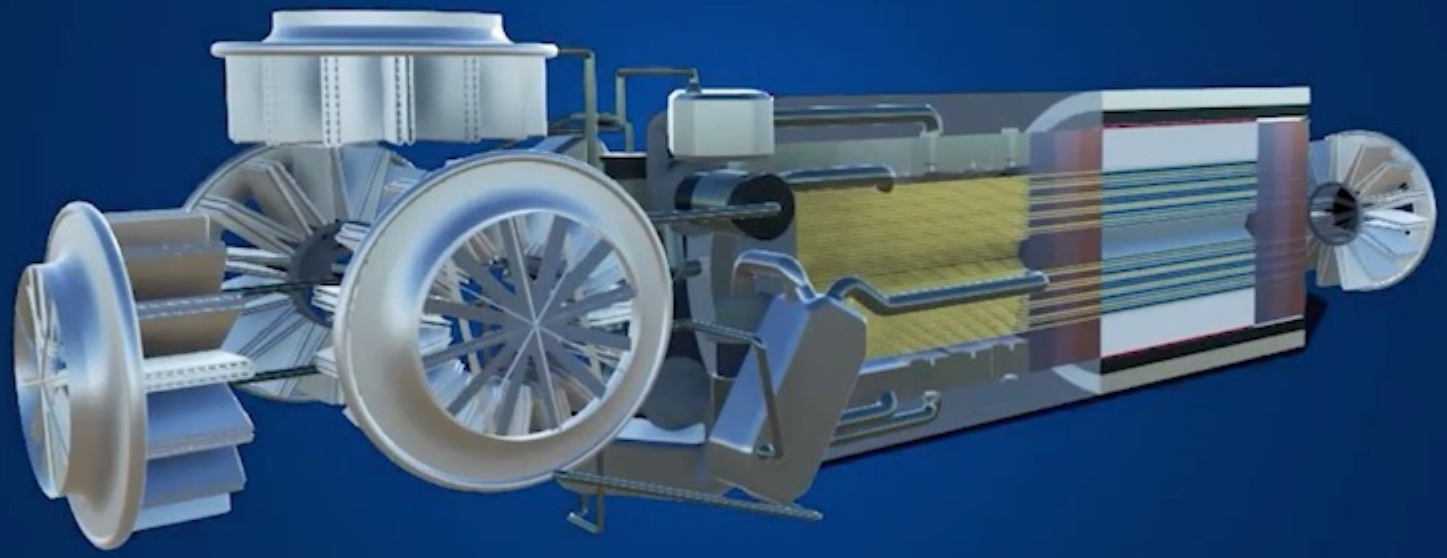
MRP Microreactor Program

LARGE, CONVENTIONAL REACTOR
700+ MW(e)

SMALL MODULAR REACTOR
Up to 300 MW(e)

MICROREACTOR
Up to ~10 MW(e)

MICROREACTORS

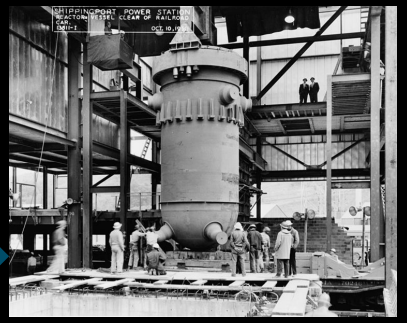


SMALL REACTORS, BIG POTENTIAL

Impact of INL's work on Nuclear Industry

EBR-I (INL)

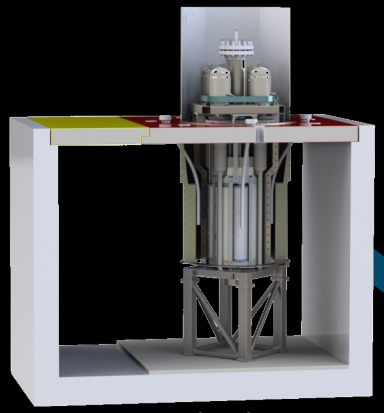
Commercial



Commercial Demo

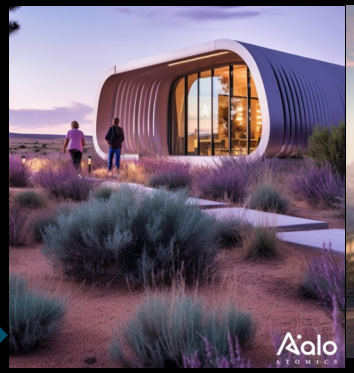
Commercial LWR

LWR 1951 1953 1954 1957 1960



MARVEL (INL)

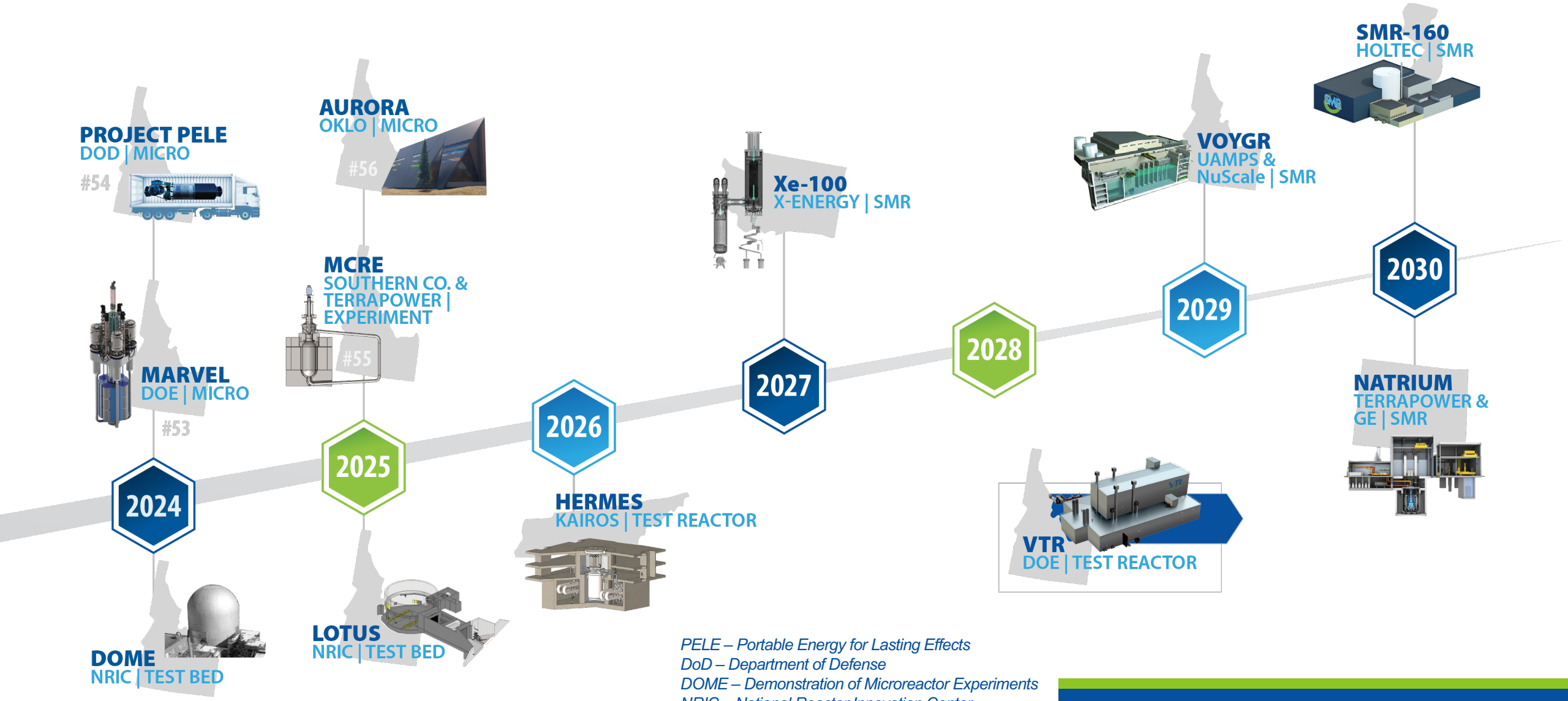
Commercial



Commercial Microreactors

Microreactor 2023 2024 2025+

Accelerating Advanced Reactor Demonstration & Deployment



PELE – Portable Energy for Lasting Effects
DoD – Department of Defense
DOME – Demonstration of Microreactor Experiments
NRIC – National Reactor Innovation Center
LOTUS – Laboratory for Operating and Testing in the U.

