National Reactor Innovation Center

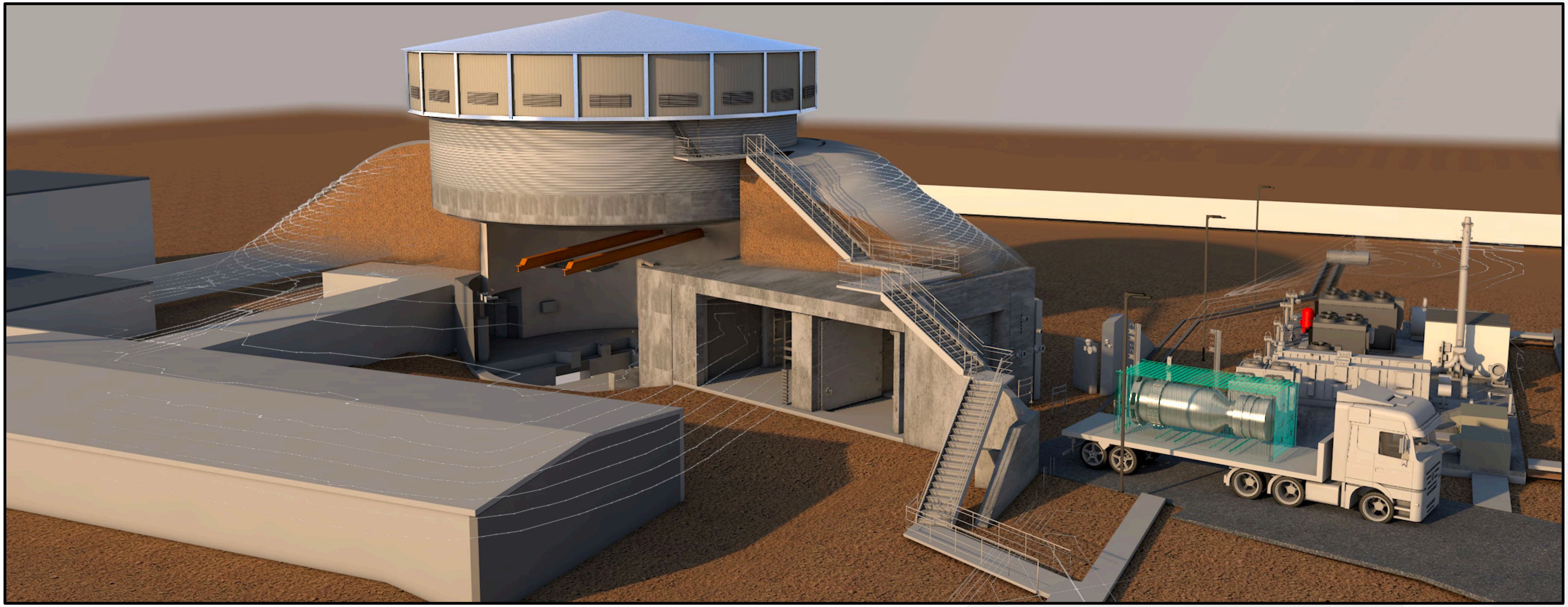
Laboratory for Operations and Testing in the United States (LOTUS)

NRIC Test Bed

NRIC-LOTUS Project Team – Aaron Balsmeier, Jacob Rymer, Scott Reynolds, and Scott Smith

04/23/2024

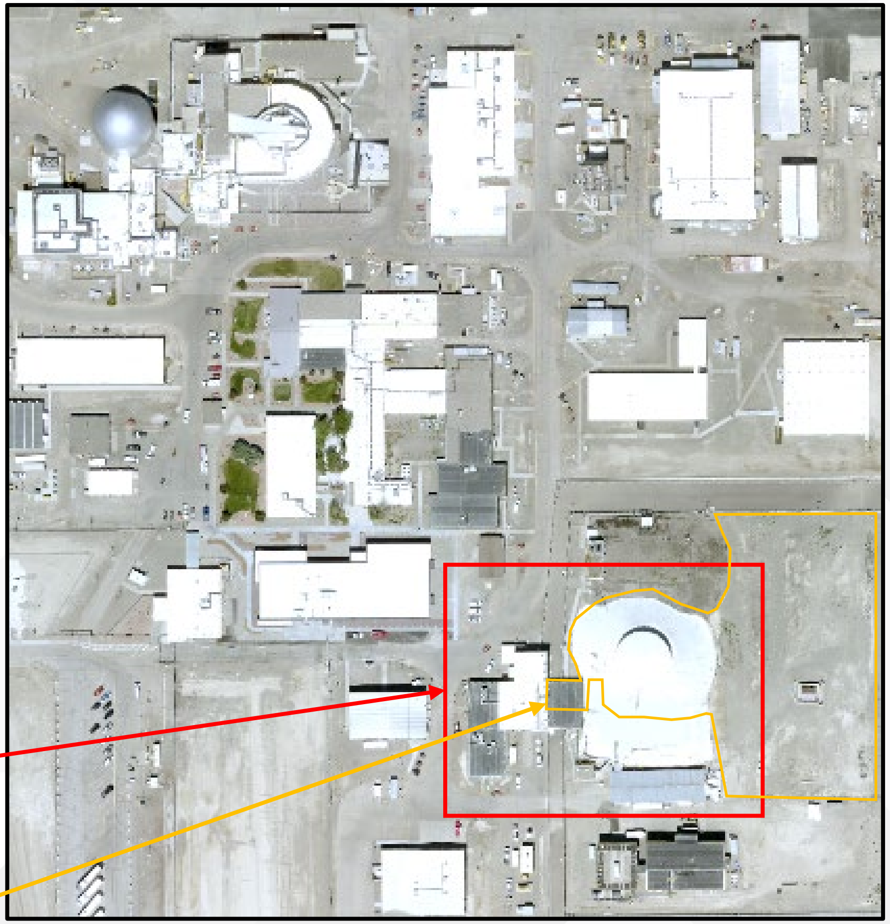
NRIC-LOTUS Test Bed



NRIC-LOTUS Information

Location: INL Materials and Fuels Complex (MFC); Zero Power Physics Reactor (ZPPR) Facility

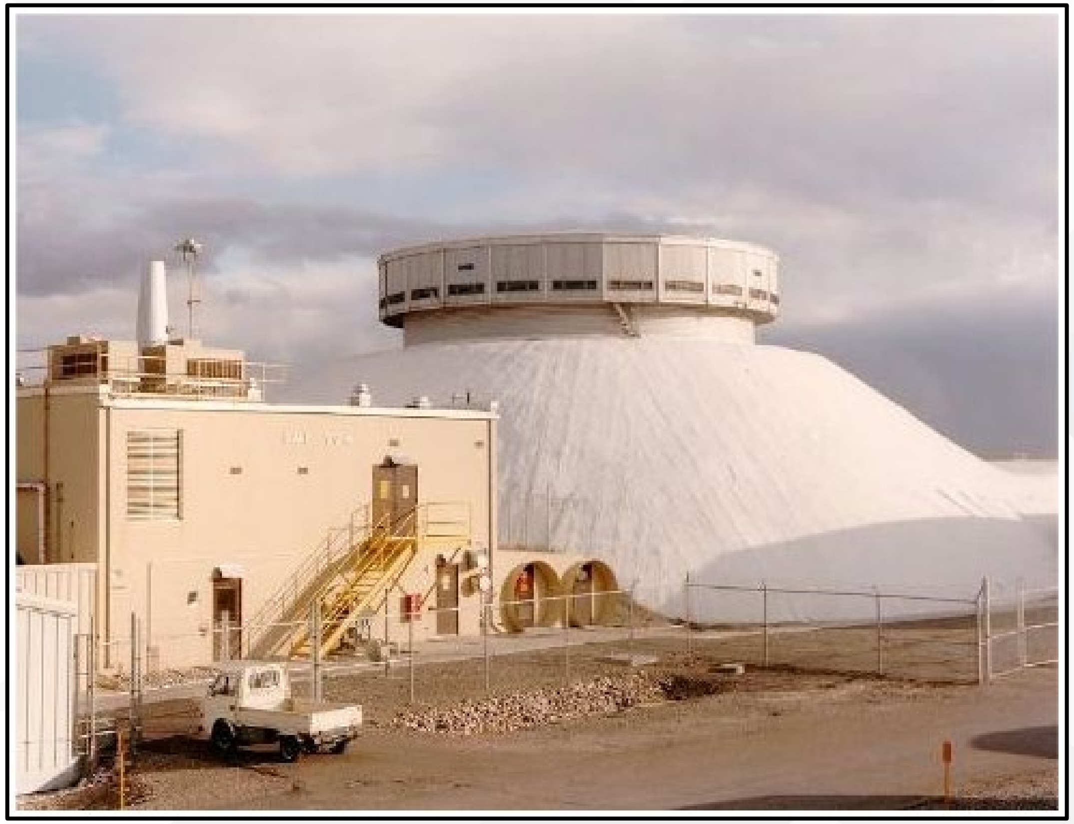
Purpose: Provides infrastructure to support DOE authorized experiments requiring a Hazards Category 2 facility with an elevated security posture



NRIC-LOTUS Design Details

Advanced Experimental Reactors

- Fuels designs with Highly Enriched Uranium
- Cell Heat Removal – (2) redundant HVAC packages – 50kW$_{th}$
- Reactor Heat Removal – Design only – Min: 25 kW$_{th}$; Max: 400 kW$_{th}$
- Argon Cover Gas – 2 scfm, 90 psig (SS), 15 scfm, 90 psig (1 hr max)
- In Cell Equipment Power
  - Normal – 480VAC, 450A, 3 phase
  - Auxiliary – 208VAC, 160A, 3 phase
- Cell Provides Radiological Confinement
- Cell Geometry – 30ft usable inner diameter; 16ft 11in (bottom of crane hook); Recessed pit area
- Entry Tunnel – 13ft x 13ft clear pathway
- Polar Crane Capacity – 5 tons



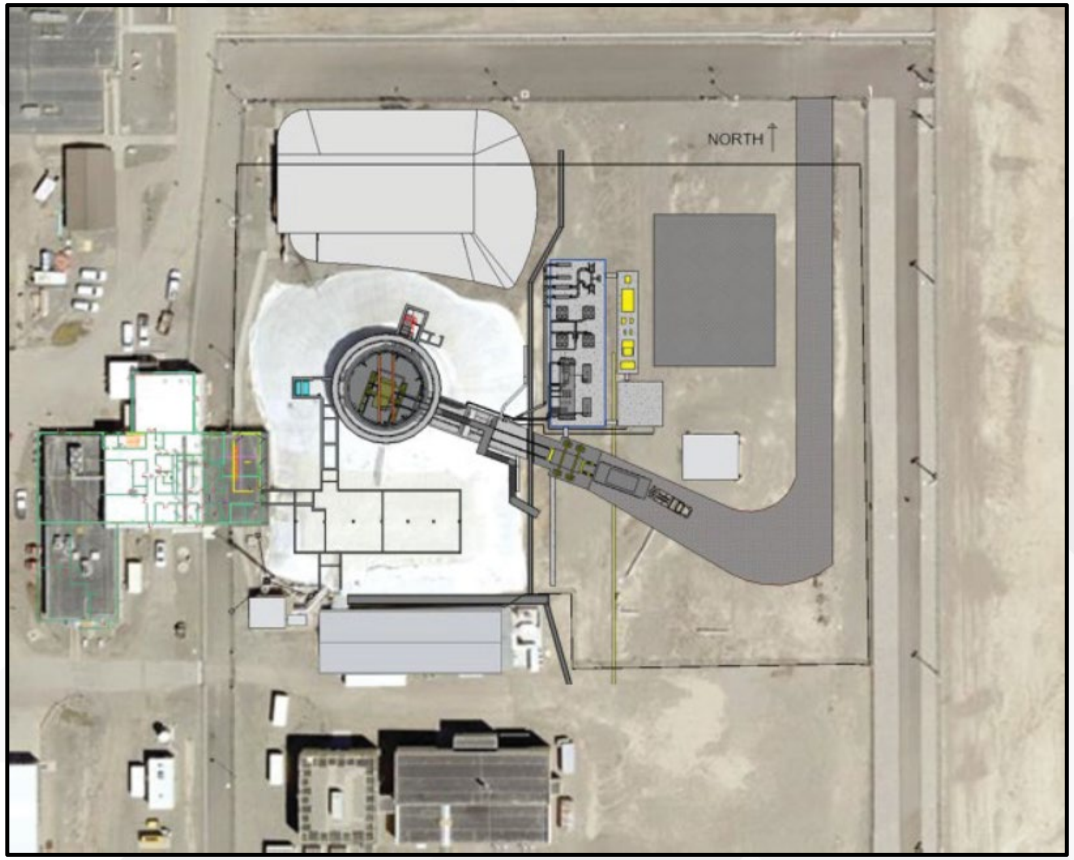
NRIC-LOTUS Project Schedule

Schedule

- Conceptual design completed - 12/2021
- CD-0 (Mission Need) approved - 3/2022
  - Tailored Approach Changed from CD-1/2/3a – 1/2023
- CD-1 approved - 6/2023
- Awarded prelim/final design - 6/2023
- Preliminary design review completed - 1/2024
- Technical independent project review (TIPR) completed – 3/2024
- Final design complete - 4Q/FY24
- Submit PDSA – 4Q/FY24
- Submit CD-2/3 – 2Q/FY25
- Construction finish forecast* - 2Q/FY27
- Operational readiness forecast**– FY27/FY28

* To be informed based on construction bids

** Start of operational readiness to be influenced by completion of construction. Operational readiness anticipated to require ~9 months. Opportunity to initiate first reactor experiment install coincident to operational readiness activities.



NRIC-LOTUS Project Funding

Major Project Area	FY22 (A)	FY23 (A)	FY24	FY25	FY26	Total	Notes
Total Estimated Costs – Capital Account		$22.25M	$32.00M	$18.75M		$73.00M	Includes TEC management reserve
Other Project Costs – Capital Account	$6.56M	-$1.85M	$2.90M	$9.00M	$8.59M	$22.20M	Includes OPC management reserve
Total LICP Budget*						**$98.20M**	

LICP: Line-Item Capital Project

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NRIC-LOTUS Next Steps

- Complete Final Design
- Update Safety Design Strategy
- Complete Preliminary Documented Safety Analysis
- Update project documentation to support CD-2/3
- Submit Documentation for CD-2/3
- Establish Performance Baseline and award construction subcontract

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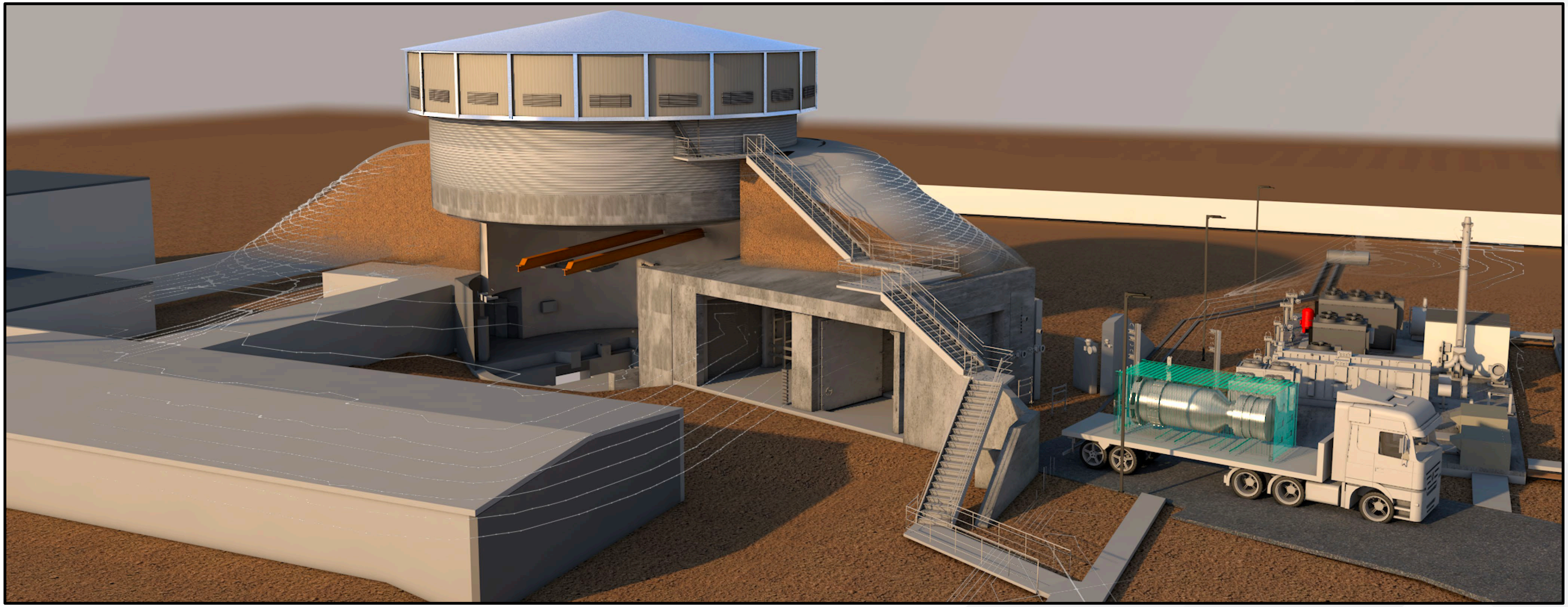
NRIC-LOTUS Digital Model



Questions?

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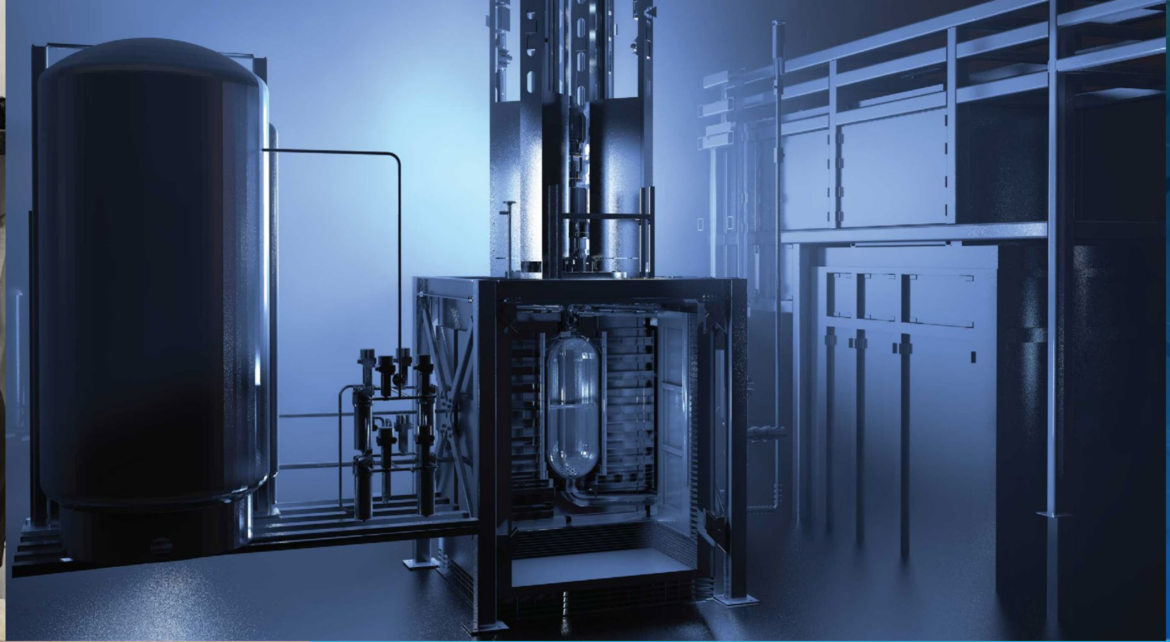
www.nric.inl.gov



James A. King, PhD
MCRE Project Deputy Director

April 23, 2024

Molten Chloride Reactor Experiment (MCRE) Project Update

INL is managed by Battelle Energy Alliance for the US Department of Energy

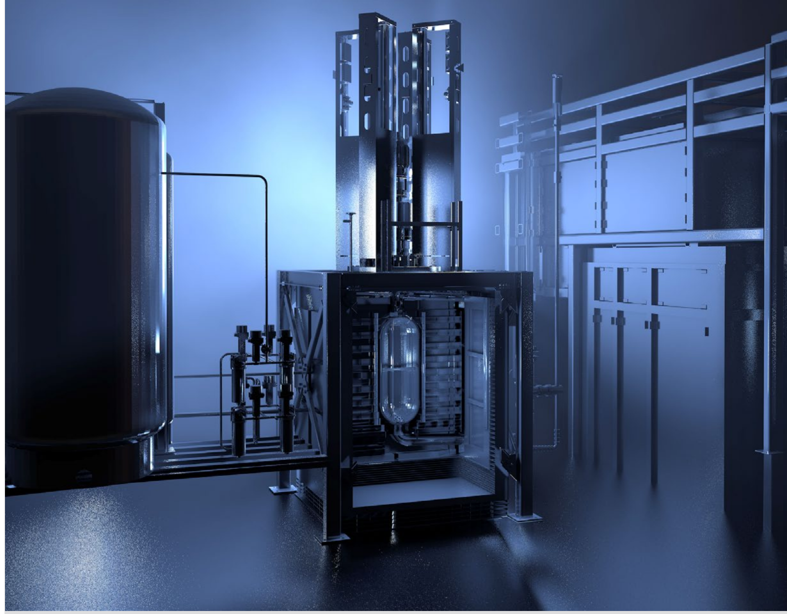
Idaho National Laboratory

INL/MIS-24-77644

MCRE lays the foundation for commercial MCFR deployment

Molten Chloride Reactor Experiment

- Advanced Reactor Demonstration (ARD) Risk Reduction Award
- Collaboration led by Southern Company
- TerraPower responsible for reactor design and fabrication
- INL responsible for fuel salt production, reactor installation, operation, and post-operations decommissioning
- INL host site, NRIC-LOTUS reactor test bed
- Critical operation in 2027