MARVEL Can Enable a New Class of Nuclear Reactors

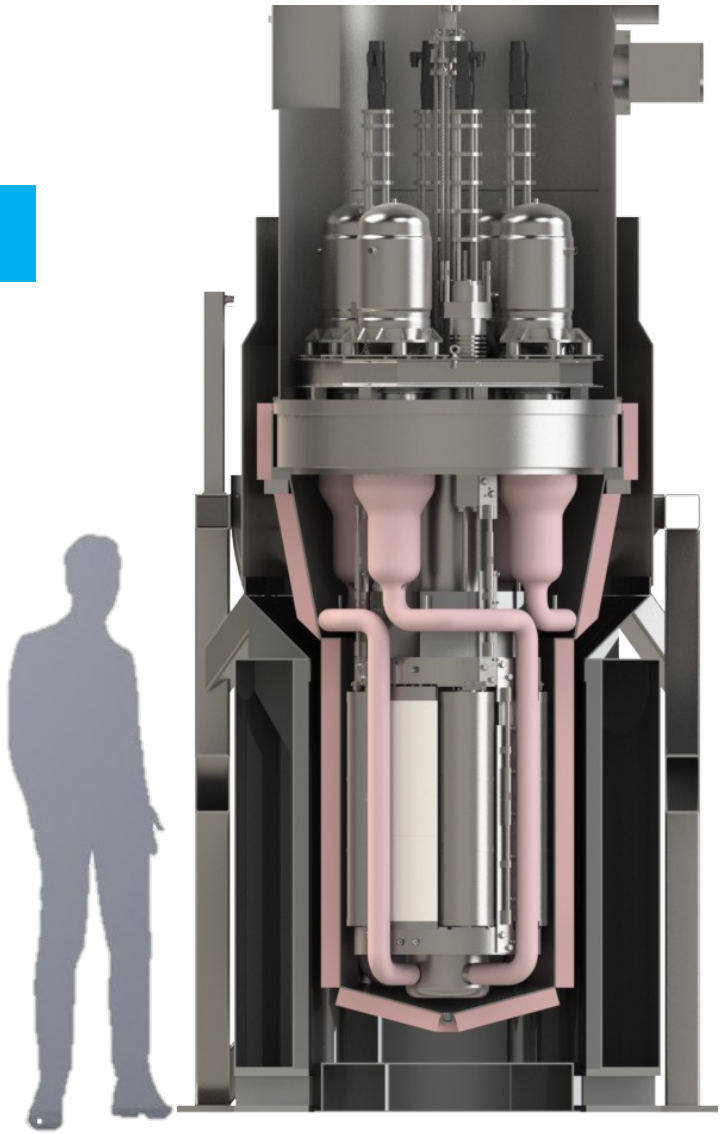
Project Goal: Build a Test Microreactor ASAP

DOE Idaho Operations Office

Office of NUCLEAR ENERGY

Key Design Features	
Thermal Power	100 kW (85kW nominal)
Electrical Power	~20 kWe (QB80 Stirling Engines)
Primary Coolant	NaK eutectic
Fuel	HALEU-(UZrH), 304SS clad
Moderator	Hydrogen
Primary Coolant Boundary	SS316H

~7.5 metric tons
<15 feet tall



INL Idaho National Laboratory

Los Alamos National Laboratory

Argonne National Laboratory

WALSH Engineering Services

Qnergy Reliable Remote Power

Creative Engineers, Inc. United States | Canada | International

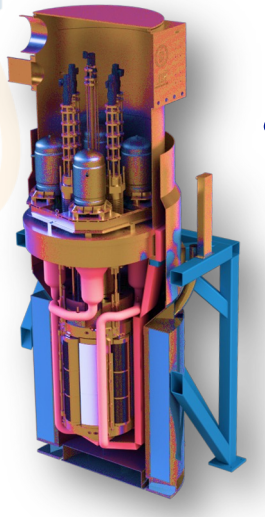
PREMIER Technology, Inc.

MATERION

MRP Microreactor Program

MARVEL Value Statement for Developers

Aalo ATOMICS · Westinghouse · BWXT BWX Technologies, Inc. · Xenergy · RADIANT · OKLO · GENERAL ATOMICS · HolosGen

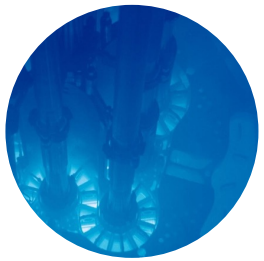


"With many companies working on microreactor concepts behind closed doors, I see unique value in having a system that can be shared and discussed across teams "

Fuel

Reactor Controls

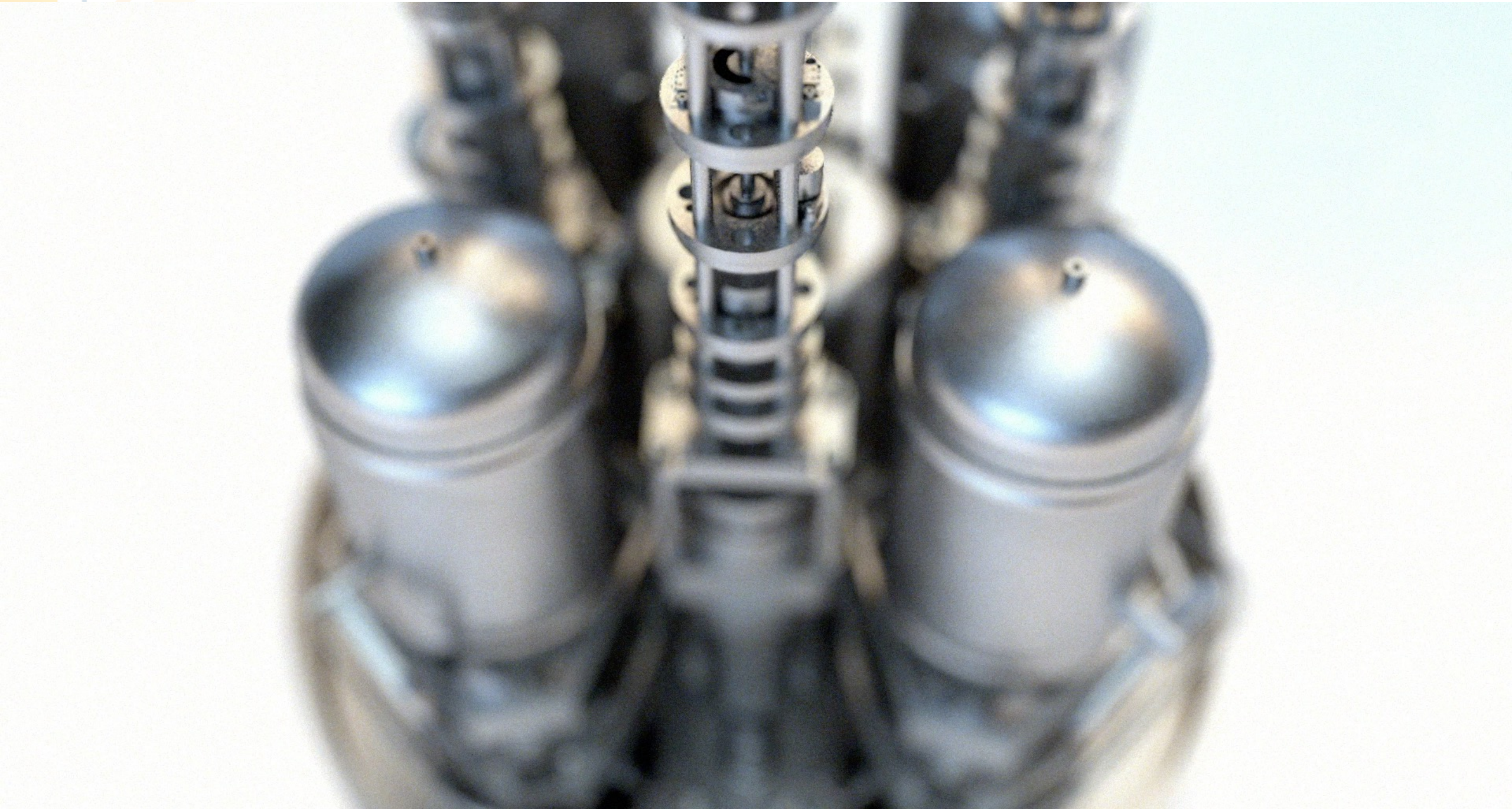
NEPA



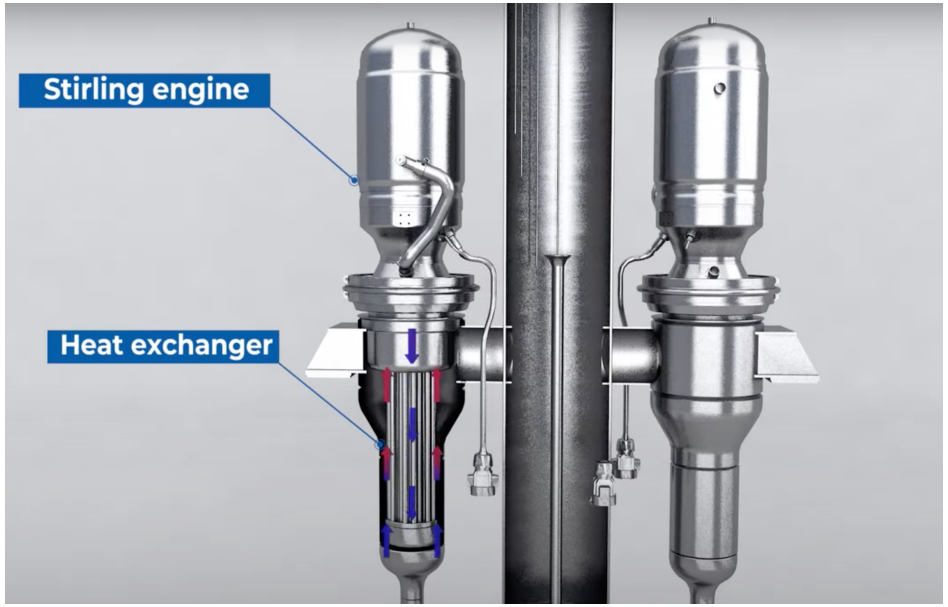
Fuel Loading

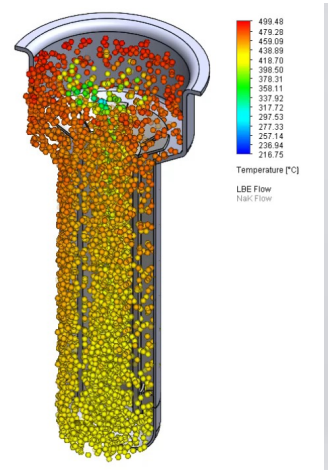
Power Conversion

MRP Microreactor Program




Convection loop

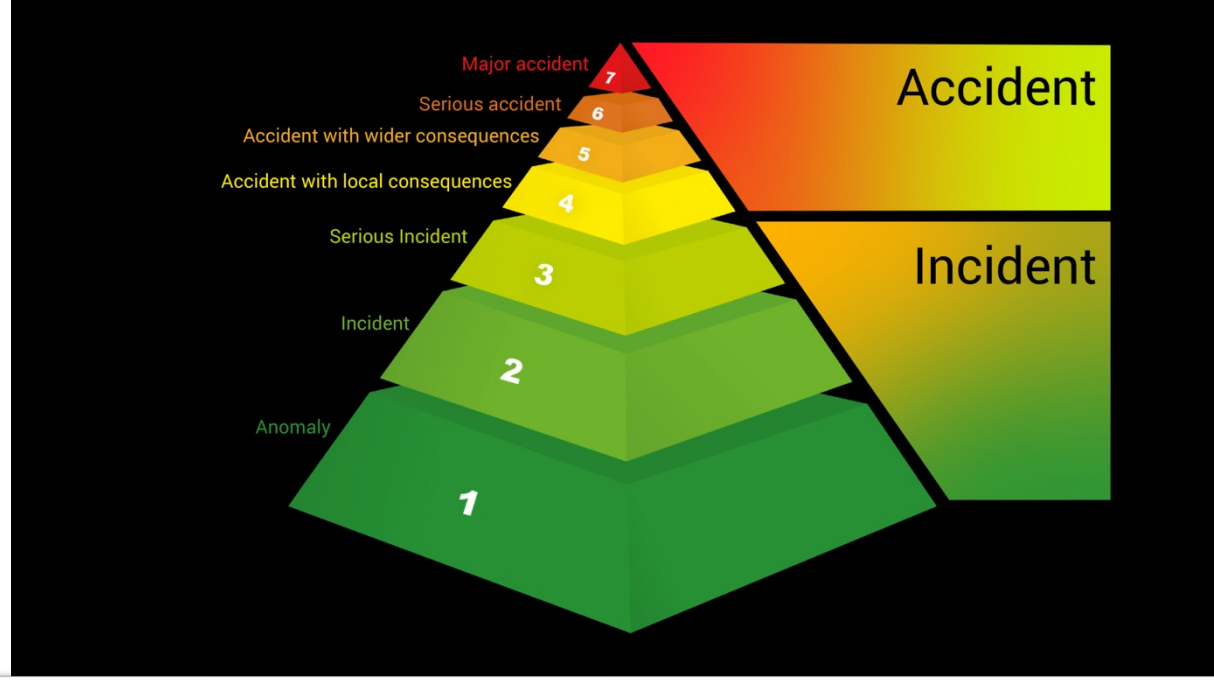

Stirling engine
Heat exchanger

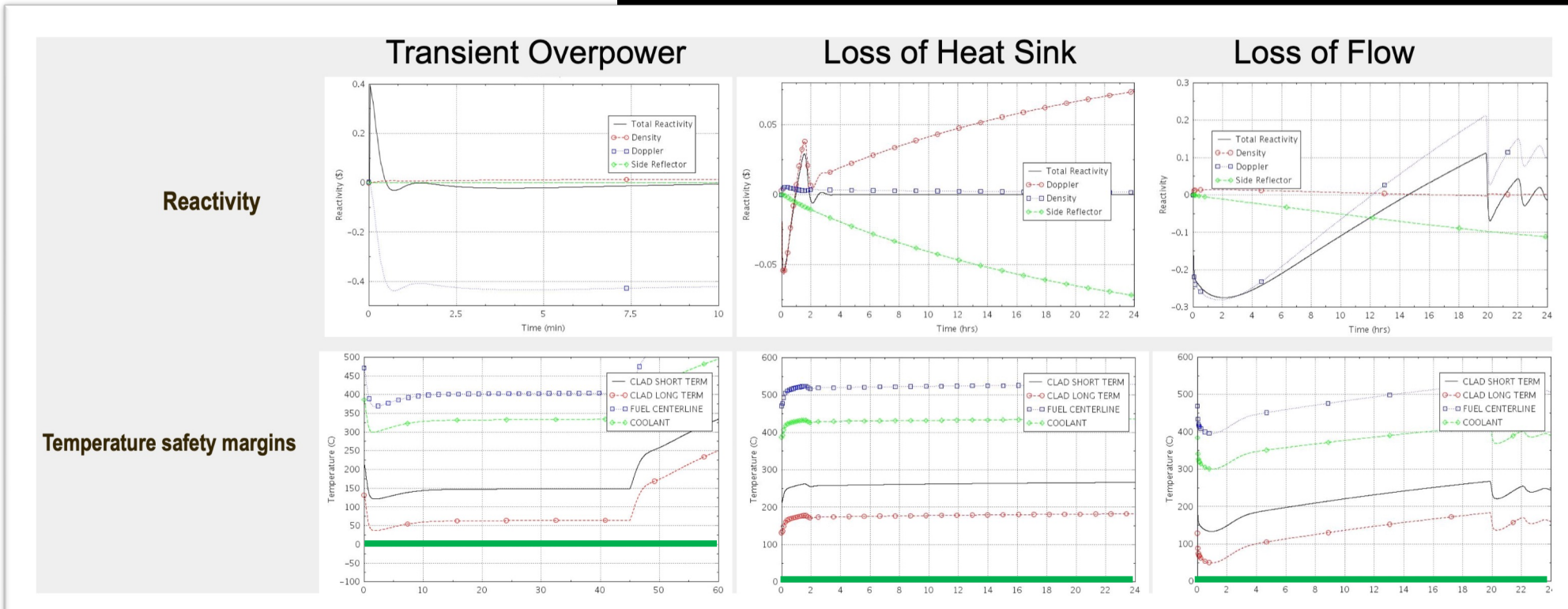

499.48
479.28
459.09
438.89
418.70
398.50
378.31
358.11
337.92
317.72
297.53
277.33
257.14
236.94
216.75
Temperature [°C]
LBE Flow
NaK Flow

Electromagnetic meter

Unparalleled Safety

- No safety concerns
- Even in the worst case, extremely unlikely cases





Rickover's Paper Reactor vs Practical Reactor

*"An **academic reactor** or reactor plant almost always has the following characteristics: (1) It is simple. (2) It is small. (3) It is cheap. (4) It