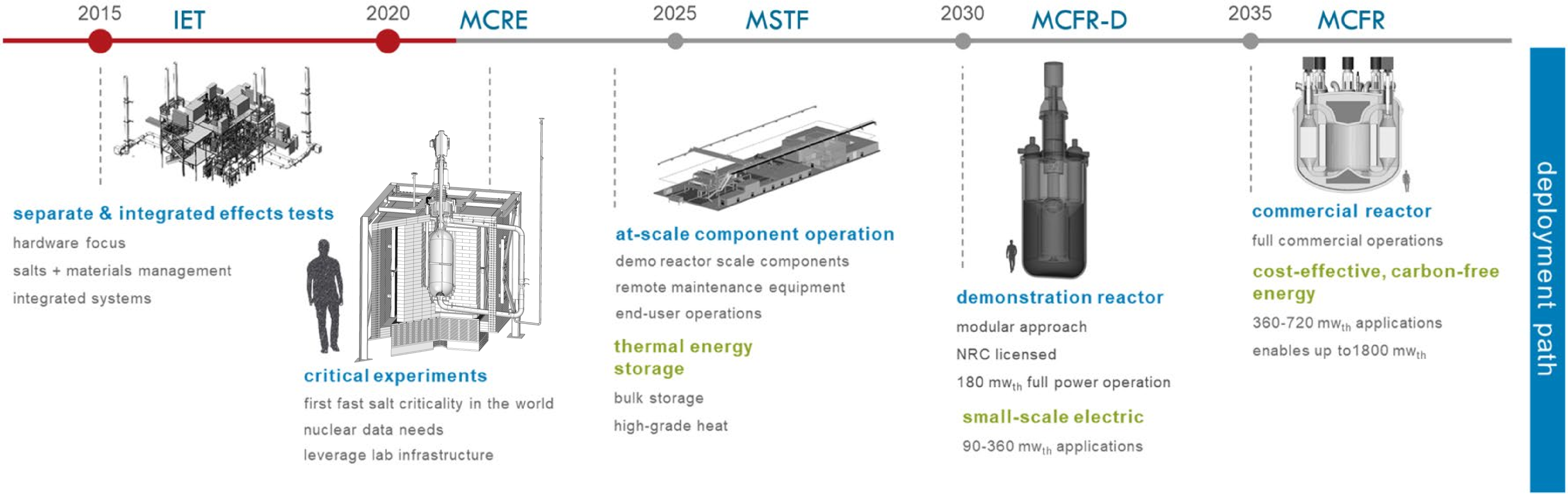


Objectives

1. **Safely achieve criticality**
2. **Determine reactor physics and kinetic parameters to reduce uncertainty and gather data**
3. **Demonstrate fuel handling strategy for chloride fuel salt**
4. **Initiate industrial supply chain for molten salt components**
5. **Collect data for licensing framework**

Southern Company | TerraPower A Nuclear Innovation Company | INL Idaho National Laboratory | orano Giving nuclear energy its full value | 3M | EPRI | CORE-POWER

MCRE *is the second large demonstration along the MCFR deployment path, building upon DOE's ARC'15 investment in the Integrated Effects Test (IET)*



TerraPower
A Nuclear Innovation Company

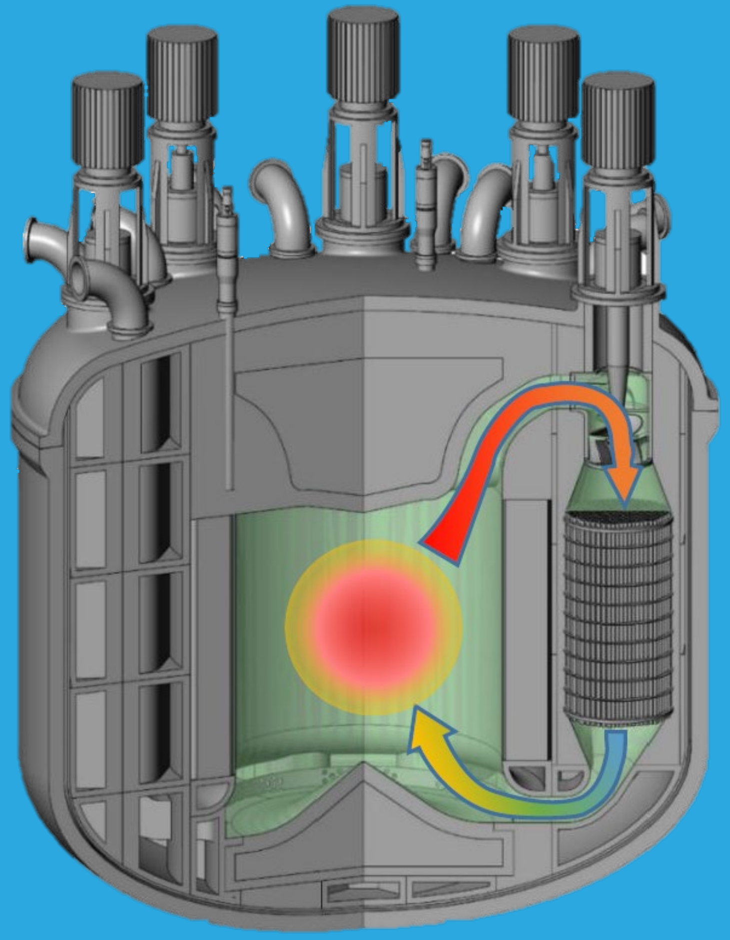
Molten Chloride Fast Reactor (MCFR)

Liquid Fuel Salt

- High operating temperature improves power conversion efficiency and enables valuable industrial applications
- Low pressure system removes need for thick, expensive vessel walls
- Flowing fuel eliminates need for refueling outages and provides load following reactivity control

Fast Neutron Spectrum

- Core can tolerate fission products and achieve high burnup
- Reactor breeds new fuel and utilizes that fuel directly without need for a reprocessing plant
- Destroys longest-lived nuclear waste isotopes, reducing amount of waste and shortening the hazardous lifetime



INL MCRE team has developed an elegant process for fuel salt synthesis

INL MCRE Project Status

Recent Accomplishments

- Fuel Salt Synthesis Line Final Design activities complete
- Initial full-scale fuel salt synthesis demonstration (9kg depleted uranium) complete
- Completed world-first measurement of oxygen concentration in fuel salt
  - Results show INL synthesized fuel salt outperforms technical specification
- Reviews completed for 14 of 17 total MCRE systems in preparation for plant level Preliminary Design Review in May

FY24 Deliverables

- Begin installation of Fuel Salt Synthesis Line
- Fabricate first-article set of Fuel Salt Containers
- Complete off-normal oxygen and moisture ingress experiments with fuel salt
- Perform initial salt spill experiments
- Complete Conceptual Design of Irradiated Salt Containers
- Award Design/Build RFP for Fuel Handling Glovebox (FHG)

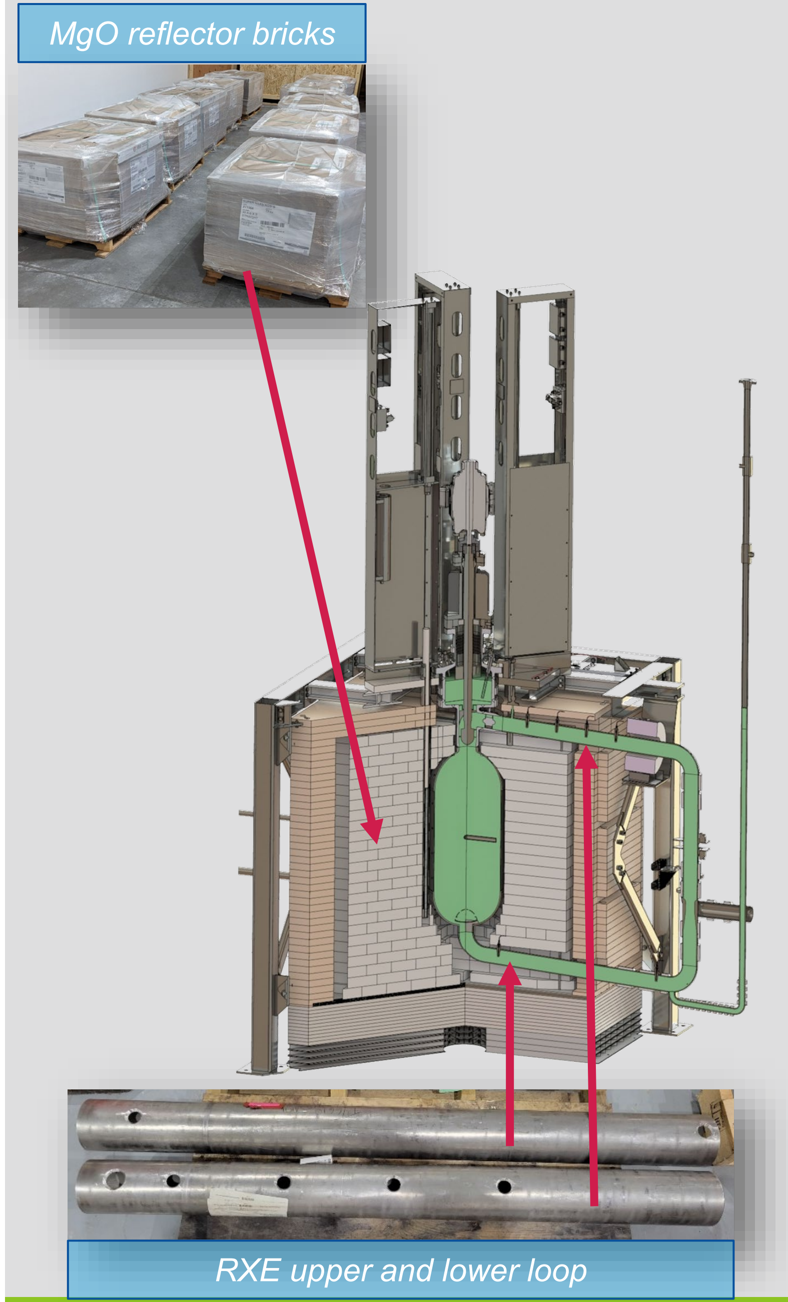
TerraPower MCRE Project Status

Recent Accomplishments

- 90%+ of MCRE equipment in plant general arrangement
- In contract (or able to extend contract) for all long lead equipment for Mockup
- Full cycle of RIPB safety evaluation completed and Conceptual Safety Design Report (CSDR) submitted
- Completed ^{35}Cl nuclear data measurements and reactor core optimization enabling significant reduction of MCRE fuel volume
- Mockup site preparation underway and initial hardware delivered
  - 30,000 lbs of MgO reflector bricks and RXE upper and lower loop

FY24 Deliverables

- Complete MCRE Plant Preliminary Design Review
- Award remaining Mockup procurements
- Begin construction of Mockup and confirm engineering design
- Develop operational procedures for Mockup and prepare for salt operations

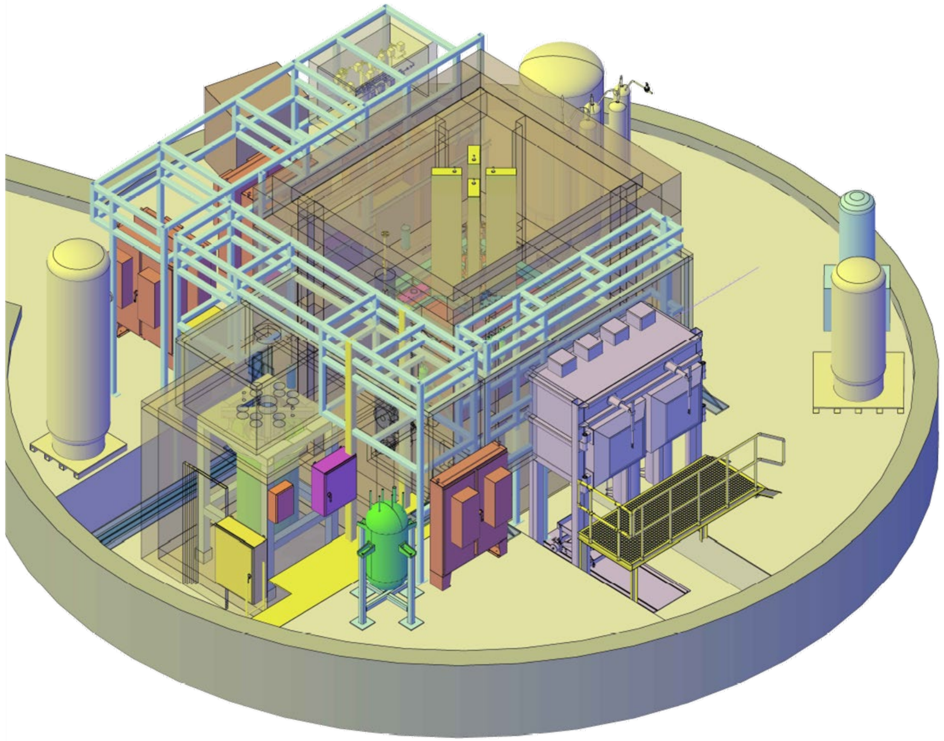


Achieving the INL Vision, to change the world's energy future, requires participation from technology developers and end users

- Challenges facing the grid and reactor developers today
- Anticipated changes and strategic considerations
- Timing and magnitude of future power generation needs
- Planning processes and parameters that influence new technology adoption
- Synergies with existing collaborations and partnerships

Questions?

James King
james.king@inl.gov



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DOME Test Bed Ecosystem

Troy P. Burnett, P.E.

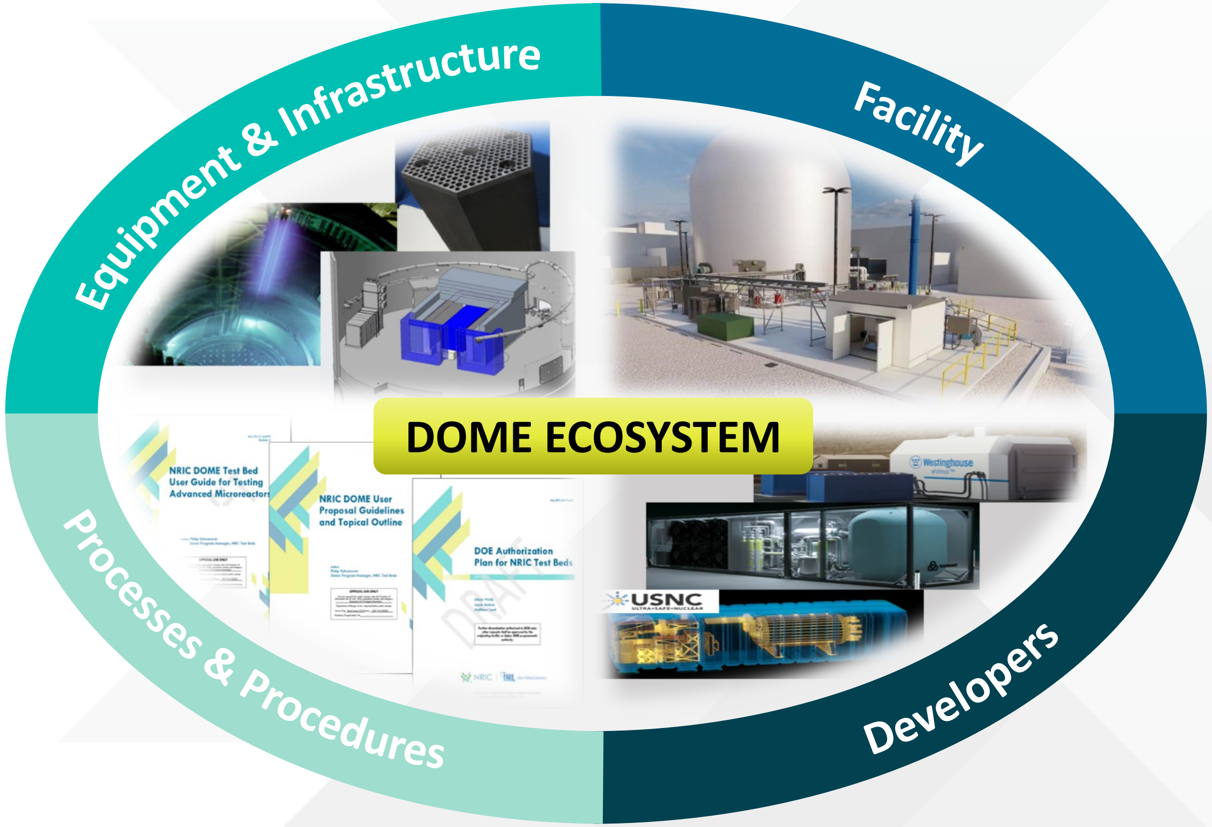
04/23/2024

DOME Panel Agenda

- DOME Ecosystem – Troy Burnett
- DOME Construction Update – Scott Smith/Brandon Hill
- Supplemental Shielding Design – Chance Price/ Kyle Reno (Enercon)
- Polar Crane Status Update – Chance Price
- Fuel Storage at INL – Todd Sherman
- DOME User Guide – Marvin Fielding
- FEEED Overview and Update –Troy Burnett
  - Westinghouse – Erin Orga
  - USNC – Wes Deason
  - Radiant – Elliott Korb

DOME Test Bed Ecosystem

- DOME Ecosystem
  - Facility
  - Equipment and Infrastructure
  - Process and Procedures
  - Developers
- Current Progress and Status Updates
- Path Forward



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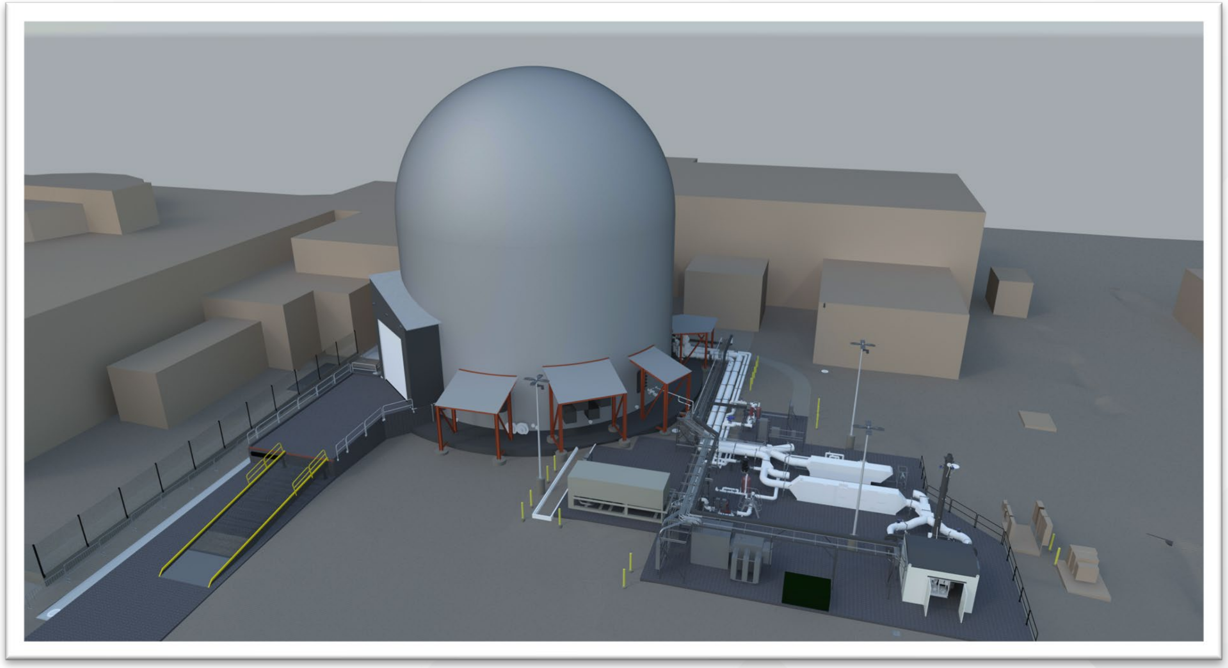
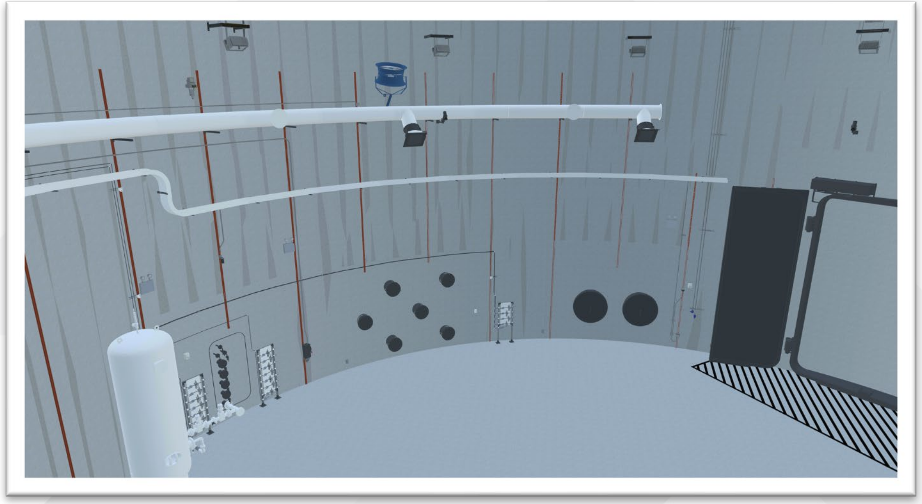
DOME Facility

- Facility Specifications
  - Hazard Category 2 facility
  - Provides safety class confinement
  - Large floor space for reactor experiments
    - ~ 65' ft diameter
    - ~ 46 ft height to crane
  - Hatch Opening
    - ~15' wide
    - ~17' tall
  - Penetrations
    - Small penetrations for process
    - Large Penetrations for primary reactor cooling
  - Control Room
    - Space for developer control room in connecting building or pad outside





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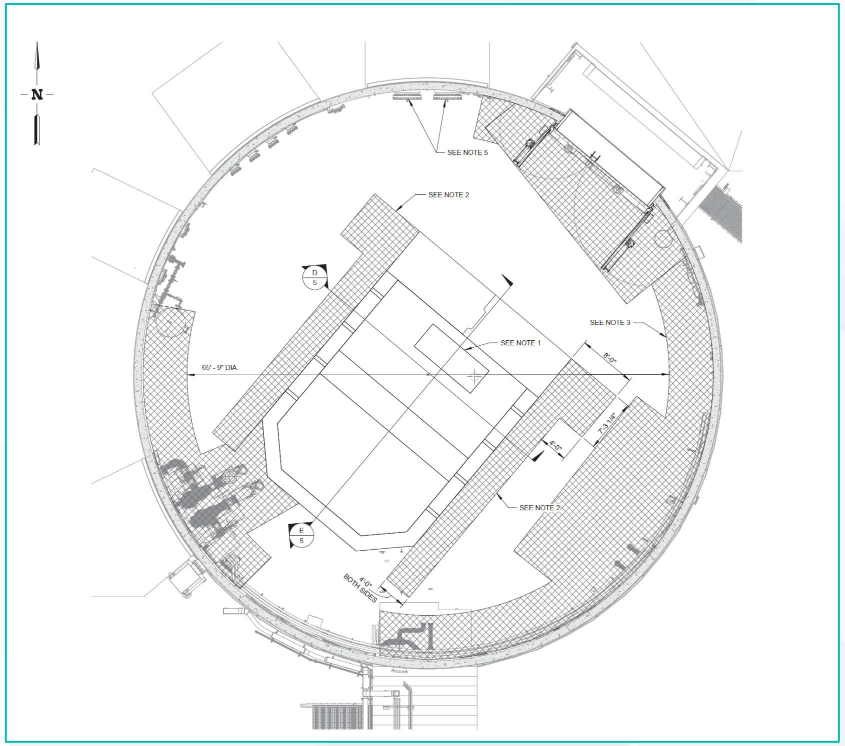
DOME Facility Continued

- Operational Features
  - Allows capacities up to 20MW thermal
  - High-Assay Low-Enriched Uranium (HALEU) TRISO fuels
  - 300kW of environmental cooling
  - Scalable to 500kW
  - 480V/400Amp electrical service
  - Exterior pad for primary reactor cooling and reactor support equipment
  - Shipping Container Capacity: ISO-668 standard



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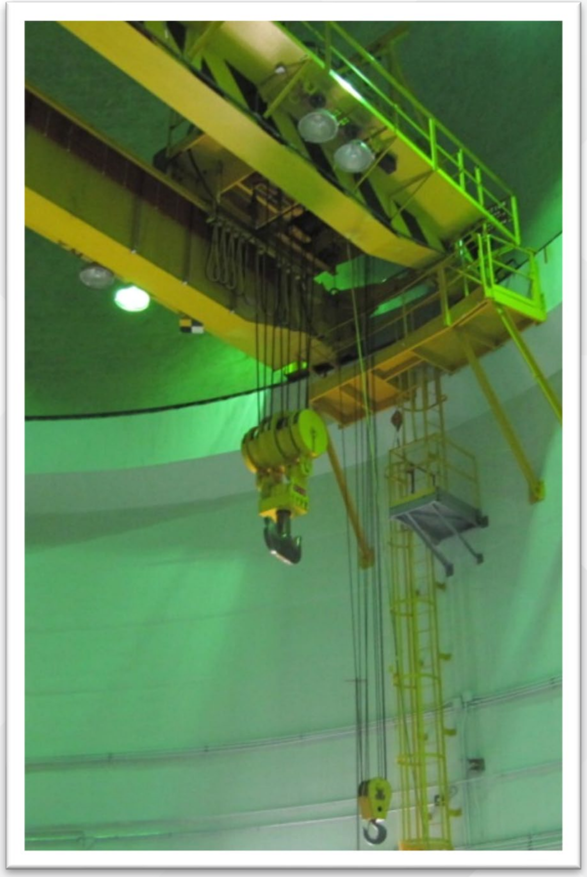
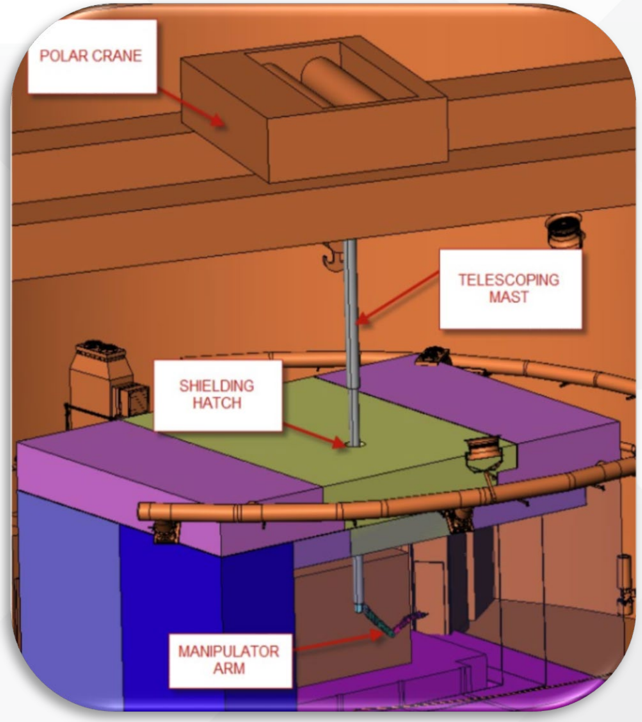
Equipment and Infrustructure

- Existing Infrustructure
  - Utility access for compressed air, deionized water.
  - Access to equipment: forklift, crane.
  - Post Irradiation Examination
  - Fire Suppression
  - Security
- Planned Infrustructure
  - 75-ton polar crane
  - Reactor handling system
  - Supplemental Shielding

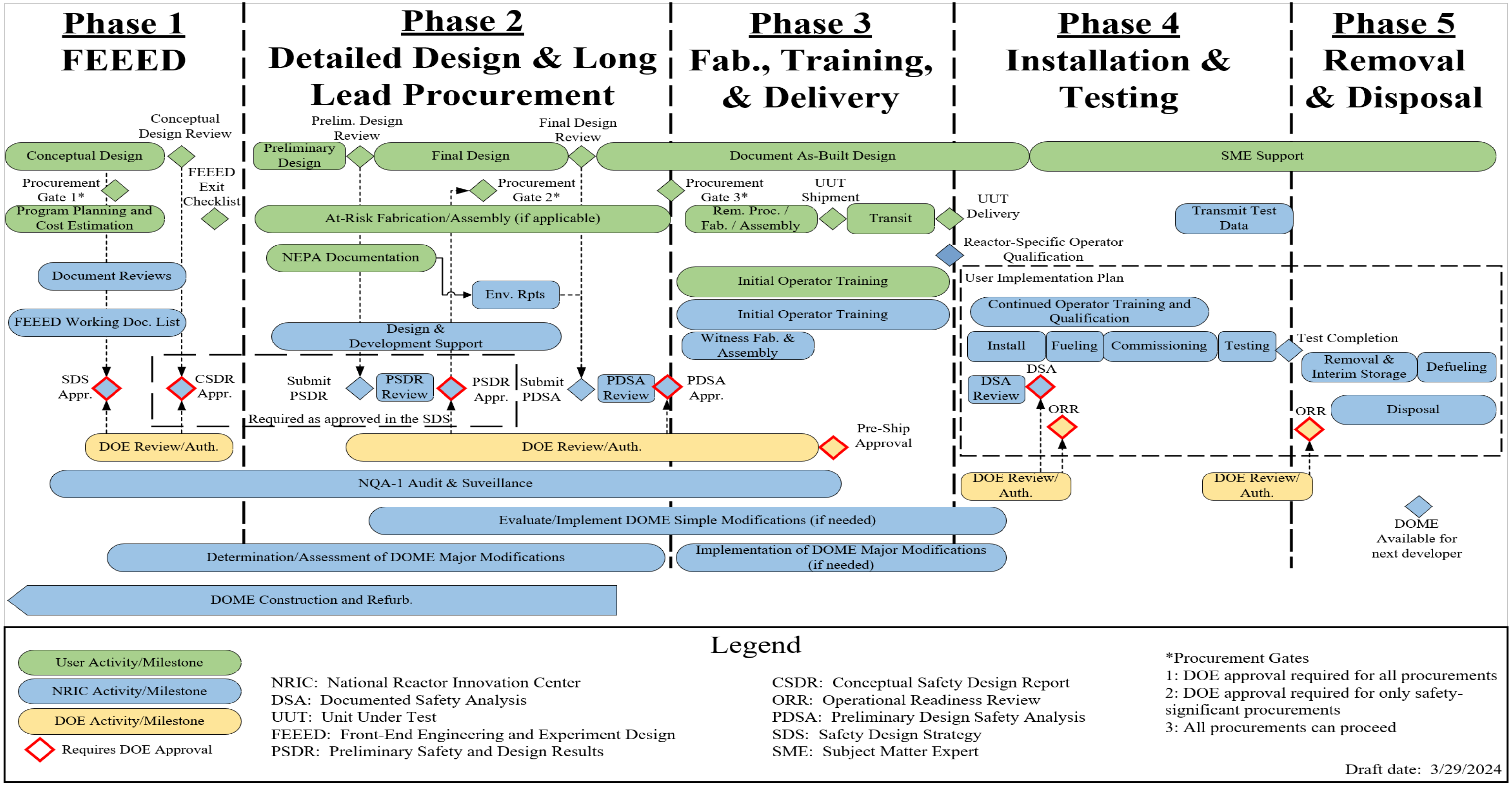


E&I Continued

- Fuel Storage
- Rad Waste management
- Rigging equipment
- Decontamination equipment
- Reactor Supplemental Shielding
- Transportation equipment
- Remotely operated equipment



Process and Procedures



Process and Procedures Cont.

- User Guide Revision
- Operations Training plan
- Environmental Assessment for testing advanced reactors in the DOME
  - Plant Parameter Envelope
  - May eliminate the need for a full Environmental Assessment for each reactor

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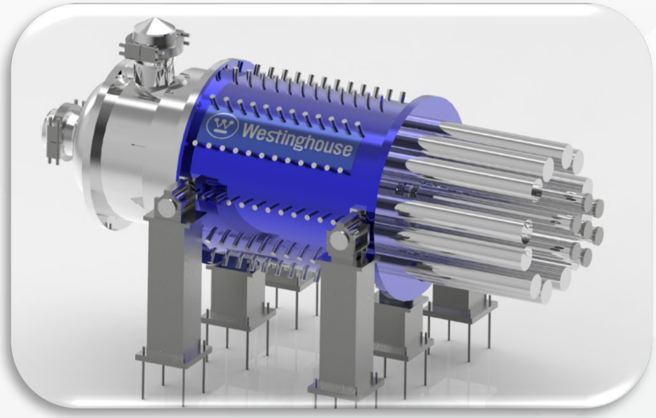
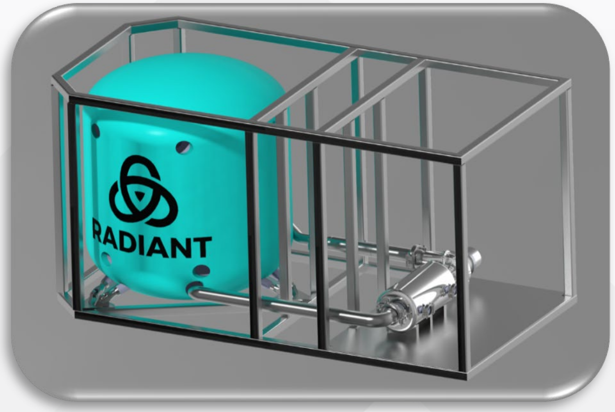
Developer Engagement

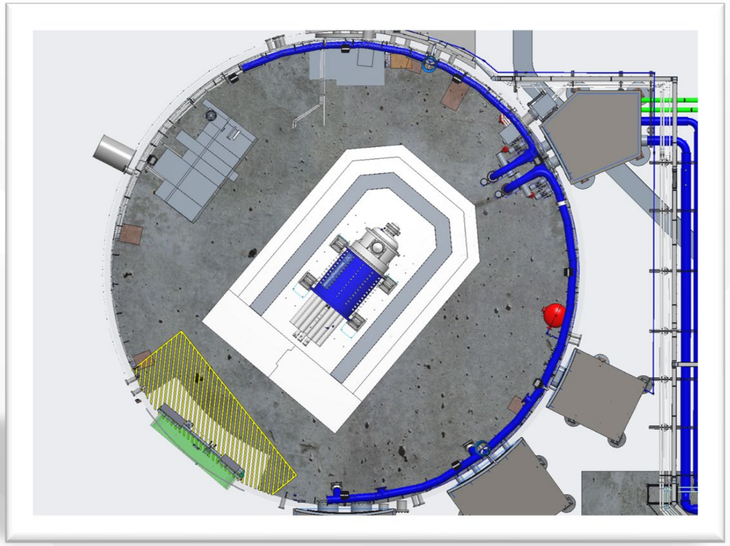
- Front End Engineering and Experiment Design (FEEED)
  - Awarded 3 FEEED applicants in 2023
    - Radiant
    - USNC
    - Westinghouse
- Progressing toward Phase 2, Detailed Design and Long Lead Procurement

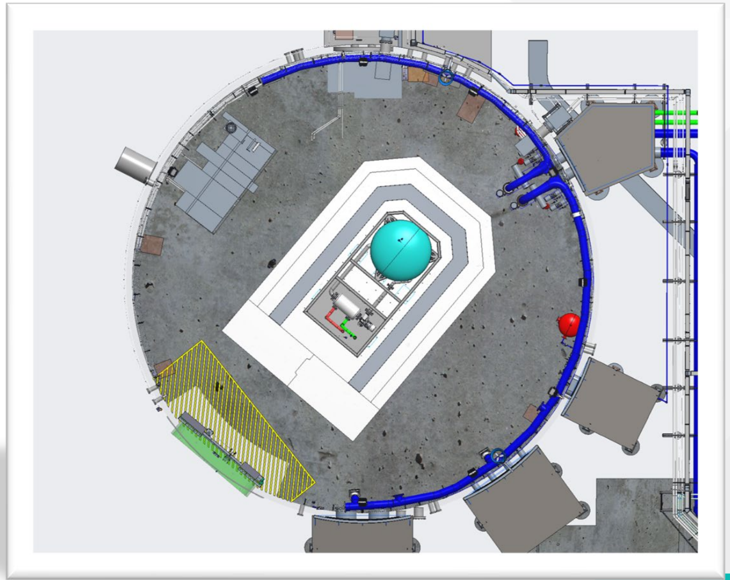




Look Ahead

- Program Development
  - Environmental Assessment
  - Update DOME User Guide
  - Fuel Cycle Plan
- Equipment and Infrustructure
  - Initiate Polar Crane Repair
  - Supplemental Shielding
    - Finalize Design
    - Begin Procurement
  - Reactor Handling System
  - Develop Fueling/Defueling Strategy





Summary

- DOME Facility Construction
  - Full Construction Release granted to Estech October 2024
  - Scheduled to complete late FY 2025
- Test Bed Equipment and Infrustructure
  - Numerous tasks underway
  - Plan is in place to support reactor installation in 2026
- Process and Procedures for Testing
  - Continue to define the program in more detail
  - Continued improvement
- Developer Engagement
  - Continue progressing through FEEED with 3 developers
  - Looking to progress to Detailed Engineering and Long Lead Procurement

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DOME Construction

Scott Smith

Brandon Hill

04/23/2024

Accomplishments

- Construction Subcontract award to ESTECH - Aug 23
- Partial Notice to Proceed for ESTECH mobilization - Sept 23
- Final NTP for full construction activities - Oct 23
- Quality Inspection Support awarded to ATLAS - Feb 24
- Request for Proposal to award a Commissioning Agent subcontract issued - Apr 24
- Construction activities projected completion - Jun 25

Accomplishments – Schedule and Cost Improvements

The NRIC Team continually evaluates methods to improve schedule and cost:

- Construction specification allows the QL3 subcontractor to order NQA-1 components for future commercial grade dedication by BEA.
- Epoxy Irradiation experiment to allow for more efficient and cheaper installation of the DOME Hatch.
- GFE strategy:
  - Allowed the Construction award to be QL3 vs QL1
  - Long lead procurements prior to subcontract award

Government Furnished Equipment

- The Project employed a strategy to provide GFE to the Construction Subcontractor resulting in Project cost and schedule improvement.
  - NRIC procurement of NQA-1 GFE allowed the Construction Subcontract to be awarded as QL3 vs QL1.
  - Long lead procurements prior to subcontract award resulting significant schedule improvement up to greater than 1 year.
- GFE Received as of Apr 24 include:
  - Pressure and temperature detectors, Swagelok valves, HEPA filters, medium voltage transformer, and low voltage switchboard.

Government Furnished Equipment

Expected schedule for receipt of rest of GFE includes:

- Radiation monitor – Jul 24 (Mirion).
- Power and I&C Penetration assembly - Aug 24 (Mirion).
- Hatch and Utility Penetration Assembly – Aug 24 (Petersen).
- Containment Isolation Valves (air exhaust, and water) - Aug 24 (Enertech).
- Plant air - Spring 2025 (Valcor)
- Personnel door - Jun 24 (Walz & Krenzer).
- AHU expansion tank - May 24 (Gritton).
- Safety Class Duct Bank - June 2024 (TRENWA).
- Medium Voltage Sectionalizer - Summer 2025 (D&S). A mitigation plan to install a temporary sectionalizer is in place to ensure this does not impact schedule.

Risk Management

Significant project risks to cost and schedule include the following.

- Delay in receipt of Government Furnished Equipment due to supply chain issues or Contracting/QA requirements.
- Additional design improvements based on unexpected field conditions.
- Potential scope change to include crane repair or thermal sleeve installation in the construction subcontract.

Schedule – Major Milestones

- April 2024 - Award Commissioning Agent Subcontract
- June 2025 - Complete Construction
- October 2025 - DOE Approve Documented Safety Analysis
- March 2026 - Complete Testing
- March 2026 - Complete Turnover and Operational Readiness
- April 2026 - Complete Project

Schedule and Cost Performance

SPI and CPI Data as of March 2024:

- **CPI – 1.1** – slightly under budget due to late invoicing by the construction subcontractor for procured items than was planned. This CPI trend is expected to trend towards 1.0 as these items are ordered.
- **SPI – 0.8** – currently behind schedule due to finding unexpected underground utilities and weather delays. Schedule recovery is trending towards 1.0 as the project continually identifies more efficient ways to perform the work.

DOME Construction Flythrough

The video includes a 3D model projection of the DOME facility final design including recent photos of current construction progress.