is light. (5) It can be built very quickly. (6) It is very flexible in purpose ("omnibus reactor"). (7) Very little development is required. It will use mostly "off-the-shelf" components. (8) The reactor is in the study phase. It is not being built now.*

*On the other hand, a **practical reactor** plant can be distinguished by the following characteristics: (1) It is being built now. (2) It is behind schedule. (3) It is requiring an immense amount of development on apparently trivial items. Corrosion, in particular, is a problem. (4) It is very expensive. (5) It takes a long time to build because of the engineering development problems. (6) It is large. (7) It is heavy. (8) It is complicated."*

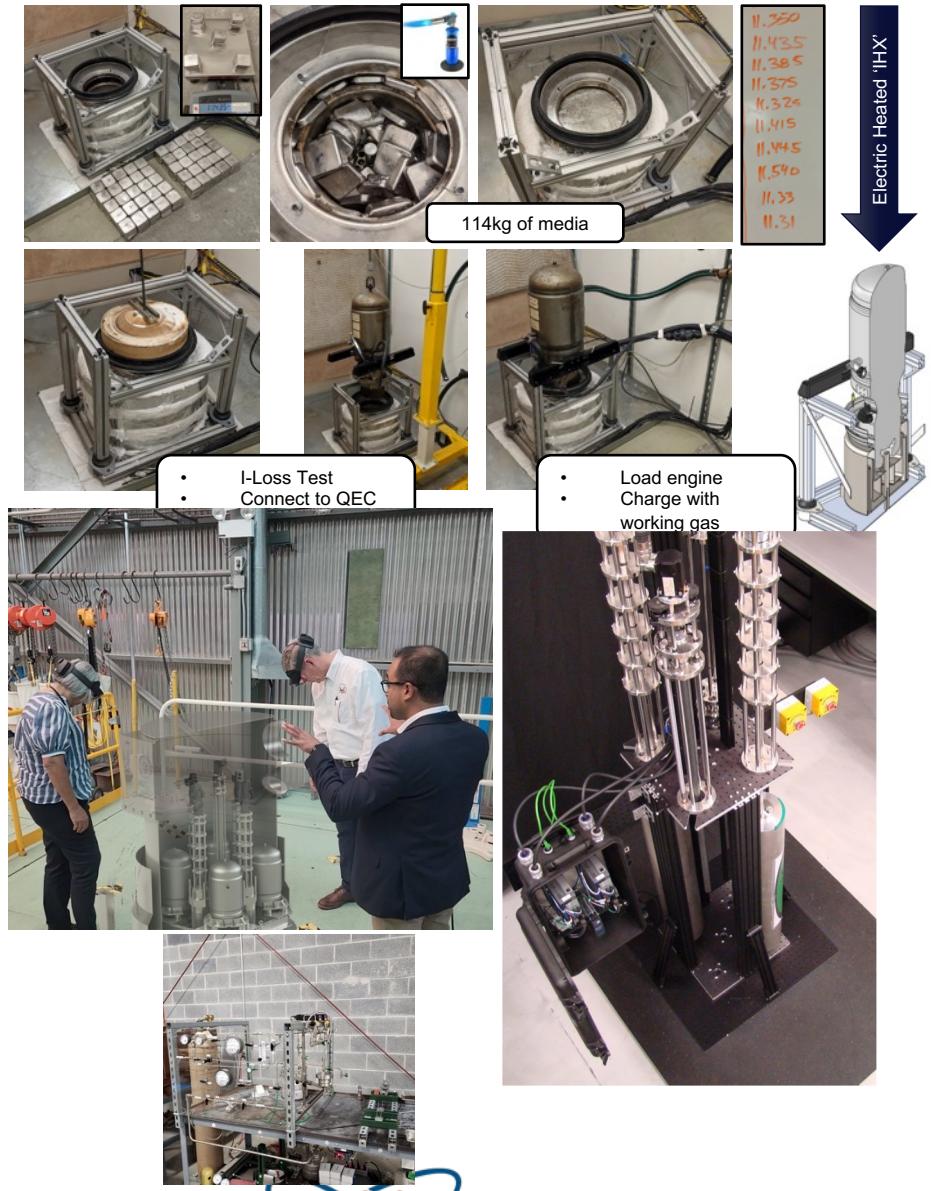
--Hyman Rickover, 1953

"The Father of the Nuclear Navy"