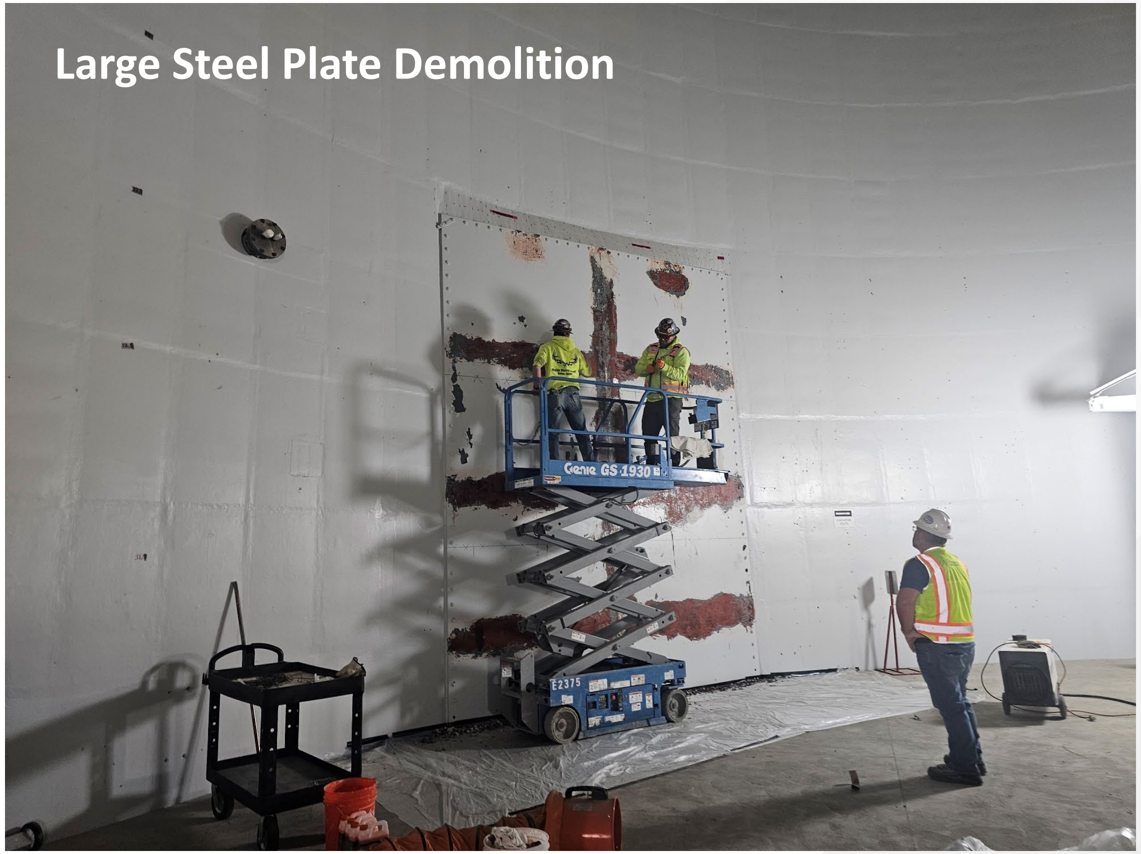
VIDEO

https://confluence.de.inl.gov/download/attachments/107380978/2024-02-13%20NRIC%20Video%202.mp4?api=v2

Additional Photos

DOME Penetrations and Hatch Location Markings

Additional Photos Cont.



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Additional Photos Cont.

Additional Photos Cont.

Additional Photos Cont.

Questions?

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DOME Reactor Supplemental Shielding (RSS)

Chance Price

04/23/2024

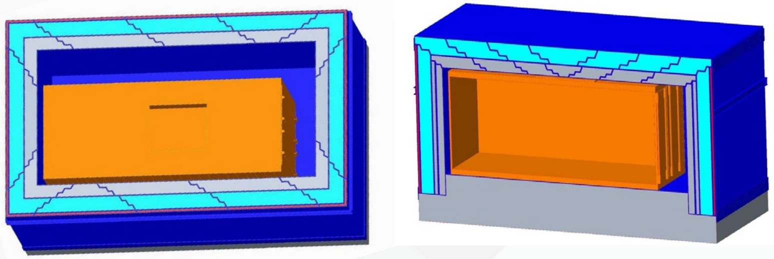
DOME RSS

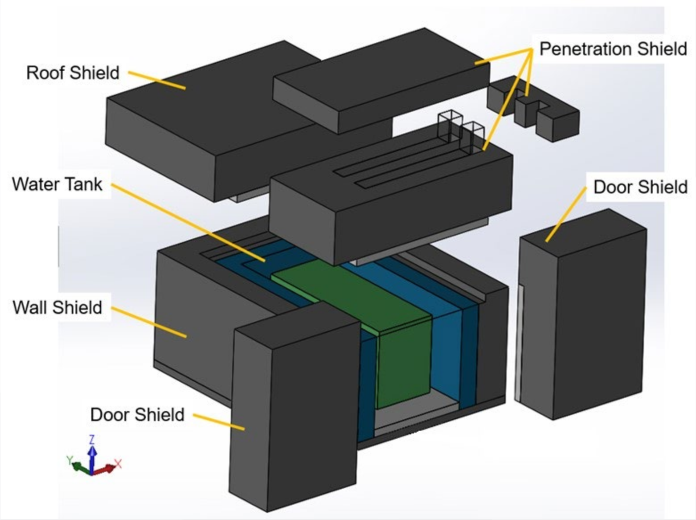
- A radiation shielding system is needed to protect personnel and equipment from harsh neutron and photon fluxes during:
  - Reactor operations
  - Post shut down operations
  - Disassembly
  - Decommissioning

- Examples of RSS driving requirements
  - Radiological Controls
    - Operating dose rate: the dose rate during normal reactor operations shall be <0.5 mrem/hr at the exterior wall of DOME containment
    - Outdoor radiation limit: shielding shall provide the dose to a facility worker outside of DOME to <0.05 mrem/hr at 50 ft from the exterior wall of the DOME
  - Temperature
    - Reactors may have operating temperatures up to 800C
    - The RSS shall be capable of removing up to 100 KW of heat during normal operating conditions
      - the concrete structure has an upper temperature limit of 100°C

RSS Background

- 2022
  - December – developed the initial conceptual design (based on a modular configuration) – our initial cost estimate >$30M
- 2023
  - June – INL revised the RSS requirements from small modular configuration to being removable
  - September – developed an updated conceptual design - cost estimate $10-12M
  - December – Awarded RSS Preliminary Design Subcontract to Enercon
- 2024
  - February – Enercon presented the trade study results (alternate materials, changes to the design/configuration, and high-level cost impacts)
    - Including 3 design options
      - **Option 1 with water tank and no natural convection**
      - Option 2 with water tank and natural convection
      - Option 3 with no water tank and natural convection
  - March – Enercon delivered 60% Preliminary Design





DOME RSS

- Next Steps
  - July – Complete Preliminary Design
  - August – Initiate Final Design

- Why NRIC will provide the RSS
  - DOME has 30+ years service life with many anticipated advanced reactor tests
  - DOME is above ground with very little inherent shielding
  - Shielding solution is an over constrained challenge
    - Competing structural, radiological and thermal requirements
    - Must interface with the DOME Containment and Heat Removal Systems
    - Very large and expensive
    - NRIC/INL are best positioned to develop the design
  - HTGR reactors have very high neutron and photon flux
    - No water as a coolant
    - Intended to be mobile (no concrete structure around them)
  - DOME's primary purpose is to test advanced reactors rather than shielding

Questions?

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Reactor Supplemental Shielding For the NRIC DOME Test Bed

ENERCON Presentation

Executive Summary

Tuesday, 2/13/2024

ENERCON FEDERAL SERVICES, INC.
Excellence—Every project. Every day.

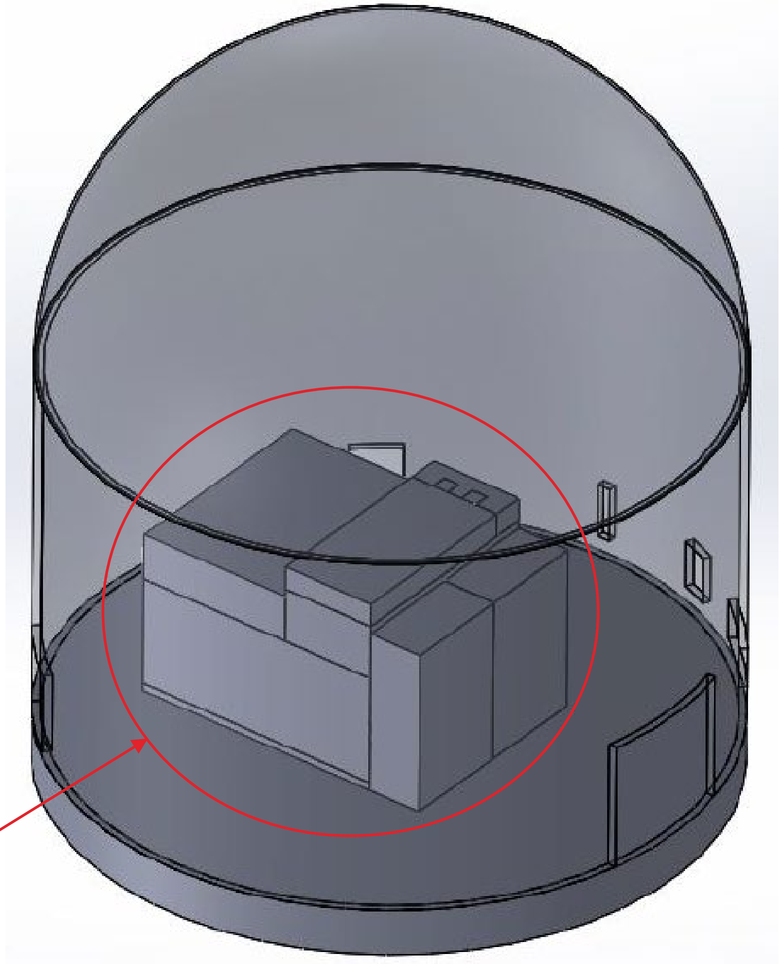
Agenda

- Objective
- Reactor Supplemental Shielding Design
  - Shielding Requirements
  - Layout
  - Materials
  - Thermal Analysis
- Open Discussion

Objective

Provide an overview of the reactor supplemental shielding being developed for the DOME test bed.

The RSS provides the radiation shielding necessary to keep dose requirements within limits when the test reactors are at full power as well as after shutdown conditions.

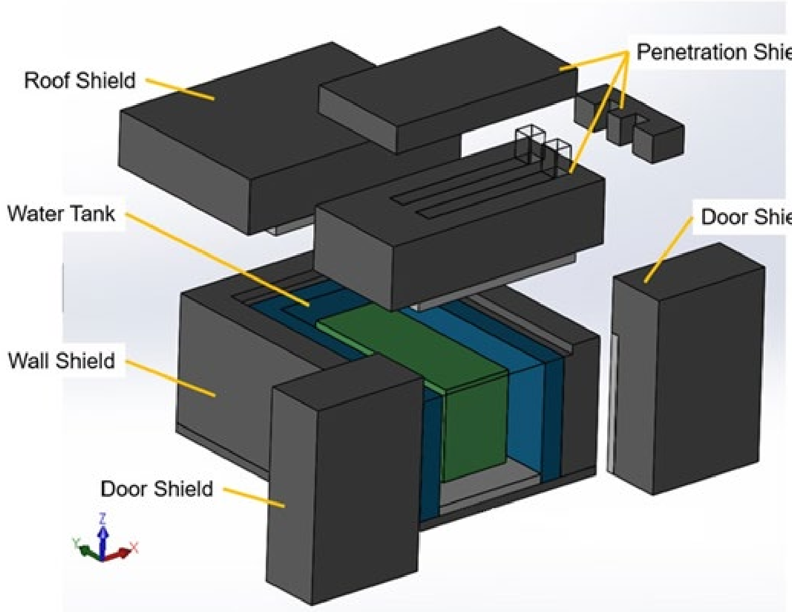


The RSS within the EBR-II containment

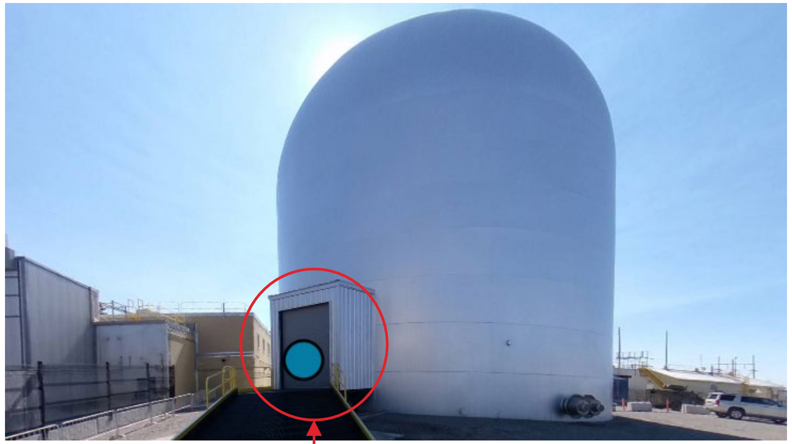
Shielding Design

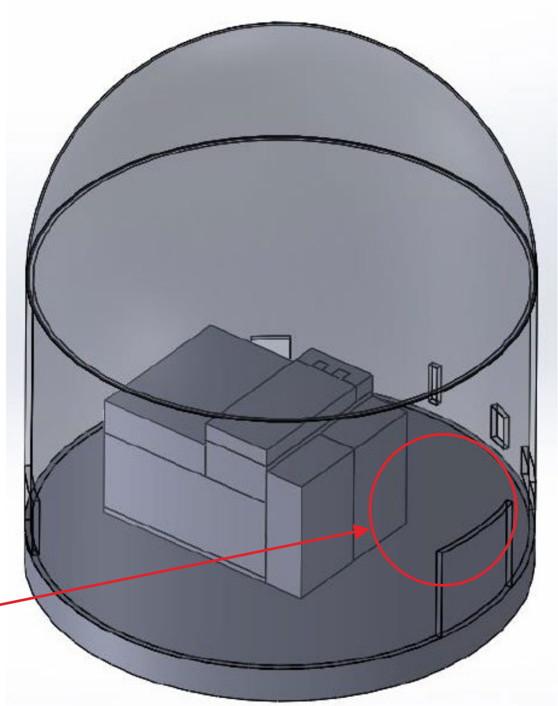
Shielding keeps dose below these levels:

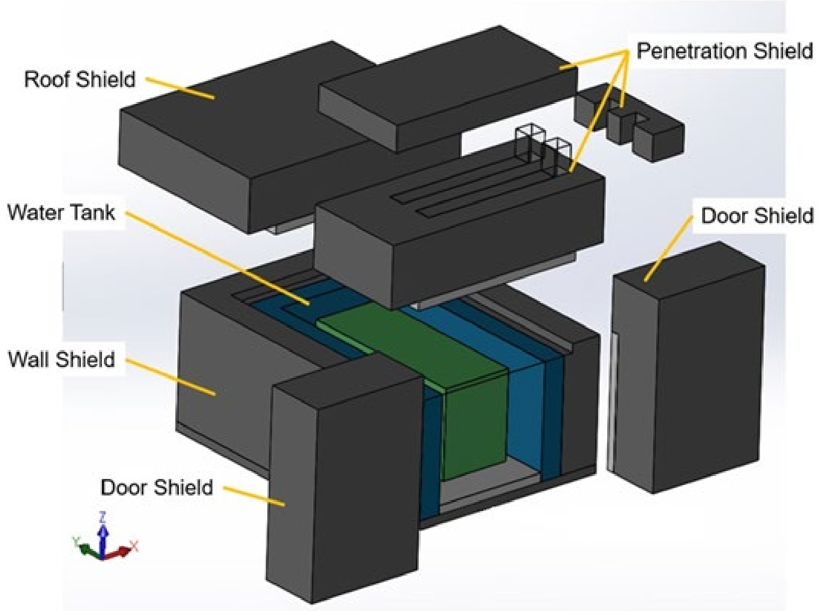
- 0.05 mrem/hr 50’ from exterior wall of DOME
- 5 mrem/hr at the exterior wall when operating
- 30 cm from components 90-days post shutdown 0.5 mrem/hr outside the shield and 5 mrem/hr inside the shielding enclosure
- ~7’ thick concrete or 4.5’ concrete + 2.5’ of water is needed to keep radiation levels within the above limits.



RSS Layout







Equipment Entry/Removal Point

Modularized RSS Design to Facilitate Installation and Removal within the DOME

Space for reactor to be located within RSS

RSS Materials

Various materials have been considered for use in shielding the reactor. In addition to the shielding capability, the following characteristics are considered

- Activation (will the materials become radioactive after exposure to radiation)
  - Activation drove the selection of aluminum over steel for the water tank
- Cost
  - Concrete is an excellent radiation shield and relatively low-cost material, so it has been used heavily for the shield design
- Weight/Space Limitations
  - These factors have been able to be accommodated without requiring the use of more exotic, expensive materials

Thermal Design/RSS Cooling

The RSS is designed to accommodate developer microreactors that output ~10 MW of thermal power during normal, full-power operation.

Normal Operation:

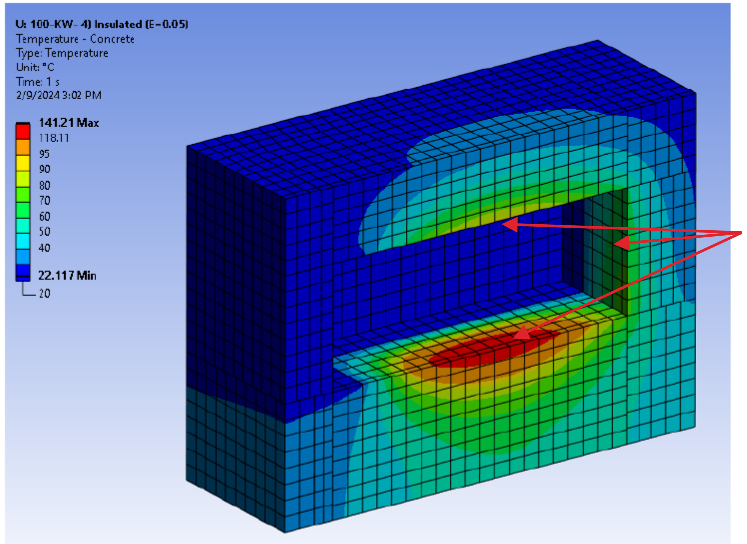
- 99% of the heat is removed by the primary fluid during normal operation
- The remaining heat (1% or up to 100 kW) is removed by active cooling of the water tank through a chilled water system.

Post-accident/Shutdown:

- If active cooling systems are lost, the RSS must accommodate the decay heat coming from the reactor for a period of three days. This decay heat is initially ~7% of the reactor power (up to ~700 kW) and must be passively cooled.
- The water tank is sized to hold enough thermal mass for the three-day accident period to protect the surrounding materials from exceeding their temperature limits.

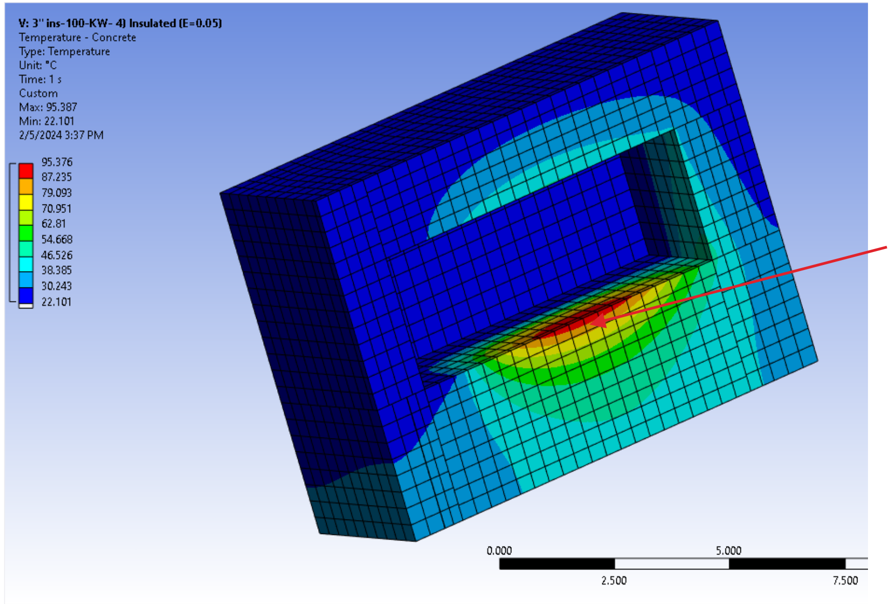
ENERCON
Excellence—Every project. Every day.

Thermal Design/RSS Cooling



Reflective insulation added on floor, door, and roof

Steady-state concrete temperatures from conceptual design



Steady-state concrete temperatures from preliminary design

Aluminum plates added under insulation on floor to help spread heat toward the water tank away from floor. These resolved the overtemperature issue on floor concrete and brought max concrete temperature <100C

The goal of the thermal design of the RSS is to protect materials from experiencing temperature above their limit.

Summary

- The DOME test best will enable developers to gain valuable operating time and test data on their designs at reduced cost and using the world-class capabilities of the US National Lab System.
- Three microreactors are currently planned to be tested at DOME.
  - Radiant (Kaleidos)
  - Ultra Safe Nuclear Corporation (Pylon)
  - Westinghouse (eVinci)
  - We expect a lot more over the course of 30-40 year life of DOME
- DOME RSS Preliminary Design Efforts are underway!

Q & A

- Questions/Open Discussion

NRIC National Reactor Innovation Center

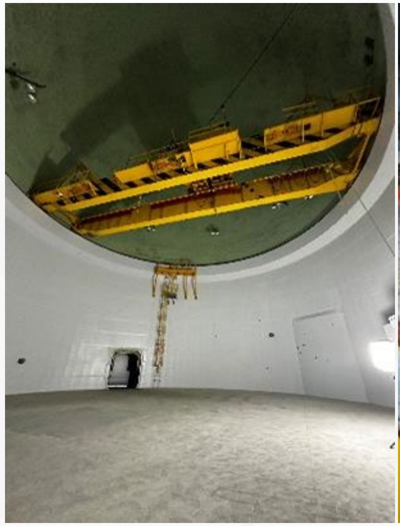
DOME Polar Crane

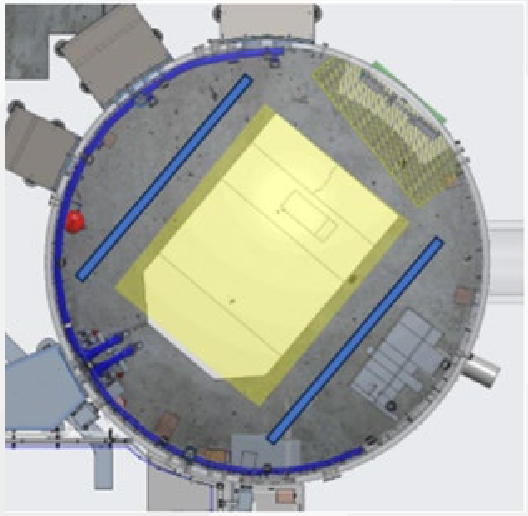
Chance Price

04/23/2024

Background

- 2015
  - The DOME polar crane was being prepared for explosive demolition
- 2018-2019
  - Budgetary planning $10-12M
    - INL cost estimates to fix was $12M
    - Estimates were based on a similar project in HFEF
    - Decision was made to explore other options
- 2022-early 2023
  - Explored Gantry Crane Option
    - Space constraints
    - Flexibility constraints
    - Height constraints
    - Operational impacts to timelines
- Late 2023
  - Contracted with American Crane to perform a detailed inspection report that could be used to elicit an accurate repair estimate.
- 2024
  - Requested vendor budgetary estimates for crane repair
    - Received estimates of $4.5 to 5.5M from 2 vendors
    - At this price point, the polar crane repair is competitive with a gantry crane and provides significantly more flexibility





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DOME Polar Crane

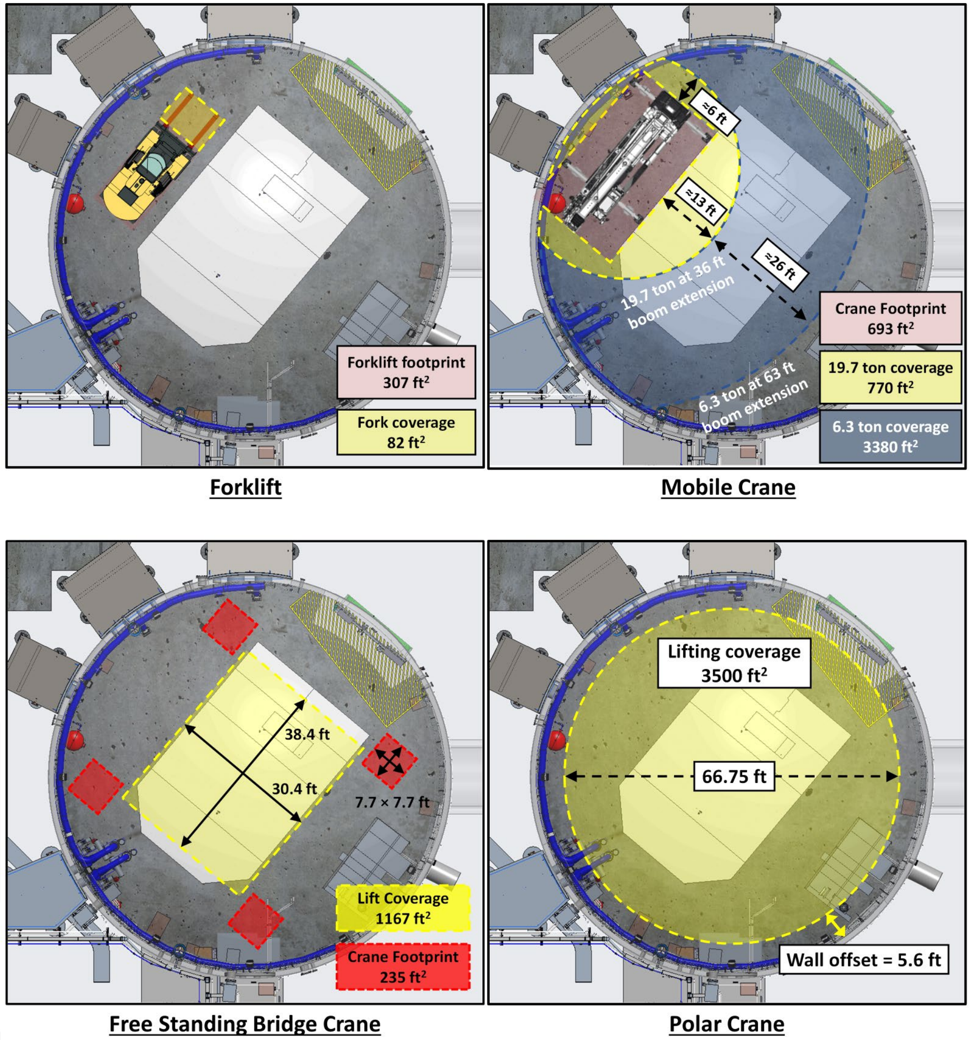
- 2024
  - Completed trade study for polar crane/gantry crane

Comparison of Crane Options for the DOME Facility

Function	Scoring (1)					
	Polar (2)		Free Standing Bridge		Mobile	Forklift
	NOG-1	CMAA Spec 70	NOG-1	CMAA Spec 70		
Lift Capacity	5 (75 to 140 tons)	5 (75 to 140 tons)	5	5	2 (6.3 to 19.7 tons)	2 (25 tons)
Lift Height	5 (38.5 ft)	5 (38.5 ft)	3 (34.8 ft)	3 (34.8 ft)	3 (36 ft)	1 (10.25 ft)
Lift Coverage (**see figures**)	5	5	2	2	2	2
Lift Velocity (3)	5 (1.7 in/min)	5 (1.7 in/min)	5	5	3	1
Footprint (**see figures**)	5	5	3	3	1	1
Single Failure Proof	5	0	5	0	0	0
Efficiency (4)	5	5	2	2	2	2
Capital Cost	$5.5M	$3M	$5M	No data	$0.5M	$0.5M

Notes:

1. Score of 0 to 1: least desirable or does not fulfill needs.
   Score of 2 to 3: could fulfill needs if accommodations are made or additional design restrictions are made.
   Score of 4 to 5: most desirable. Meets or exceeds needs.
2. The polar crane values in this table are associated with main hoist. The auxiliary hoist of the polar crane can lift smaller loads (5 tons) to higher elevations (44 ft).
3. Slow and controlled lift velocity is important for the precise placement of heavy objects.
4. Quantity of operations needed to complete reactor experiment setup and teardown.



- Next Steps
  - Develop the DOME polar crane specification
  - Issue DOME polar crane repair subcontract

Questions?

NRIC National Reactor Innovation Center

NRIC National Reactor Innovation Center

Fuel Storage Requirements

Todd Sherman

04/23/2024

Fuel Storage Progress

- 2023
  - No fuel storage plan had been developed

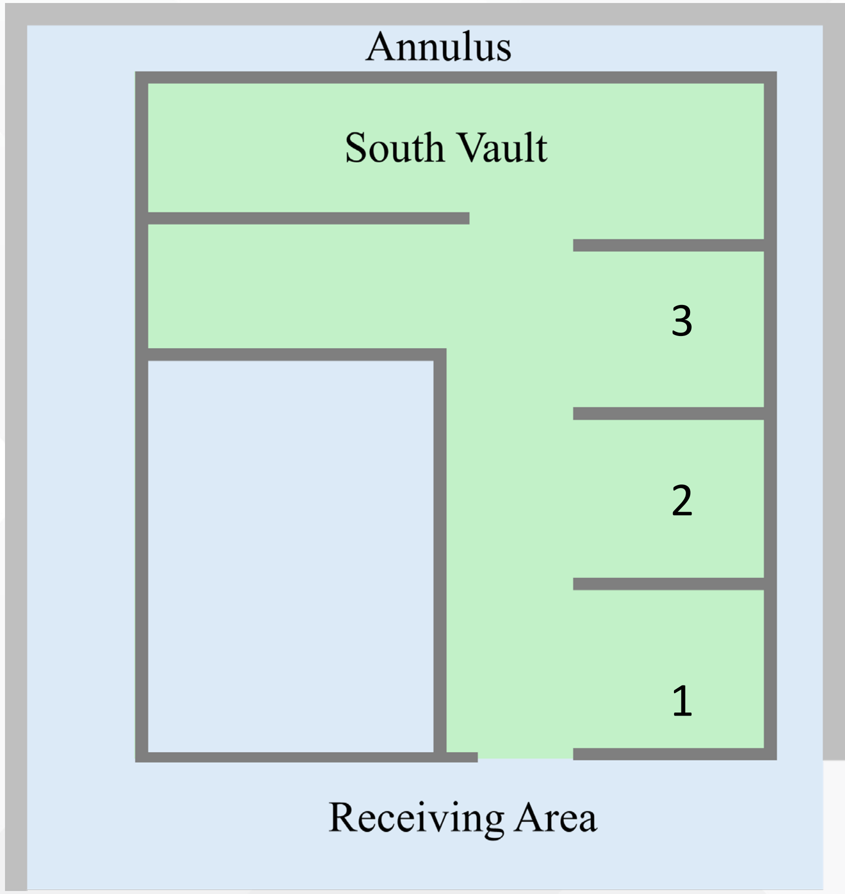
- 2024
  - The shipping and receiving requirements are understood
  - A storage location has been selected and designated
  - The storage limitations are known and incorporated
  - The INL coordination and approval groups have been determined

Shipping and Receiving

- Fuel composition, enrichment, fuel quantity per container, number of containers
- DOT certified containers
- DOT-NRC Certificate of Compliance
  - Container specific criticality safety index
- INL Safeguards witnesses the packaging and places tamper indication devices
- Packaging – INL is not responsible for packaging
  - packaging should be compatible with a standard forklift for unloading and handling
  - Disposition of shipping packaging (a.k.a. overpack) is required
- Cooperative Research and Development Agreement (CRADA) and Project Task Statement (PTS)

CPP-651

- Building CPP-651 is an approve unirradiated fuel storage facility
- The South Vault is approved for new fuel storage
  - Areas 1, 2, & 3 are designated for the NRIC microreactor fuel
- Facility limitations
  - Facility aggregate Criticality Safety Index (CSI)
  - Available floor space



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Storage

- Storage Plan and Schedule
- Container certification expiration is typically 12 months.
  - If the certification expires then repacking the fuel is required
- Repacking is highly discouraged
  - preparation and approval process is >12 months
- Shipping empty containers
  - Storage plan must include shipping the empty fuel containers to a predetermine recipient

Coordination and Approvals

- NRIC – contract and planning
- Material Security Consolidation Facility (CPP-651)
- INL Safeguards
- INL Packaging and Transportation
- Fresh fuel (i.e., prefabrication) would require additional approvals and planning
- Early coordination is vital for success

Questions?

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www.nric.inl.gov

National Reactor Innovation Center

DOME Reactor Testing User Guide

(Demonstration of Microreactor Experiments)

Marvin W. Fielding, P.E., PMP – Program Manager, NRIC

4/23/2024

Agenda

- DOME User Guide Development
- DOME User Guide Focus
- User Engagement Lifecycle for DOME
- Phase 1 – Front End Engineering and Experiment Design (FEEED)
- Phase 2 – Detailed Design and Long Lead Procurement
- Phase 3 – Fabrication, Training, and Delivery
- Phase 4 – Installation and Testing
- Phase 5 – Removal and Disposal
- Next steps


GDE-55086
Revision 0

NRIC DOME Test Bed User Guide for Testing Advanced Microreactors

Author:
Philip Schoonover
Senior Program Manager, NRIC Test Beds

DOME User Guide Development

Feb '23

- 2022 completed the "Concept of Operations (ConOps)" for MFC and DOE review
- Name changed from "ConOps" to "User Guide"
- Draft User Guide to U.S. Department of Energy (DOE) for comment
- Received DOE comments Aug '23

Sep '23

- Updated DOME User Guide based on final design
- Received DOE comments Dec '23
  - Scheduling
  - Non-technical topics subject to change
- Received input from developers

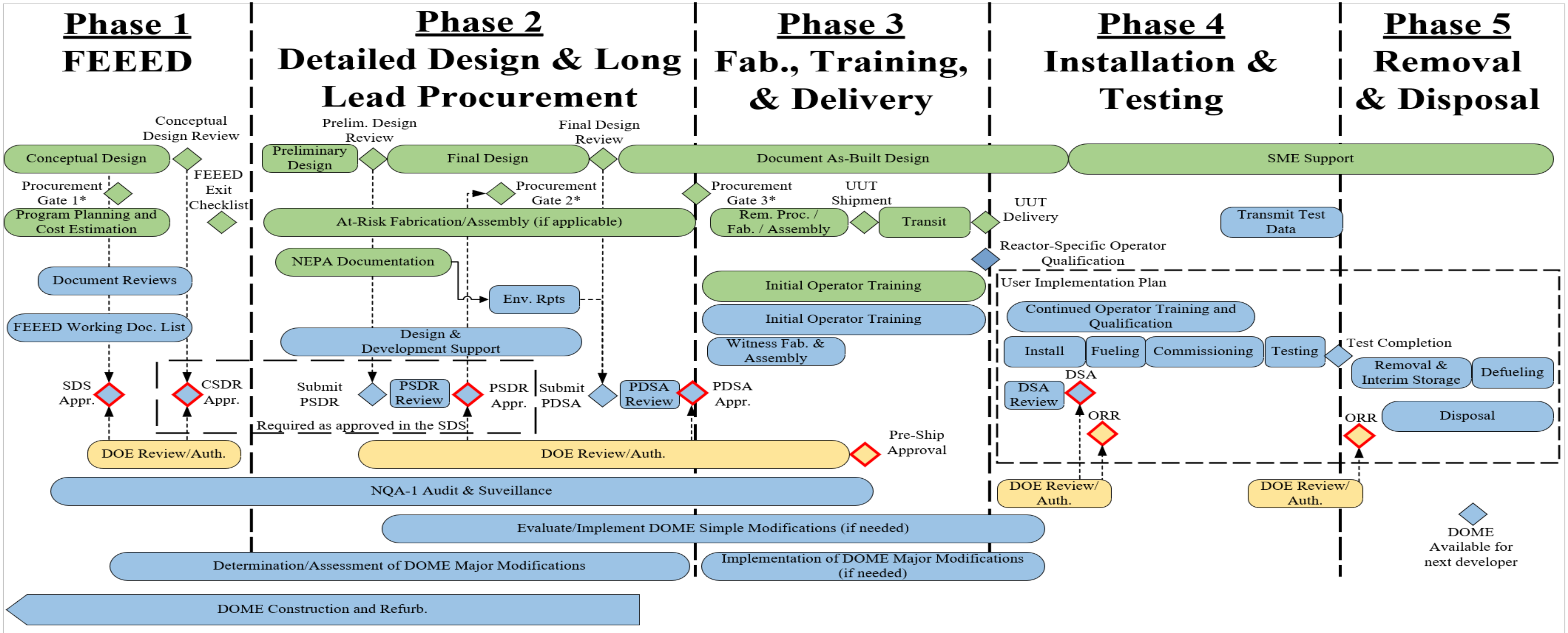
FY24

- Focused user guide on technical processes
- Document FEEED lessons learned
- Mature and document design, testing, and removal phases

DOME User Guide Focus

- Provide end-to-end technical requirements for testing in DOME
- Identify DOME facilities, equipment, and capabilities
- Identify applicable standards and documents

Advanced Reactor Testing in DOME



Legend

- User Activity/Milestone
- NRIC Activity/Milestone
- DOE Activity/Milestone
- Requires DOE Approval

NRIC: National Reactor Innovation Center
DSA: Documented Safety Analysis
UUT: Unit Under Test
FEEED: Front-End Engineering and Experiment Design
PSDR: Preliminary Safety and Design Results

CSDR: Conceptual Safety Design Report
ORR: Operational Readiness Review
PDSA: Preliminary Design Safety Analysis
SDS: Safety Design Strategy
SME: Subject Matter Expert

*Procurement Gates
1: DOE approval required for all procurements
2: DOE approval required for only safety-significant procurements
3: All procurements can proceed

Draft date: 3/27/2024

Phase 1 – FEEED

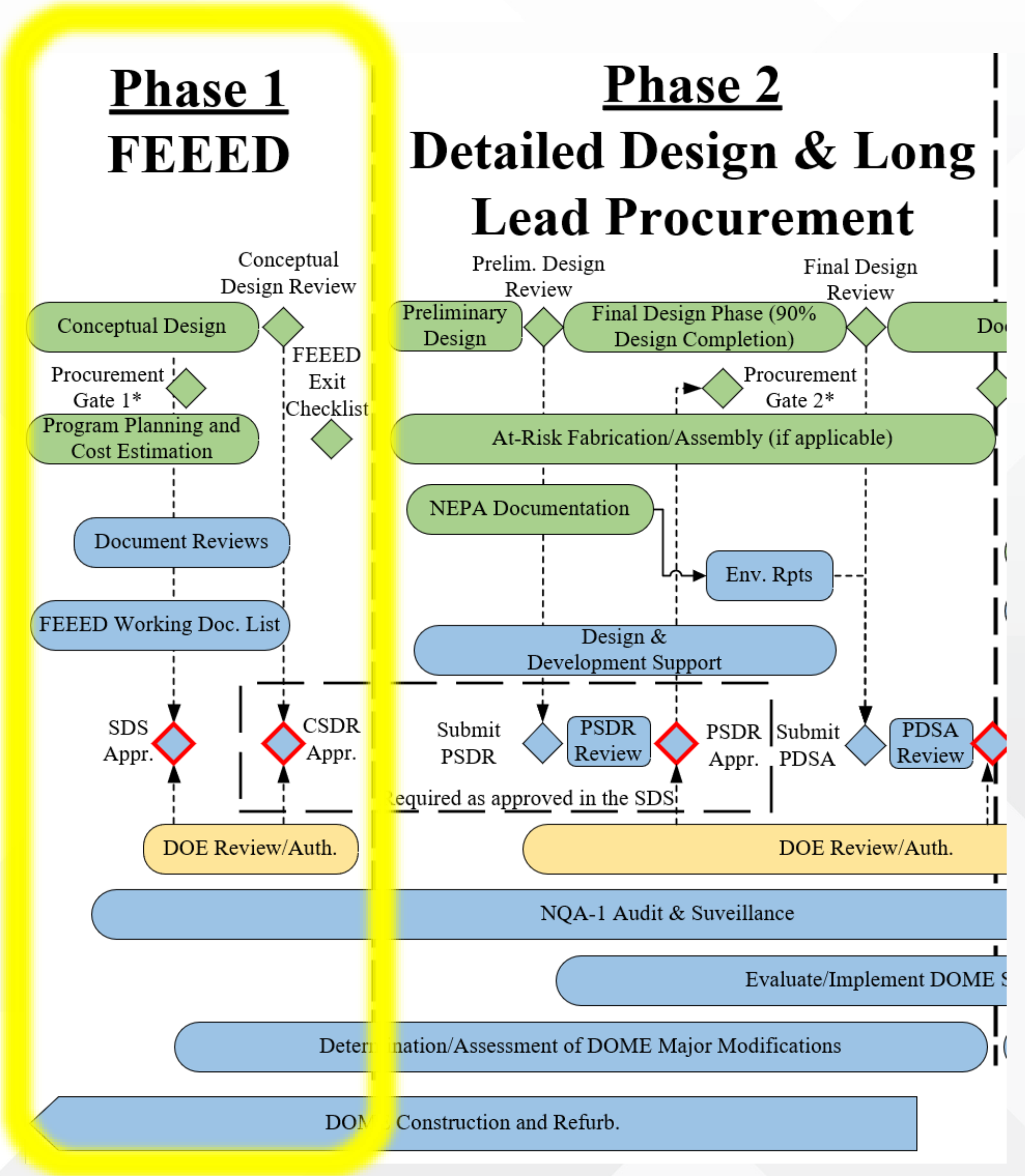
Front-End Engineering and Experiment Design