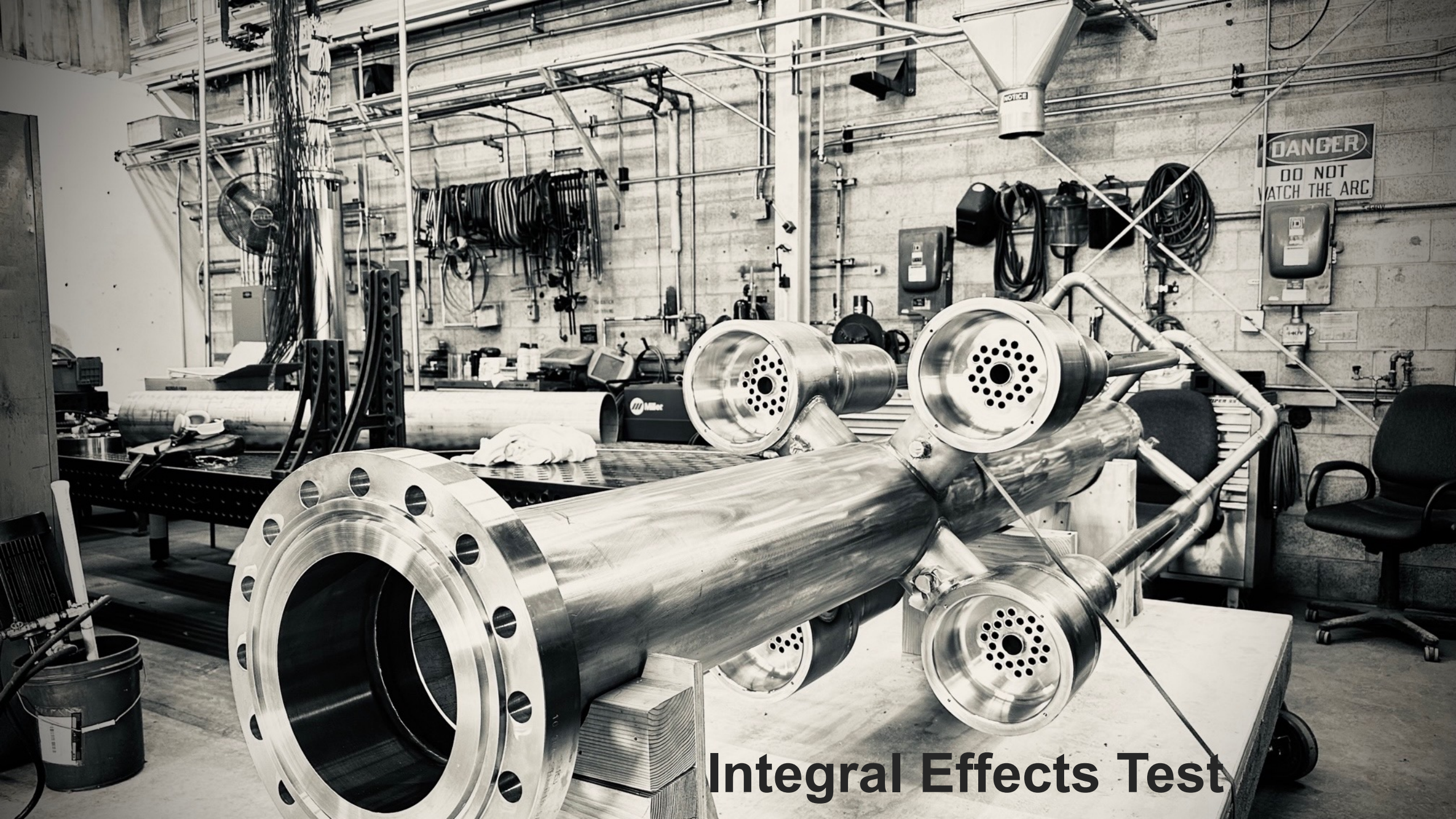
MRP Microreactor Program

Multiple Separate Effects Tests for Rapid Learning

1. Stirling Engine Operation and Control
2. Fuel Pin Fabrication and Assembly
3. Control Drum Actuator functionality- V1
4. Intermediate Heat Exchanger Test using PbBi
5. Reactivity Control Cabinet Prototype-
6. Control Drum Actuator functionality- V2
7. Reactivity Control system Qualification Test Rig
8. Central Insurance Absorber actuator
9. Neutron Detector circuit test at TREAT
10. MARVEL HMI and Simulator
11. Mixed Reality Control Room MVP
12. Alkali Metal Flow Meter Calibration



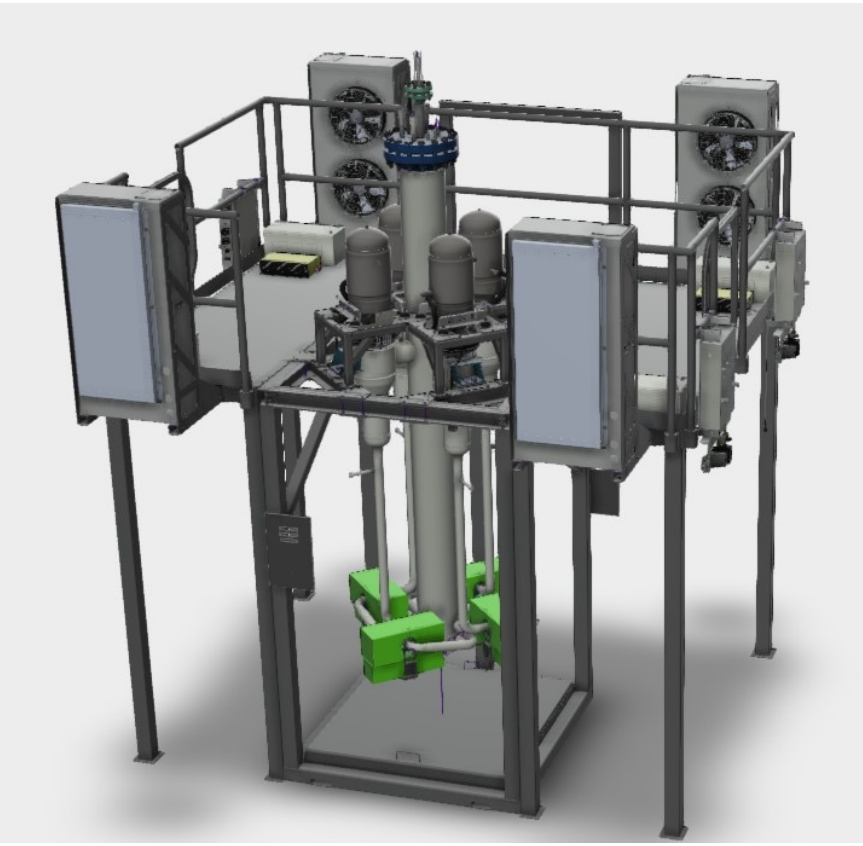
MRP Microreactor Program



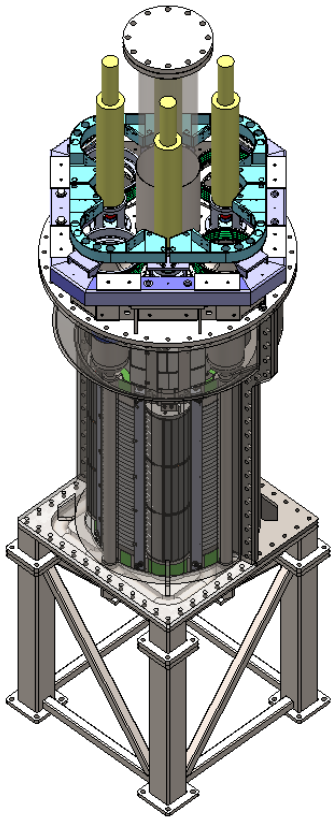
Integral Effects Test

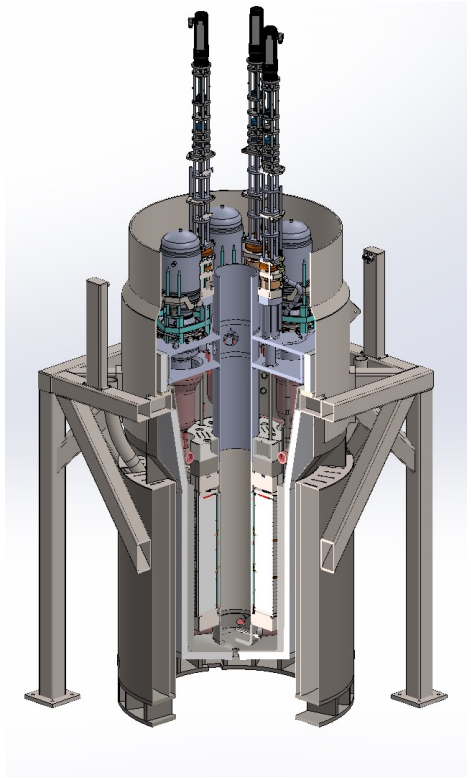
Integral Effects Test: Support structure fabrication

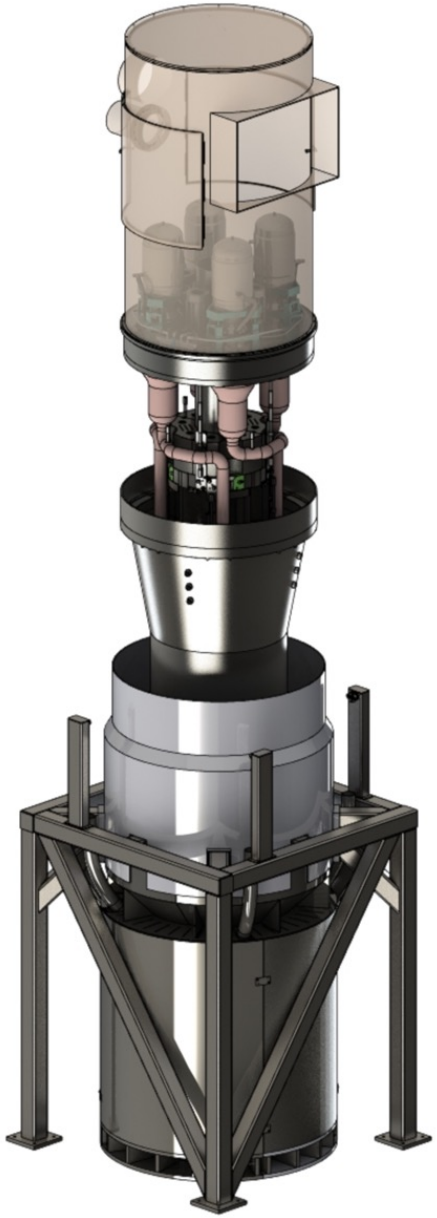
- Fabricated PCAT platform, handrails, ladders, removable PCAT stand, containment pan, and engine mounts
- All 300-series stainless steel construction
- Certified welders w/ sign-offs
- Received electrical panels, Stirling engines, other equipment in June 2022
- Received PCAT in April 2023 (dedicated, custom skid); mounted PCAT in frame 2 weeks later

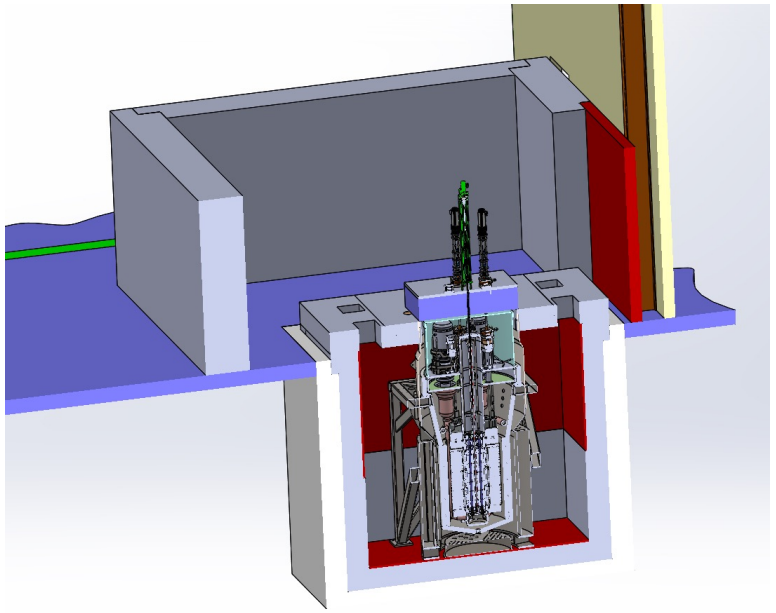


Design Evolution (last 18 months)