Key Activities

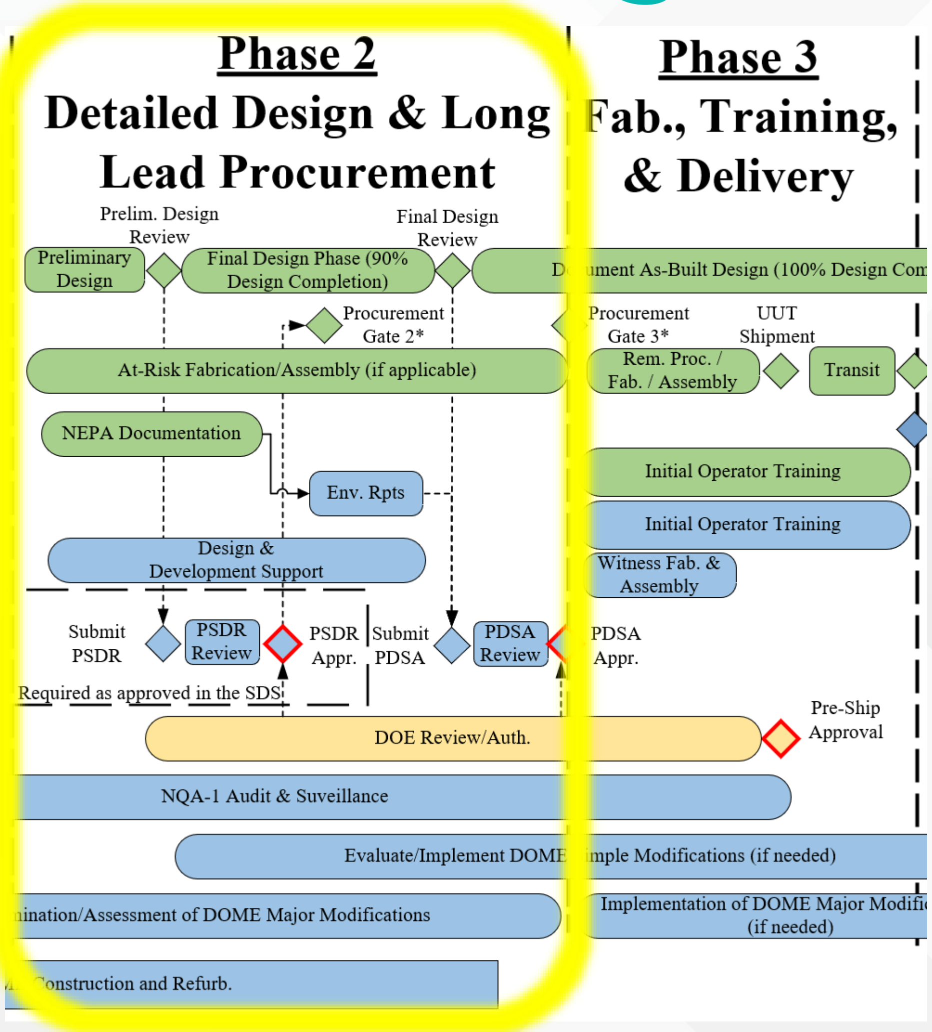
- Conceptual design and Conceptual Design Review
- Develop working documents
- Conceptual experiment design

Key Deliverables

- User Program Plan
- Class 4 Cost Estimate
- Conceptual Test Plan
- Safety Design Strategy (SDS)
- Conceptual Safety Design Report (CSDR)



Phase 2 - Detailed Design and Long Lead Procurement



Key Activities

- Preliminary Design and Preliminary Design Review
- Final Design and Final Design Review (90% design completion, required for Preliminary Documented Safety Analysis [PDSA])
- Finalize supplemental National Environmental Policy Act (NEPA) information and DOME Environmental Analysis (EA) comparison
- Progress Nuclear Safety documentation for PDSA
- Initial confirmatory reactor analysis
- Begin long lead procurement and manufacturing

Key Deliverables

- Confirmation of reactor design complying with DOME EA Plant Parameter Envelope (PPE)
- PDSA submittal

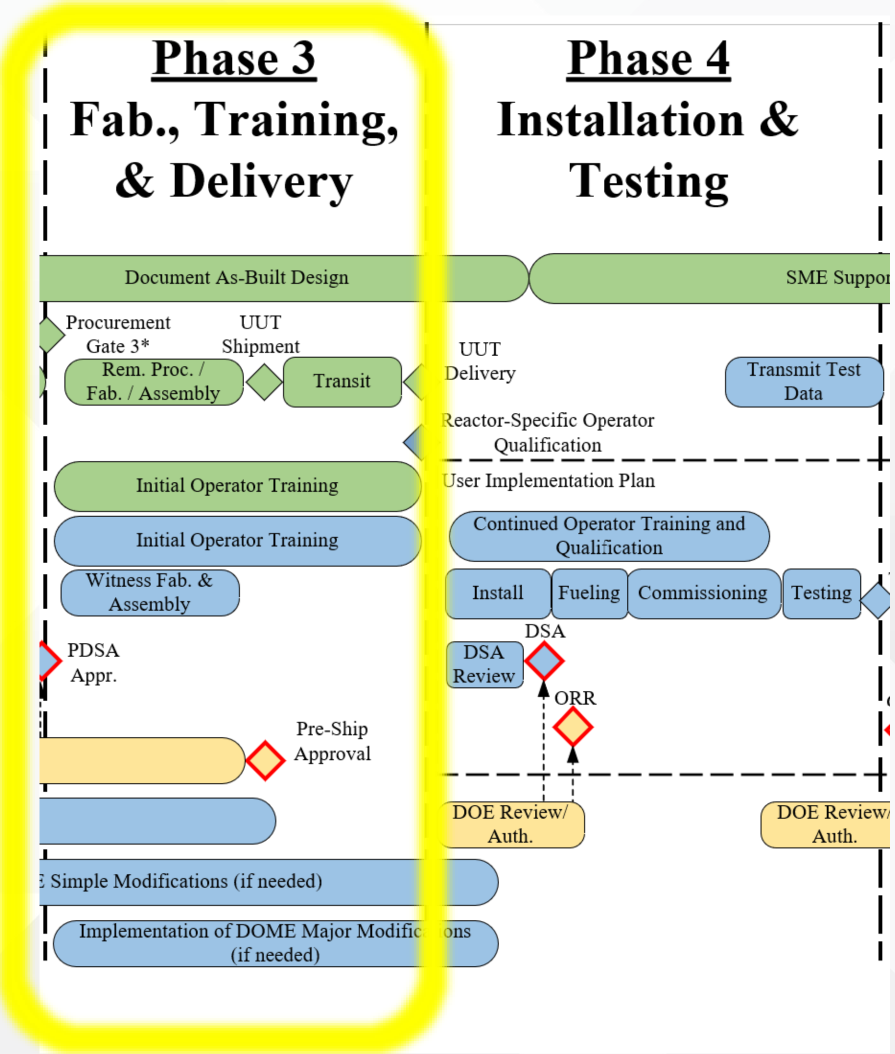
Phase 3 – Fabrication, Training, and Delivery

Key Activities

- Procurement
- Unit fabrication and assembly
- Document as-built design
- Initial Operator Training
- Idaho National Laboratory (INL) witness fabrication and assembly

Key Deliverables

- Unit delivery
- Operator qualification



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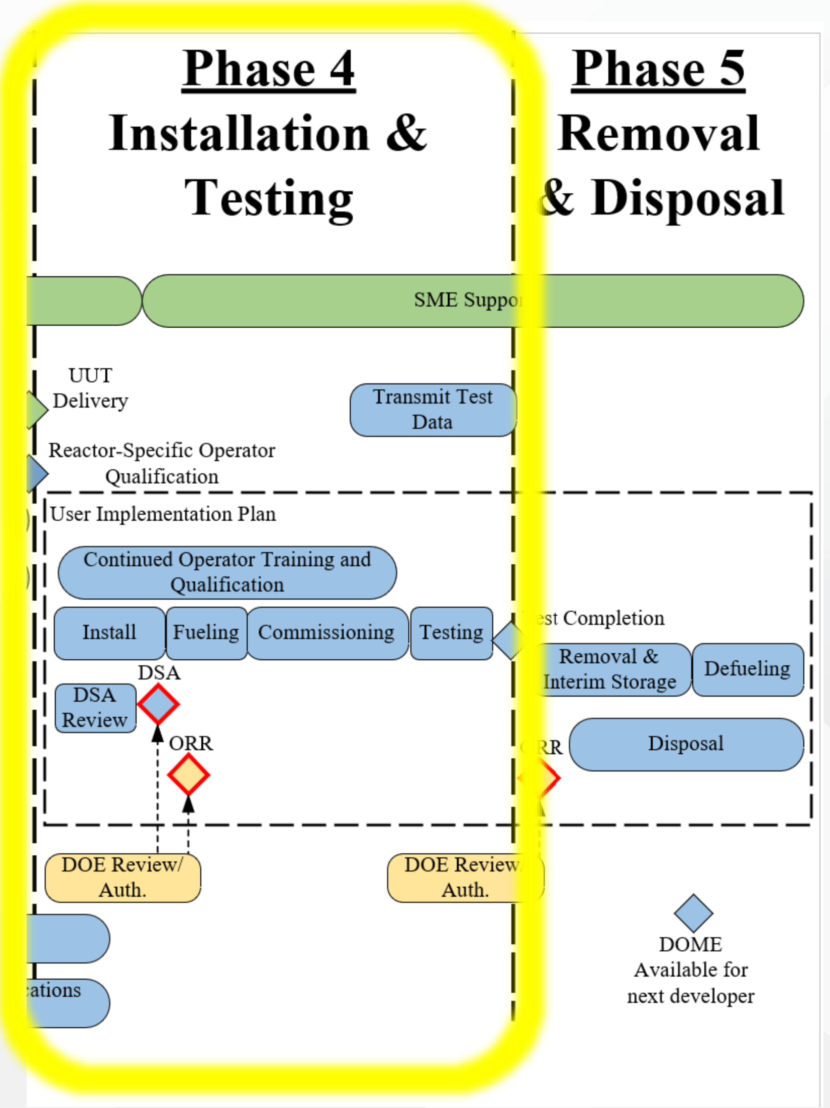
Phase 4 – Installation and Testing

Key Activities

- Unit Under Test Delivery (UUT)
- Unit installation
- Operational Readiness Reviews (ORR)
- Test campaign/Data collection

Key Deliverables

- Documented Safety Analysis (DSA)/Safety Analysis Report (SAR)
- Test Data



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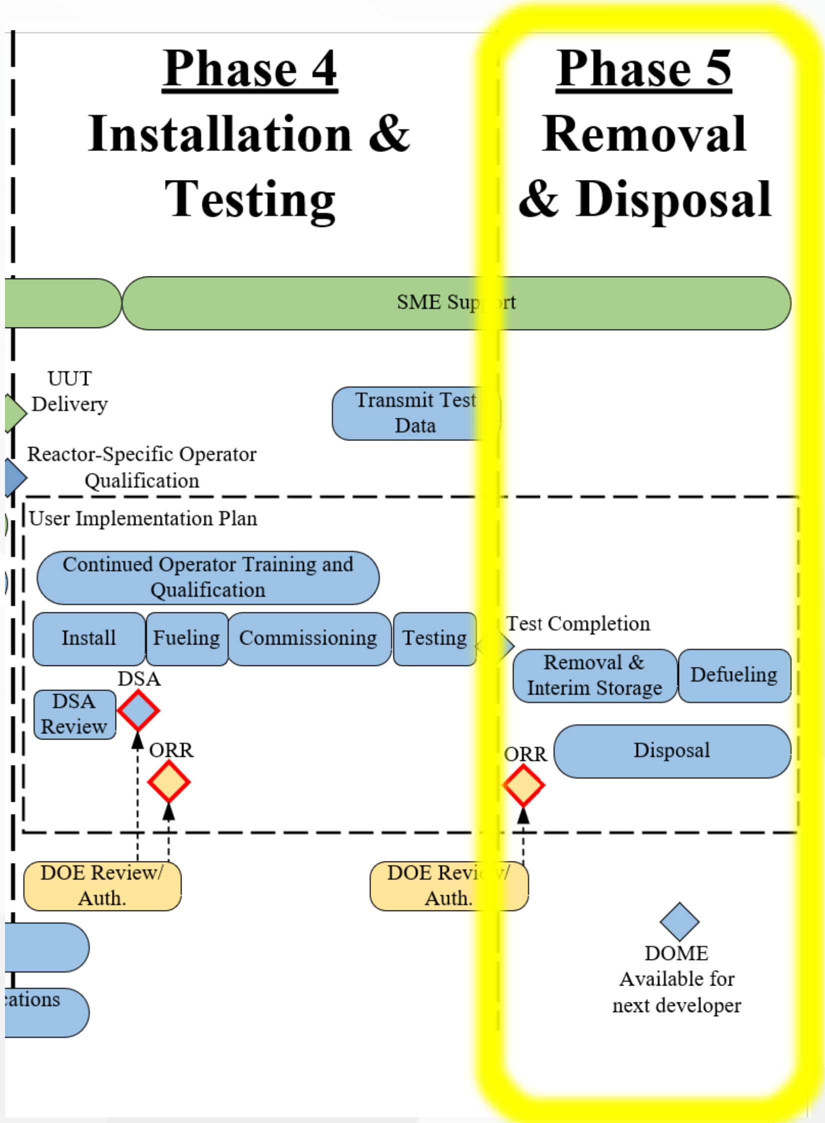
Phase 5 Removal and Disposal

Key Activities

- Shutdown and cooling
- Reactor removal
- Transport
- Interim Storage
- Defueling
- Disposal

Key Deliverables

- DOME ready for next test



DOME User Guide Next Steps

May '24
- NRIC review of revised User Guide
- NRIC National Technical Director review of revised User Guide

Jun '24
- Address and Incorporate review comments

Aug '24
- INL reviews of User Guide revision
- Submit updated User Guide 9/15/24

Questions?

NRIC National Reactor Innovation Center

NRIC National Reactor Innovation Center

DOME Front End Engineering Experiment and Design

FEEED

Troy P. Burnett, P.E.

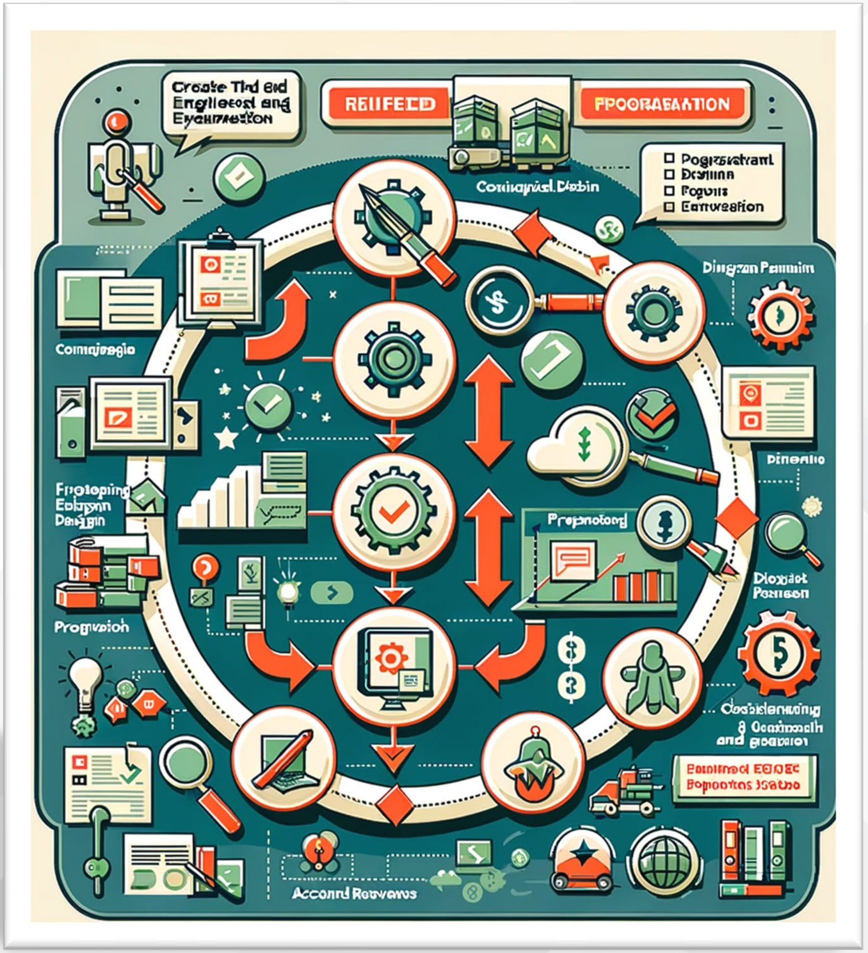
04/2024

FEEED Overview

- Explore the FEEED Process
  - Key Activities
  - Key Deliverables
- Provide an update on FEEED Progress
  - Radiant
  - USNC
  - Westinghouse

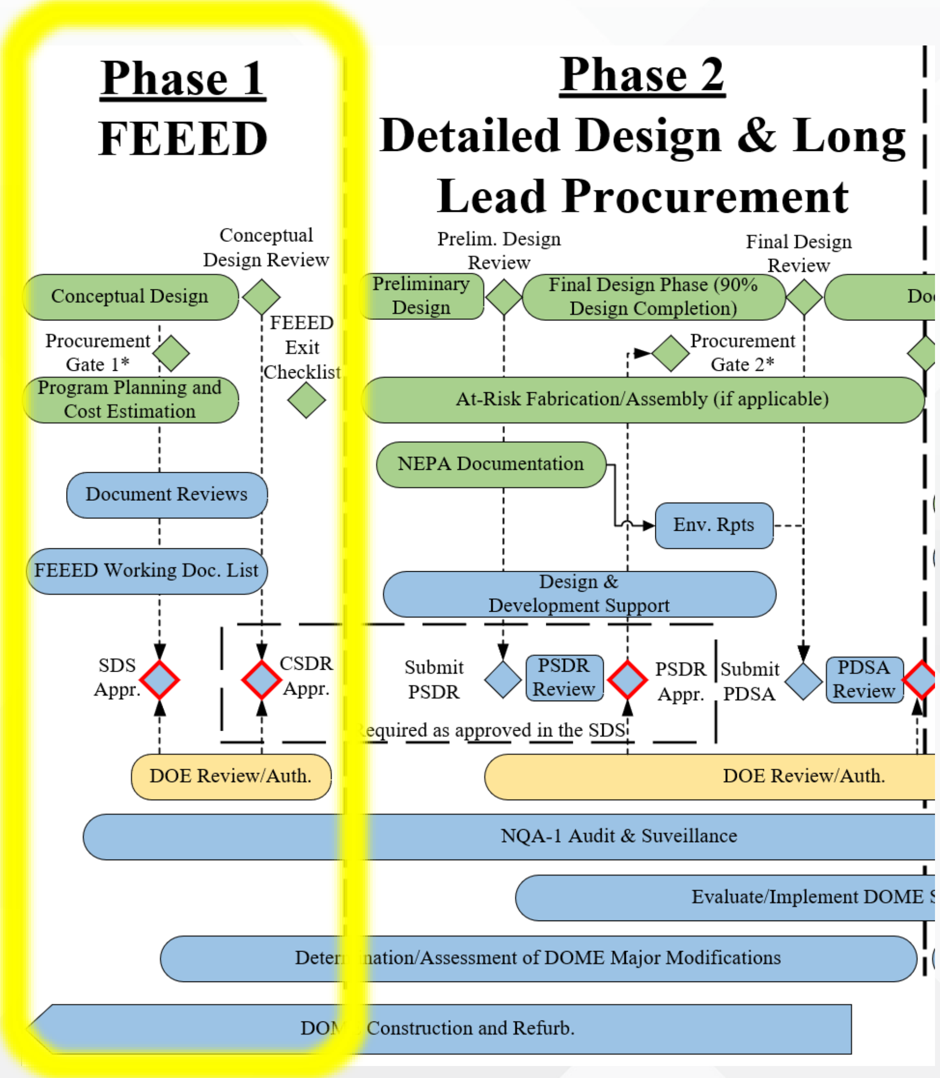
DOME Test Bed Program

- Developing a new process
- Simultaneously with developers working through the process
- There are a lot of “Known Unknowns”
- Process, procedures,….. Being developed as we go
- Thank you for helping navigate
  - Radiant
  - USNC
  - Westinghouse



FEEED Key Activities and Deliverables

- Key Activities
  - Program Planning
  - Total Project Cost Estimate
  - Conceptual Design
  - Experiment Design
- Deliverables
  - Safety Design Strategy
  - Experiment Design Outline
  - Conceptual Design Review
  - Conceptual Safety Design Report



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FY 23/24 FEEED Process

- Expression of Interest (EOI) advertised in June
  - Received seven expressions of interest
- RFP solicited in July
  - Received five proposals
- Awarded three 80/20 cost share contracts in Fall of 2023
  - Radiant
  - USNC
  - Westinghouse

FY24 FEEED Work

- Safety Design Strategy
  - Westinghouse received DOE acceptance December 2023
  - Radiant received approval March 2024
  - USNC working on submittal later this year
- Held in person design reviews
  - Westinghouse
  - Radiant
- Strategic Planning
- Consultation and Collaboration
  - Ongoing document and design reviews
  - Fuel cycle planning
  - Fuel Specification
  - Fuel fabrication

FY24 FEEED Work Continued

- Conceptual Safety Design Report
  - Radiant
    - Completed review
    - Working on submittal
  - USNC
    - Developing design and documentation
- Preliminary Safety Design Report
  - Westinghouse
    - Completed review in February
    - Comments incorporated
    - Submitted to INL for review and submittal 4/12

FY 23/24 FEEED Status Updates

- Westinghouse – Erin Orga
- USNC – Wes Deason
- Radiant – Elliott Korb

Possible FEEED Funding/Contracting Mechanism

- DOE Cost Share
  - Dependent on funding availability
  - Intended to cover costs associated with
    - NRIC/INL personnel
    - Possibly some developer costs
- Developer Funded
  - Developer covers all NRIC costs
  - Contract Type
    - CRADA
    - SPP

Questions?