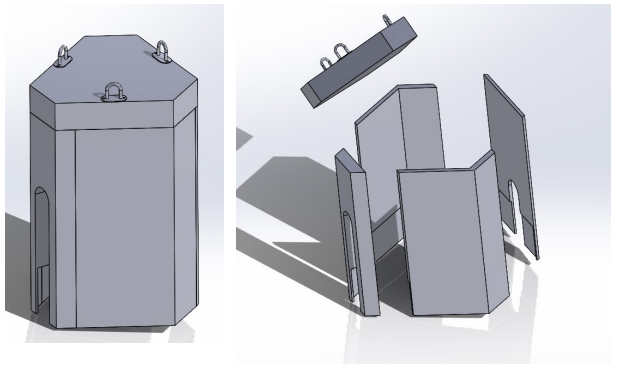


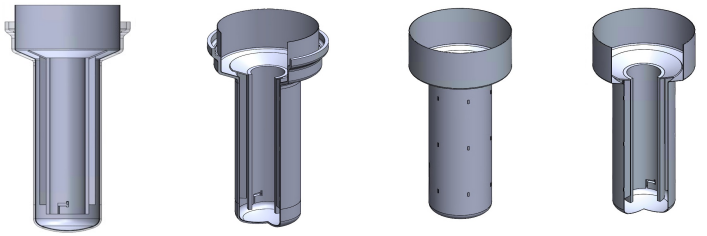


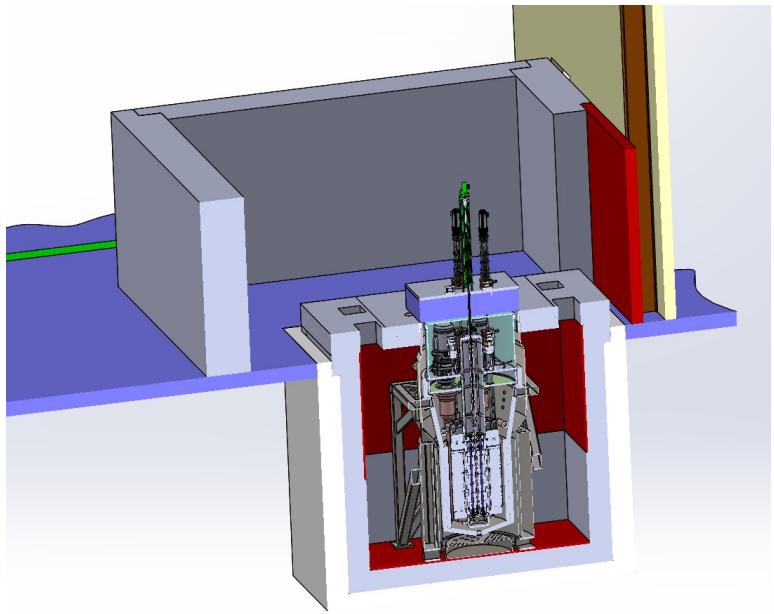


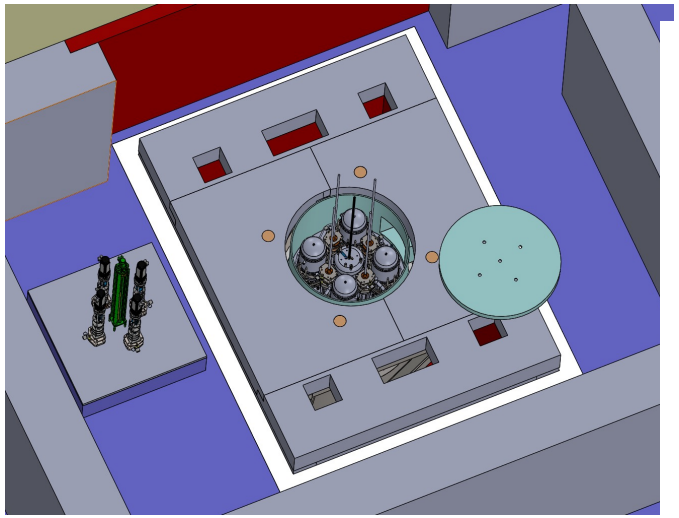
Active Design Activities for Final Design

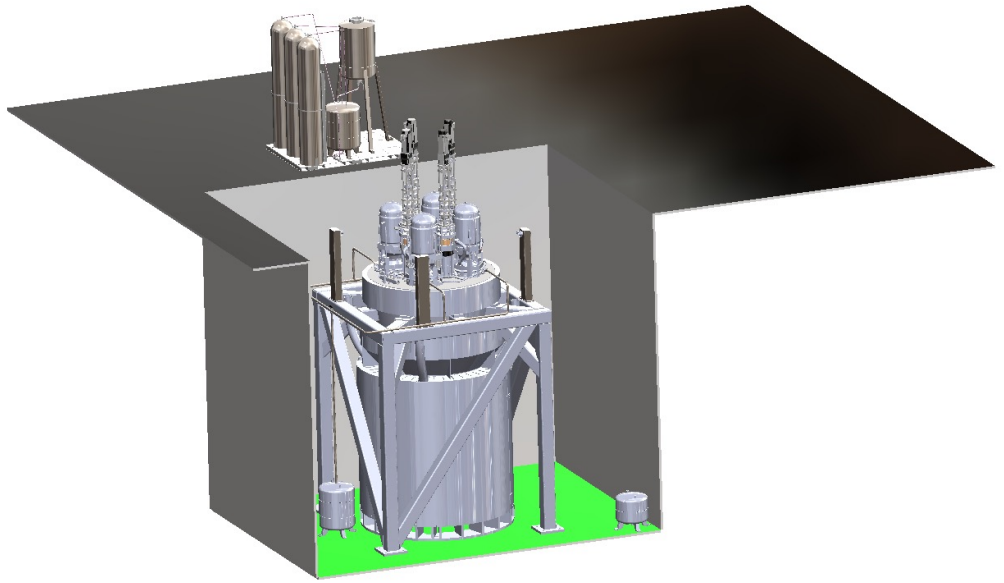
- Shielding for CD actuators
- Shielding for Stirling engines
- Secondary coolant freeze/thaw





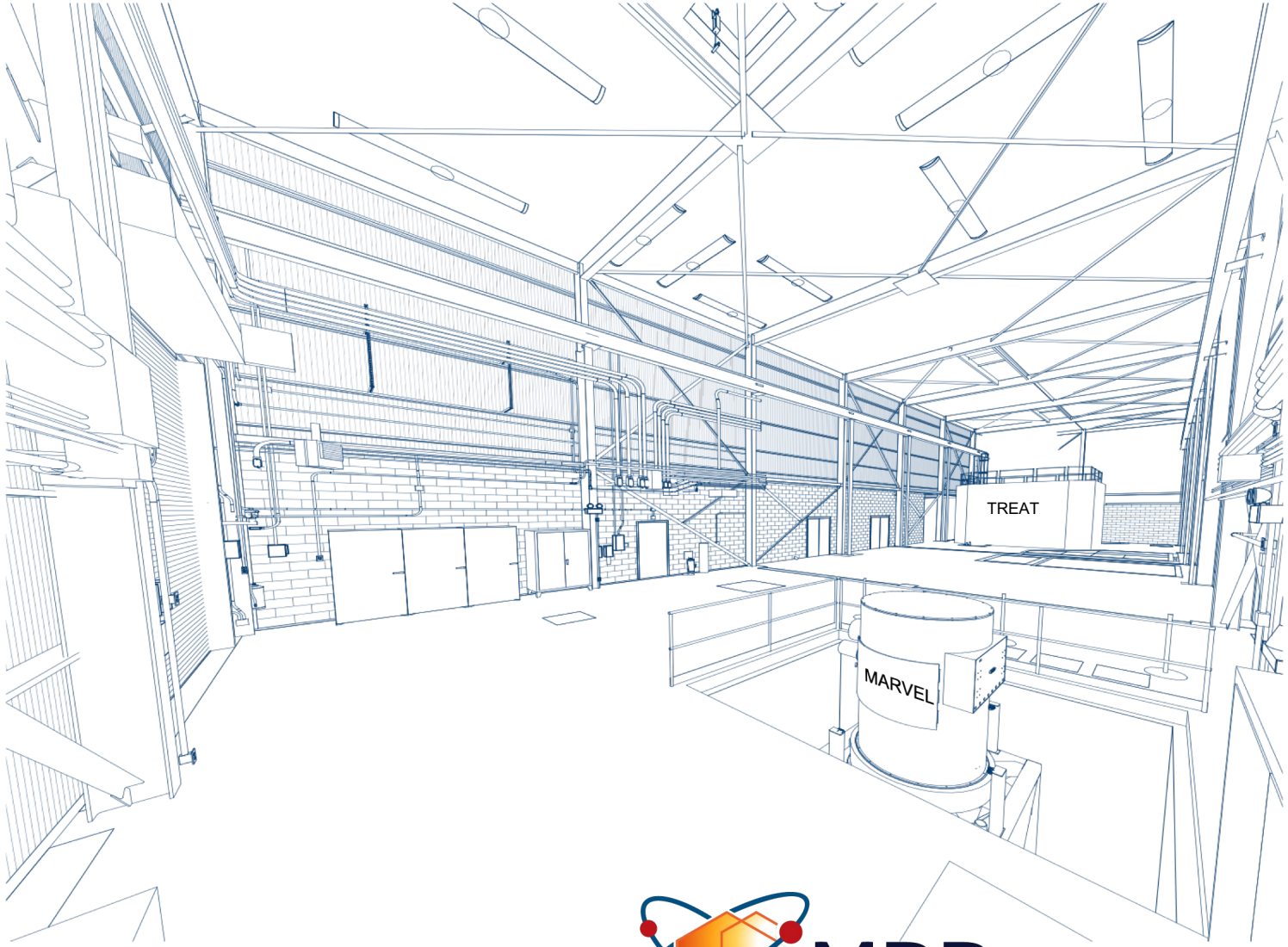






Initiation of MARVEL Construction Phase

- **Final Design Review (completed)**
  - Live Review- Sept 2022
  - 4-weeks review period
  - 440+ comments received
- **Reconciliation Engineering (ongoing)**
  - Resolutions formulated
  - Engagement of reviewers for concurrence
  - Formal process was established,
- **90% Design Completion, per DOE-STD-1189**
- Release of 260+ documents
  - Phases:
    technical review→ independent review → comments resolution→ signatures → EDMS Release→ Engineering verification
  - Summer 2023 target
- **Long Lead Procurements**
  - Purchased materials, LLP#1 (completed)
  - Fabrication Start, LLP#2 (initiated)

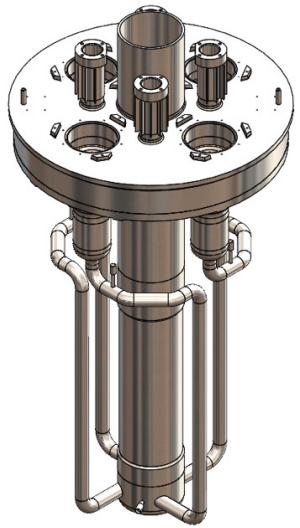


MRP Microreactor Program

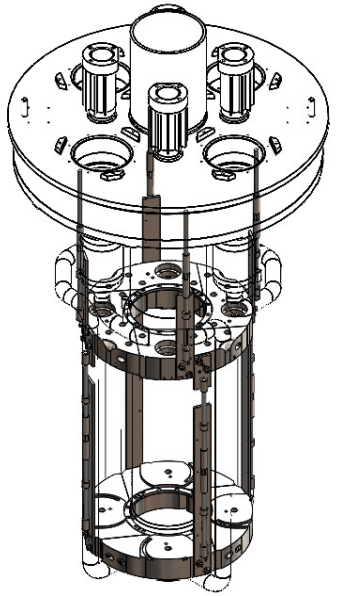
Long Lead Procurement Approvals from DOE

- **Long Lead Procurement # 1,2**
  - DOE-ID approval was received on April 26th
  - DOE-HQ concurrence on fab start
  - We have stamped and released drawings to fabricator.
  - Fabricator performed materials inspection to kick start “cutting metal”

Primary Coolant Boundary

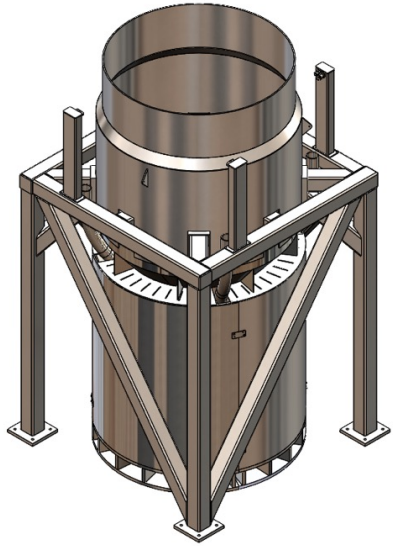


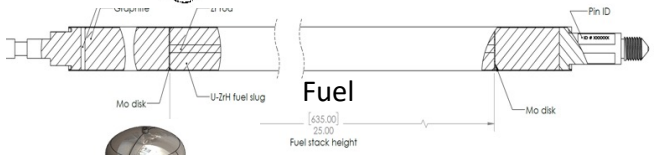
Reactor Support Structure



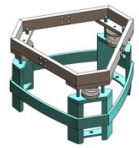
Guard Vessel

Reactor Support Frame





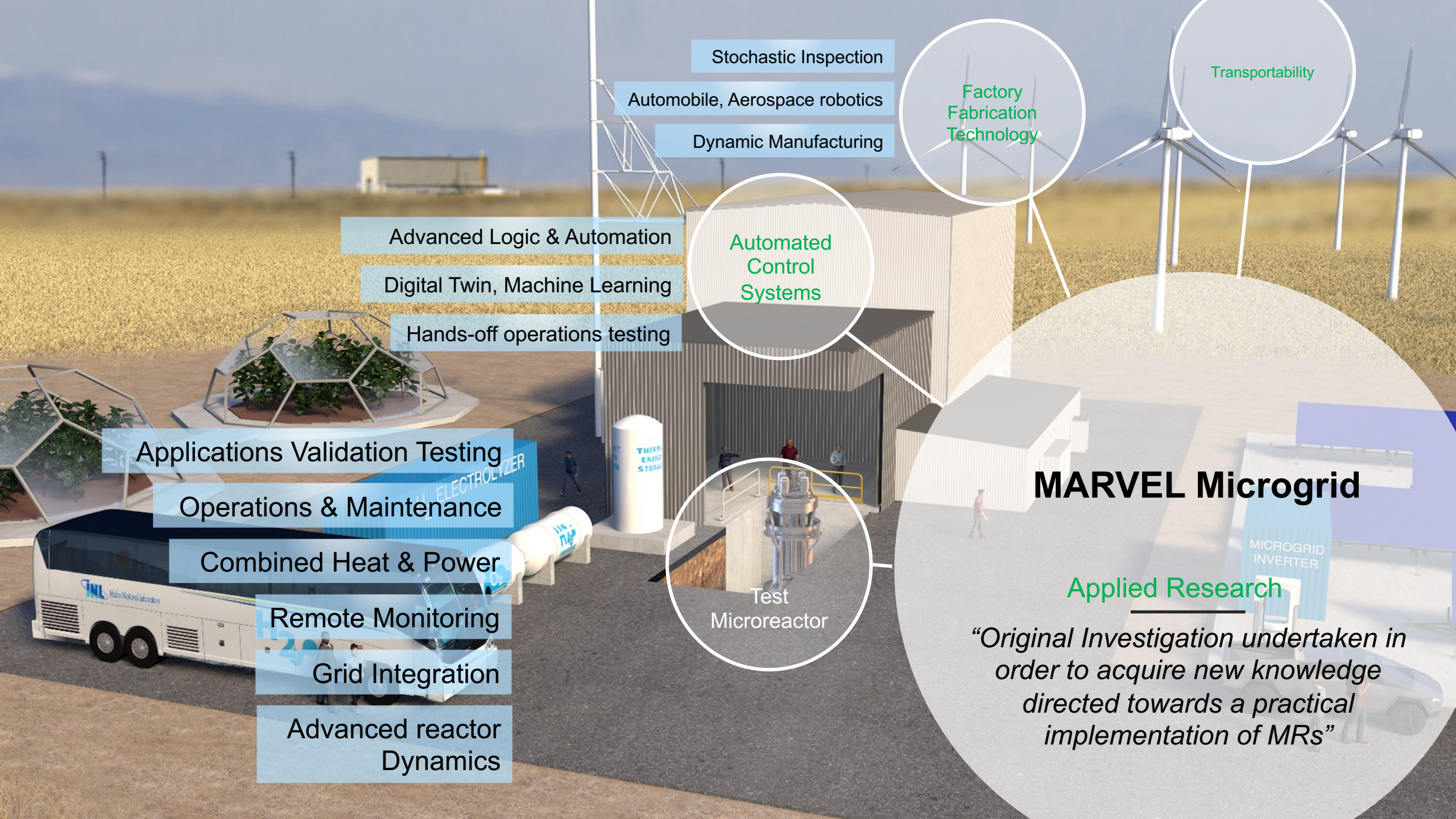
Stirling Engine



Secondary Support Structure

MRP Microreactor Program

MARVEL plans to:
Complete Construction by Summer 2024
load fuel by end of 2024


Stochastic Inspection
Automobile, Aerospace robotics
Dynamic Manufacturing
Factory Fabrication Technology
Transportability
Advanced Logic & Automation
Digital Twin, Machine Learning
Hands-off operations testing
Automated Control Systems
Applications Validation Testing
Operations & Maintenance
Combined Heat & Power
Remote Monitoring
Grid Integration
Advanced reactor Dynamics
Test Microreactor
MARVEL Microgrid
MICROGRID INVERTER
Applied Research
"Original Investigation undertaken in order to acquire new knowledge directed towards a practical implementation of MRs"

" "Small but Mighty: Unlocking a New Era of Energy with Microreactors"

- ChatGPT

Thank You