NRIC National Reactor Innovation Center

Westinghouse eVinci™

Erin Orga, Program Manager
eVinci External Testing
April 2024

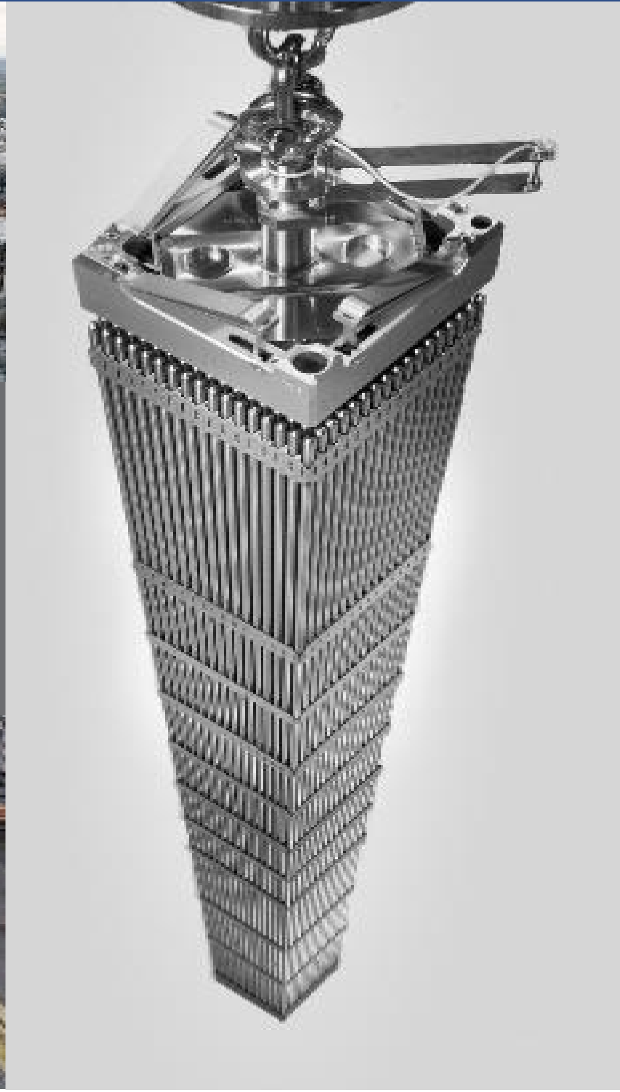
Westinghouse

Westinghouse Electric Company

MORE THAN

134

YEARS OF INNOVATION



Westinghouse established **59** other companies

He received over **360** patents for his work

Approximately **10,000** Employees

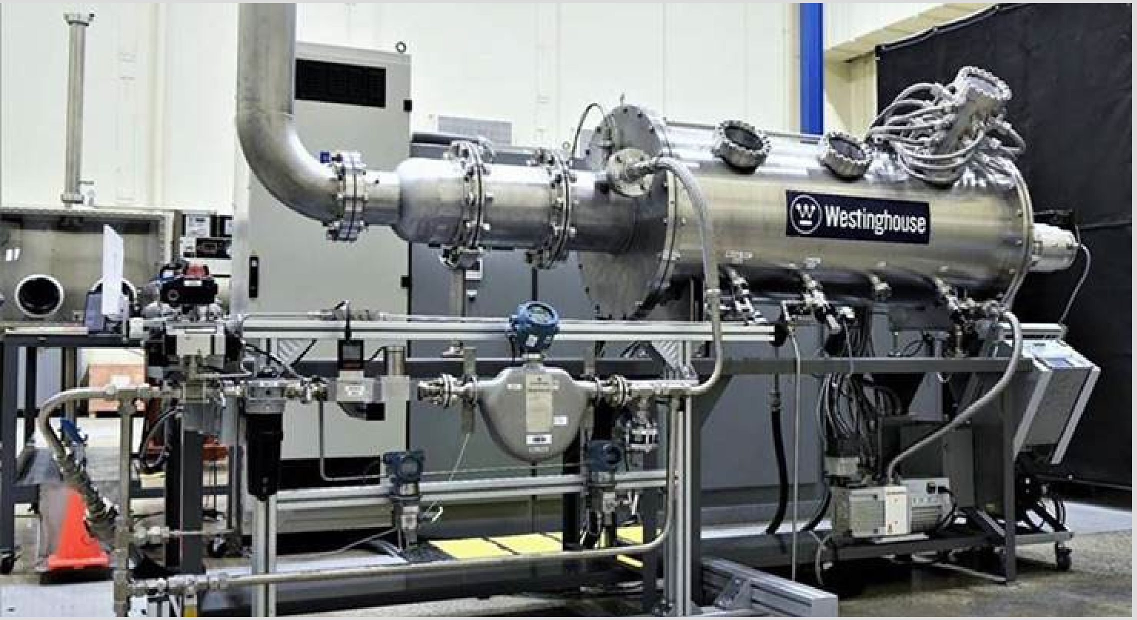
Comprised of **5** Business Units

Locations in **19** Countries

- Founded by George Westinghouse in 1886
- Responsible for some of the world's greatest advances in energy technology
- World's first commercial pressurized water reactor (PWR) in 1957 in Shippingport, Pennsylvania, U.S.

Westinghouse

eVinci Microreactor
Capability



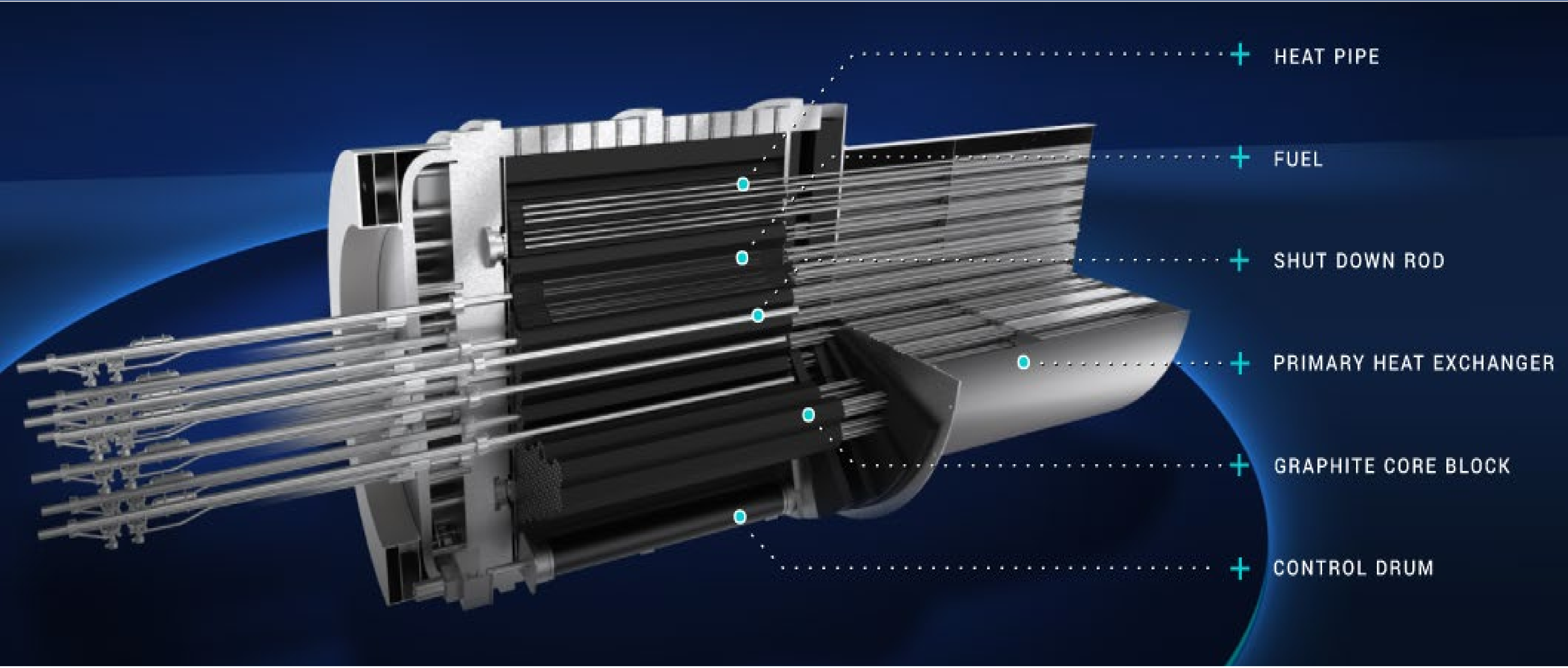
Pictured is the eVinci Electrical Demonstration Unit

Microreactor designed for safe and reliable electricity and heat generation

Technical Capabilities

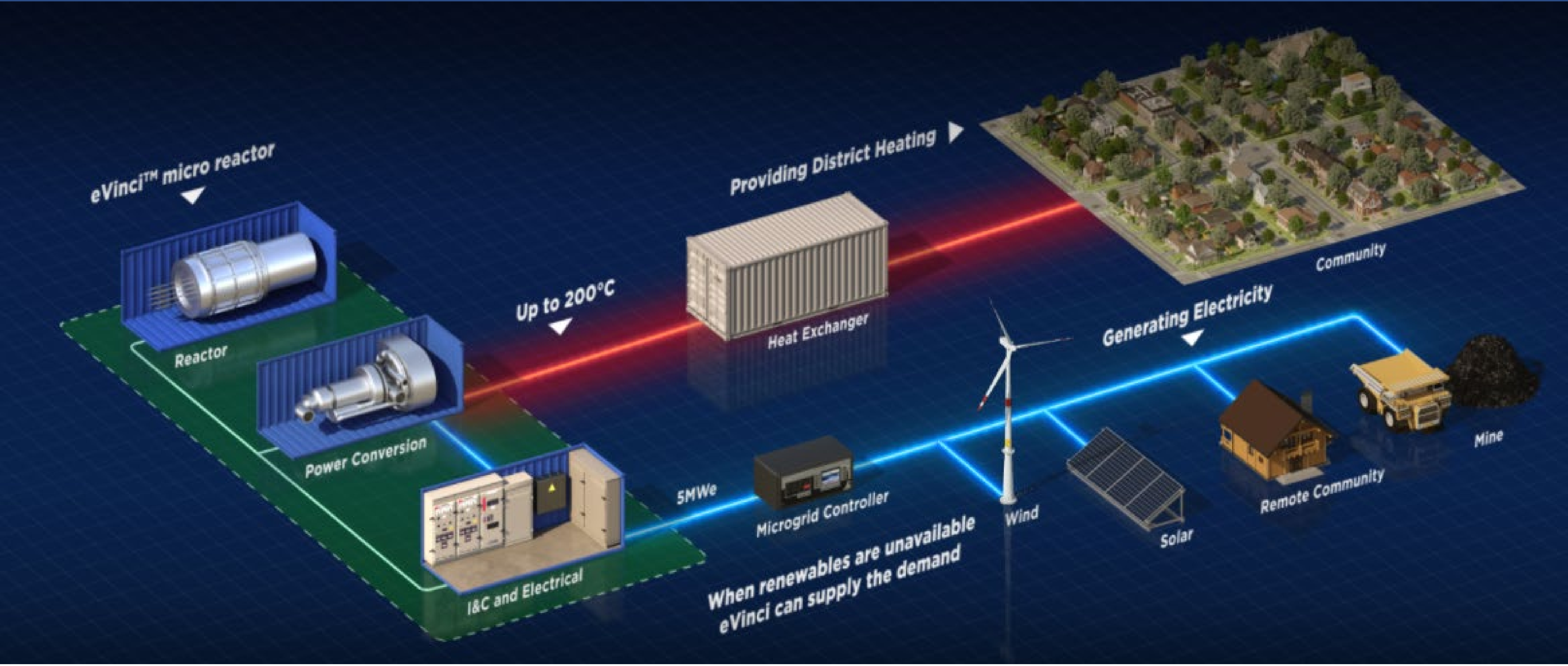
- ✓5 MWe and ~7MWth@350F heat recovery
- ✓~13.5MWth @ >1300F heat only (future)
- ✓Transportable for ease of installation and elimination of spent fuel storage on site
- ✓Cost-competitive plant lifecycle
- ✓Minimal onsite personnel
- ✓Maturing technology, manufacturing, and regulatory readiness
- ✓Cogeneration and load following capability

eVinci Microreactor
Technology



eVinci Microreactor

Combined Heat and Power Capability



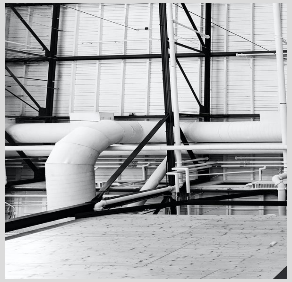
Westinghouse

eVinci Microreactor

Prospective Markets/End Uses

Remote mining operations

Industrial process heat



District heating

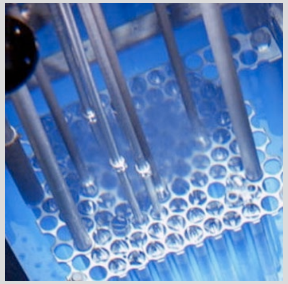
Remote communities

Hydrogen Generation

Marine Shipping

Critical Infrastructure Installations

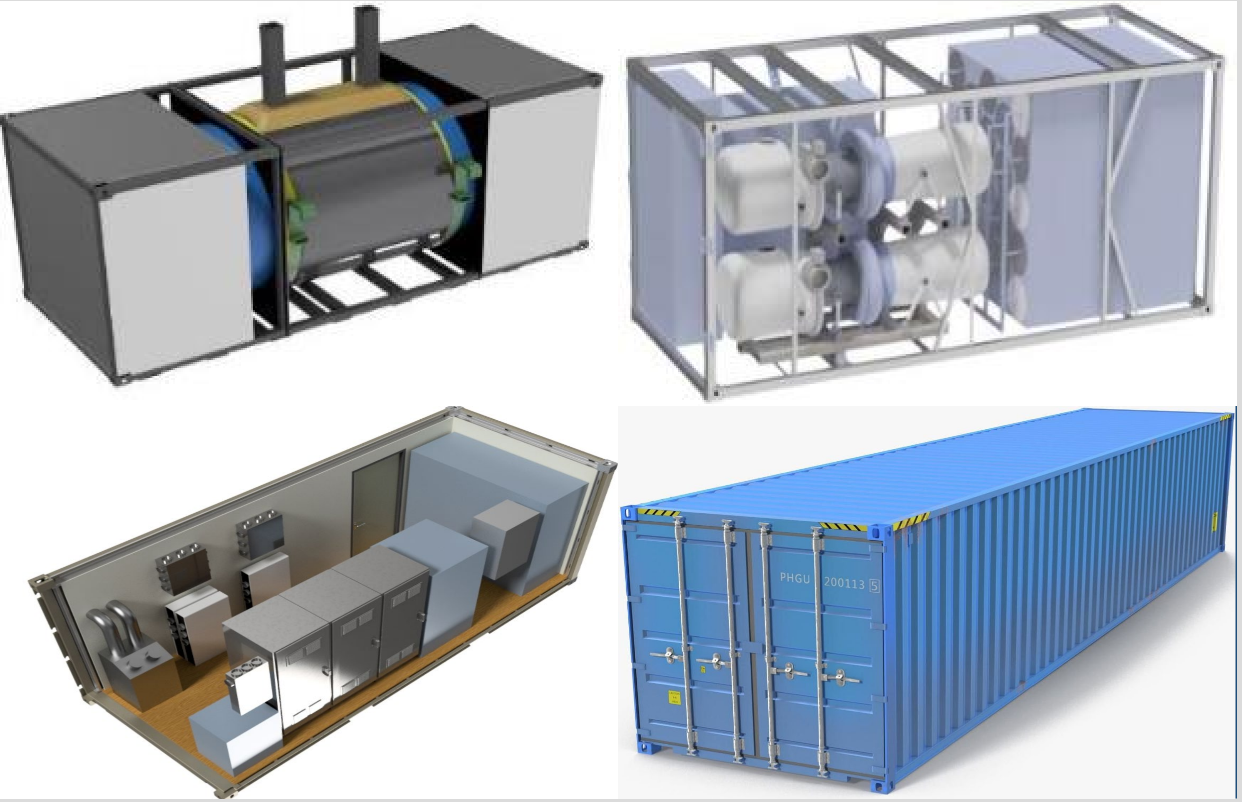
Disaster relief



Research Reactors

eVinci Microreactor Deployment

Transportability Advantages



Minimizes construction cost and labor

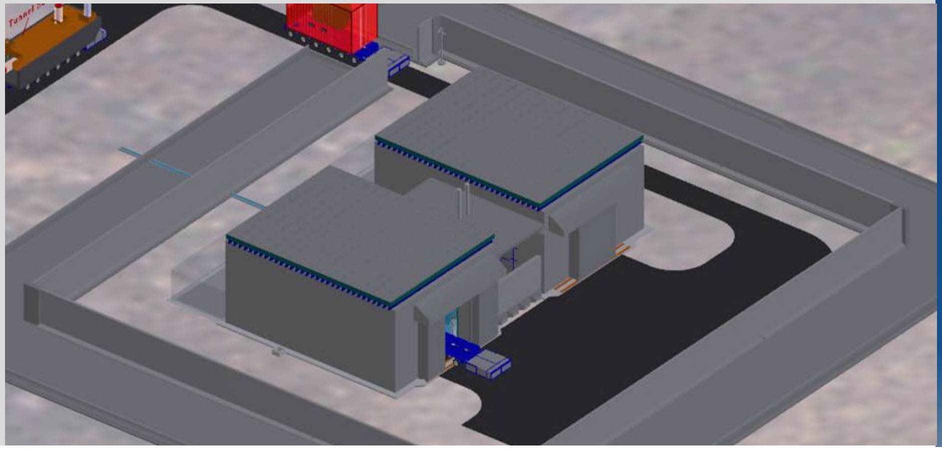
Installation to operation in less than 30 days

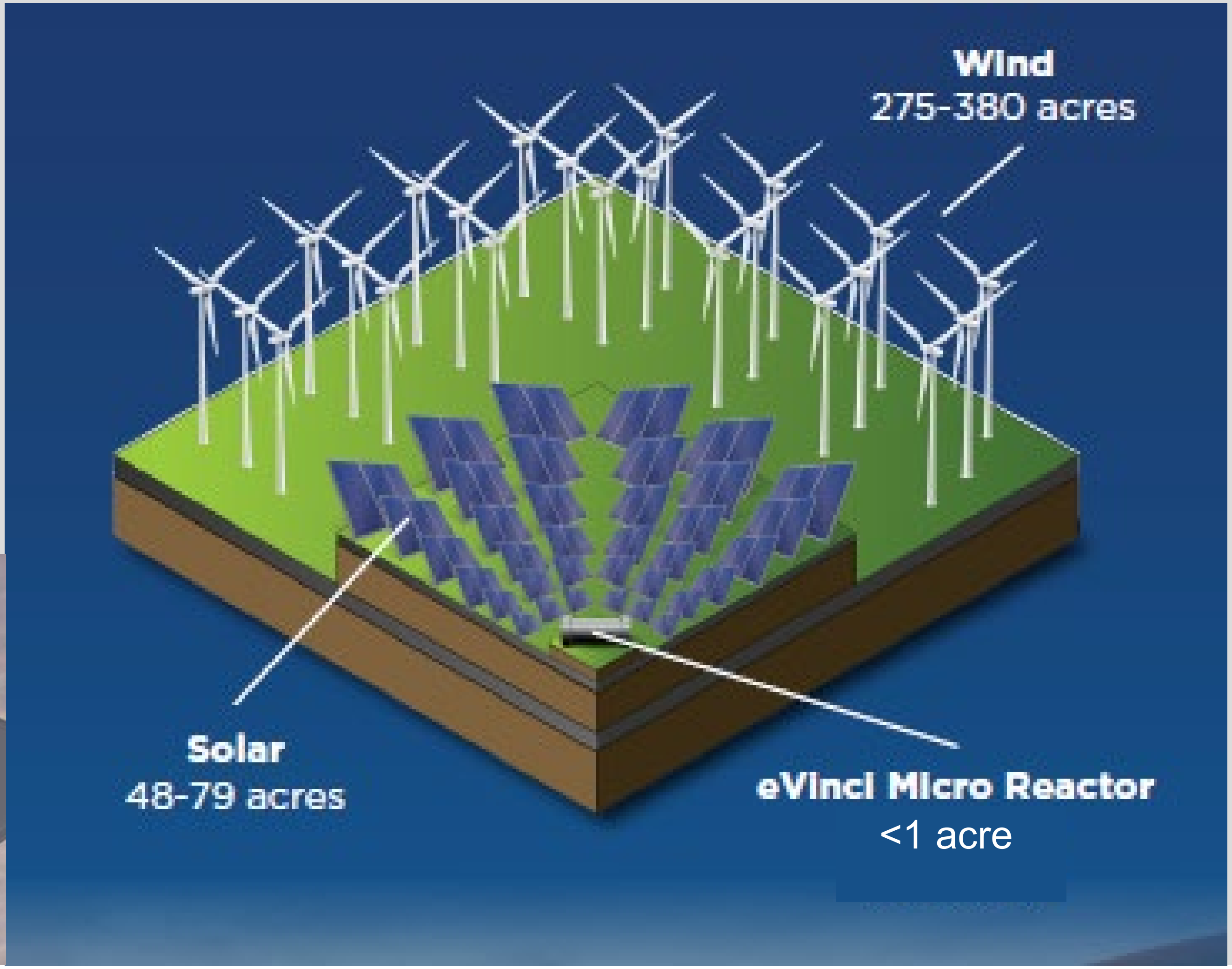
- ❑ **Entire system delivered in four truckload size containers (40' x 14' x 14')**
  - Reactor container
  - Power conversion unit
  - Instrument and controls
  - Miscellaneous support equipment

- ✓ **Weights and sizes allow for deployment in remote areas (truck/rail/barge)**
- ✓ **Allows for rapid scaling to meet demand**
- ✓ **No spent fuel or waste storage on site**
- ✓ **Minimizes decommissioning and effort to return site to green field**

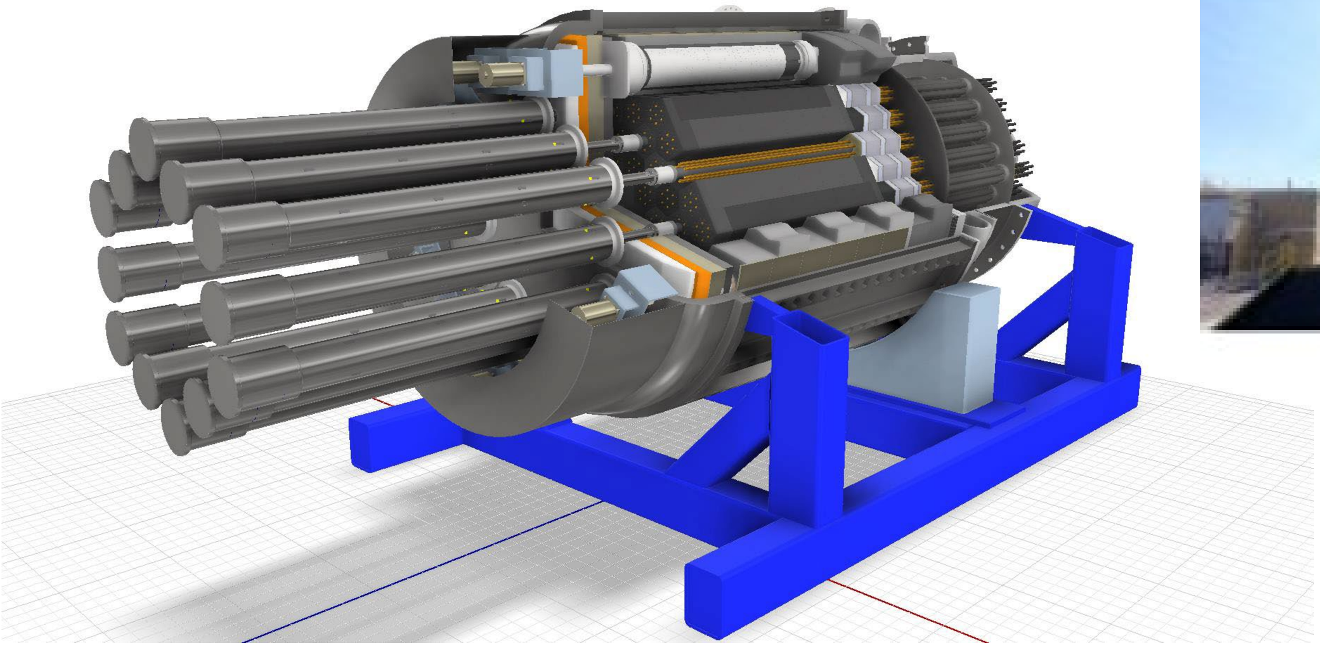
eVinci Microreactor
Footprint

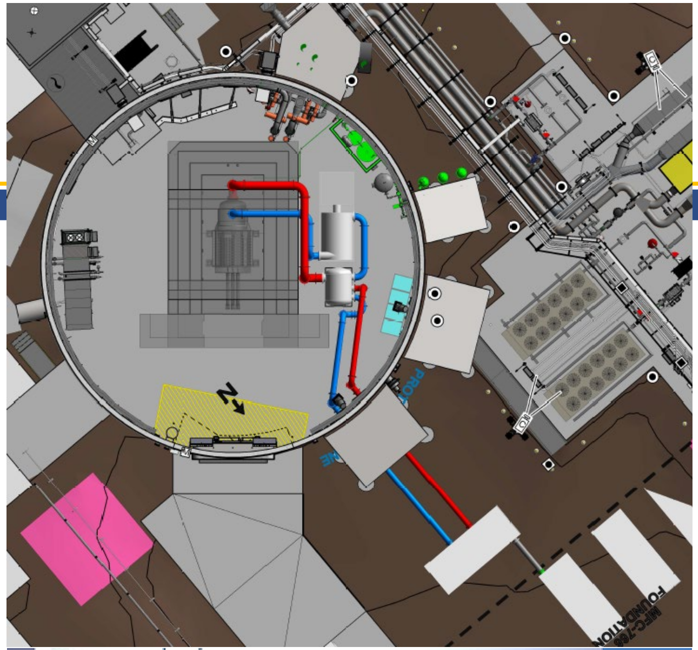
- Near 100% capacity factor versus intermittent renewable supply
- Building shields radiation
- Emergency planning zone contained within site boundary
- All construction above ground
- Site footprint: **2 acre**
- Building footprint: **0.25 acre**

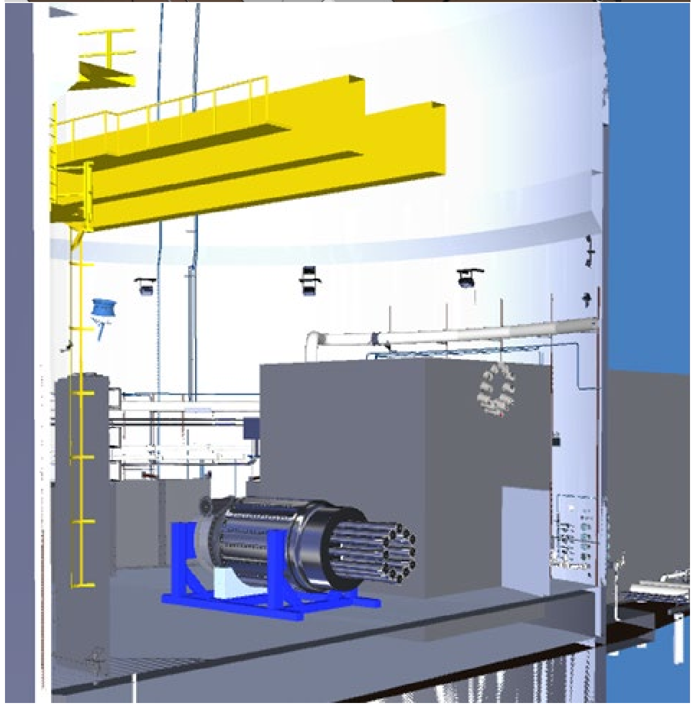




Nuclear Test Reactor



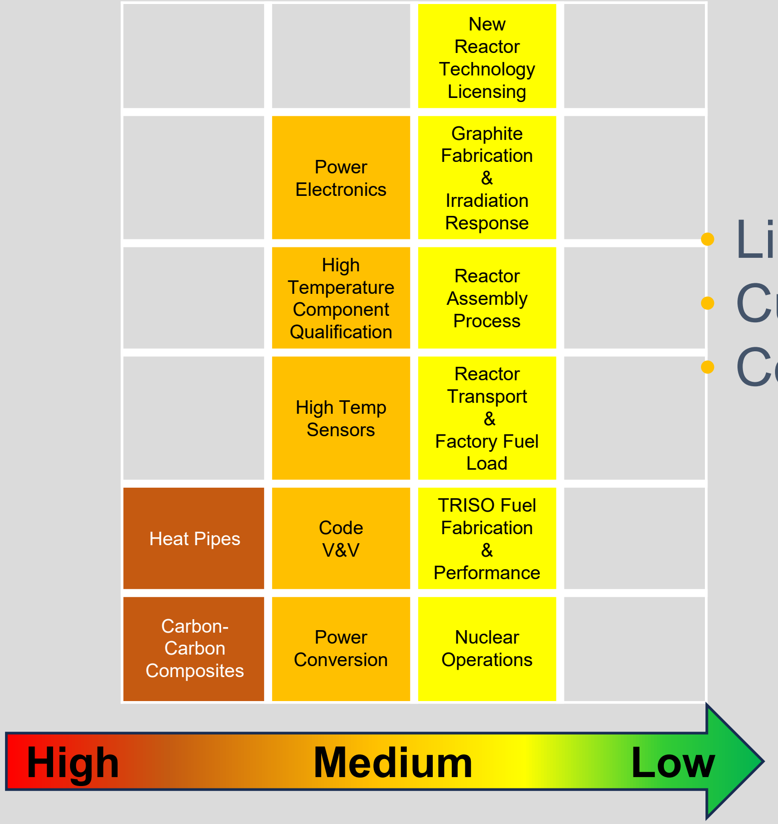




1/5 Scaled reactor demonstration at Idaho National Lab for final data and operational information to support regulatory approval

Westinghouse

The NTR Accelerates Commercialization

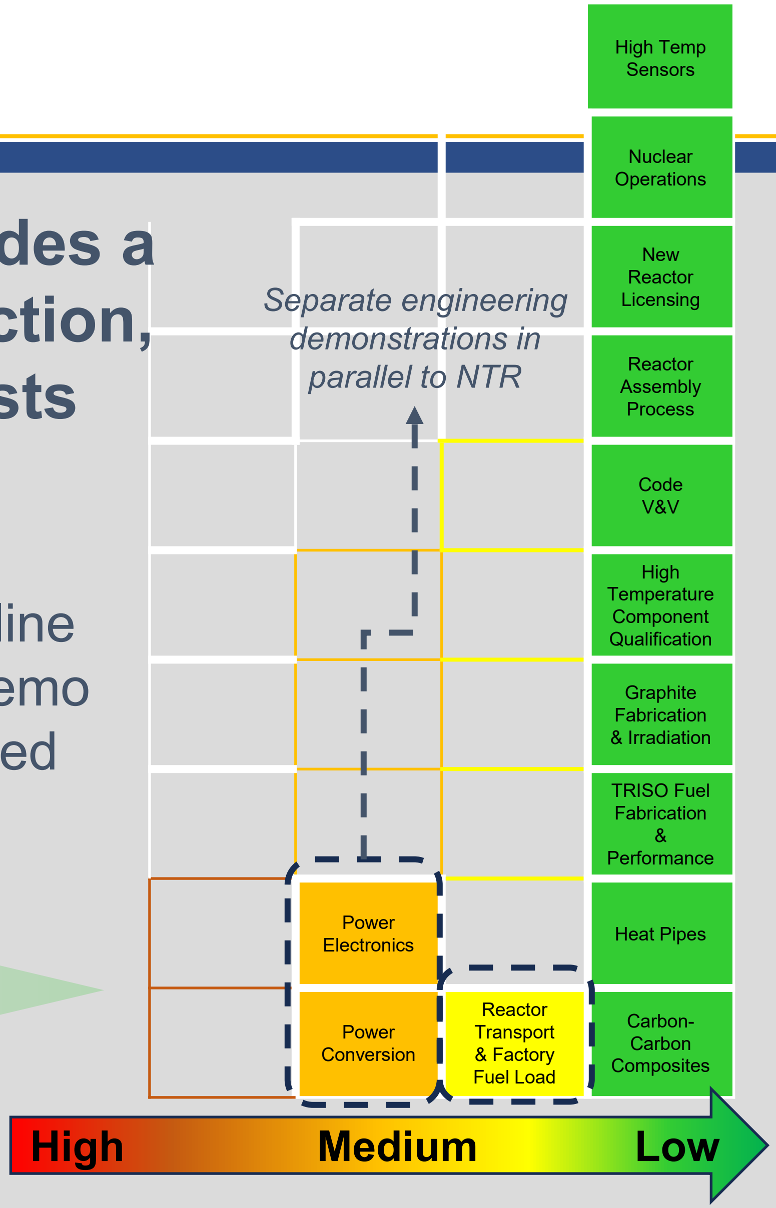


eVinci Technology Risk Scale

The Nuclear Test Reactor provides a unique opportunity in risk-reduction, not achievable in separate tests

The Result:

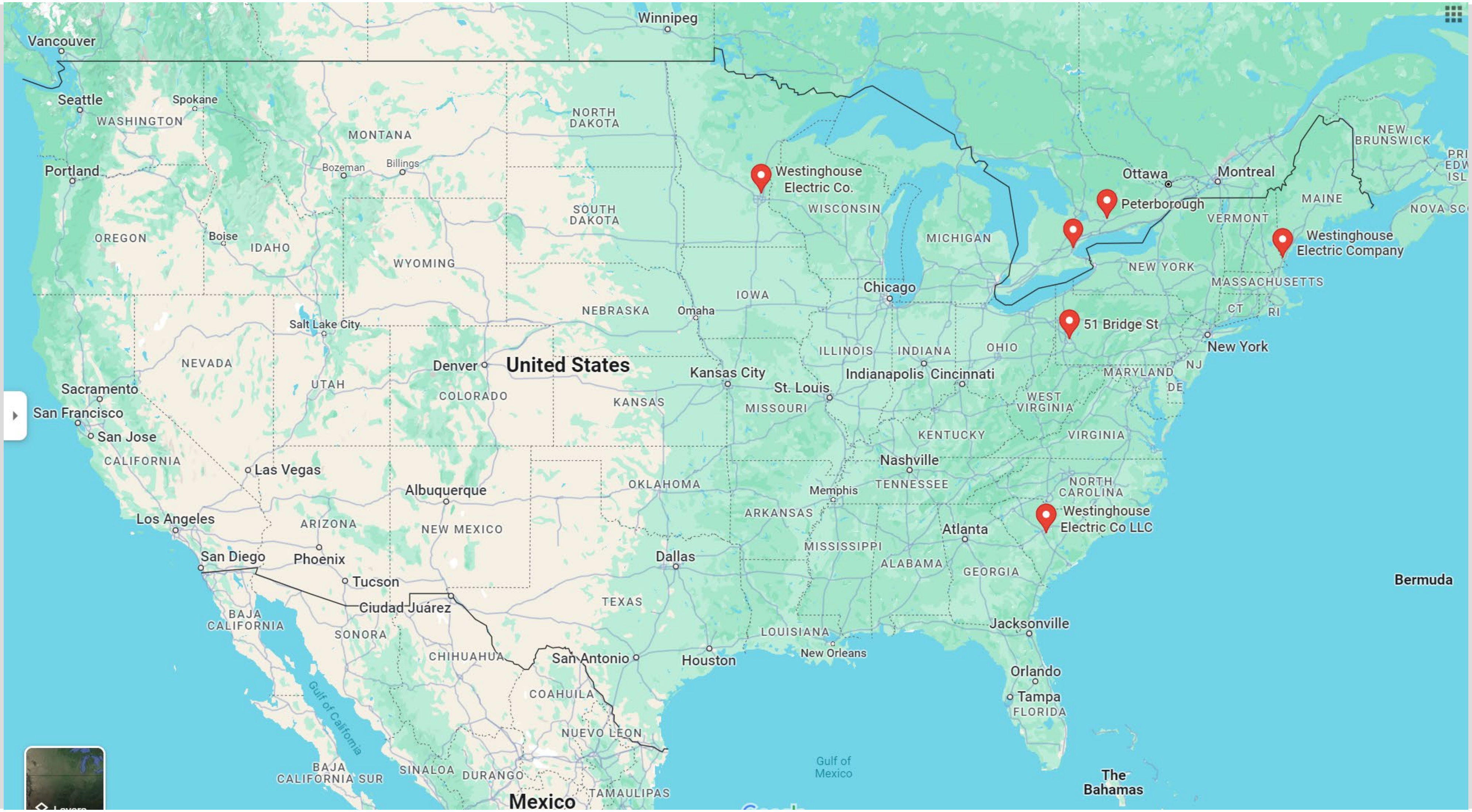
- Licensing certainty of technology & timeline
- Customer confidence through nuclear demo
- Component costs & supply chain validated



eVinci Technology Risk Scale

Westinghouse

eVinci NTR Development Locations



eVinci Accelerator

eVinci Technologies Dedicated Office

Testing, and Manufacturing Facility *Etna, PA*

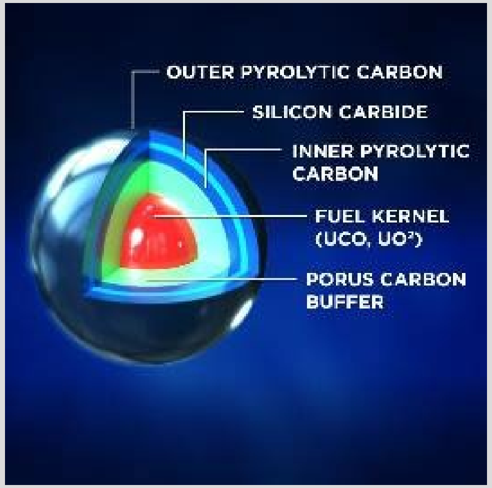
eVinci uses 19.75% enriched Tristructural Isotropic (TRISO) fuel

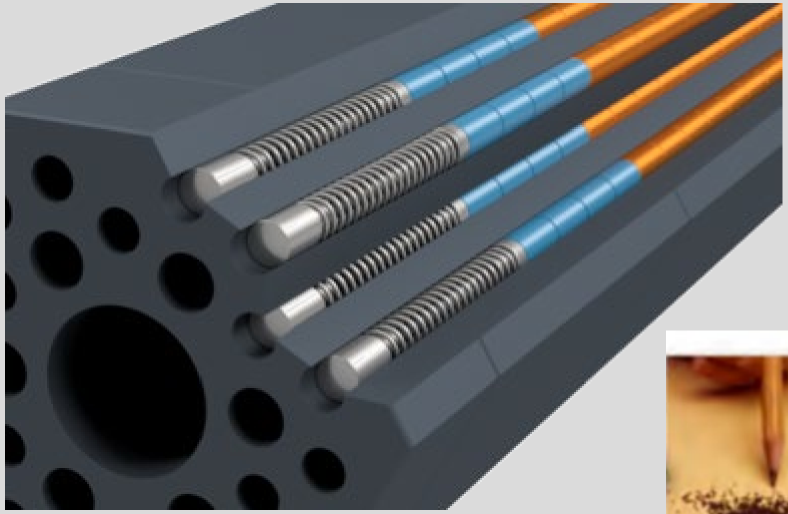
Integrated Safety, from Fuel to Canister

Unlike most other reactors, eVinci microreactor is designed to operate at atmospheric pressures, eliminating risk of fission product release. The highest level of safety of fuel and radiation is maintained within many redundant layers of **functional containment.**

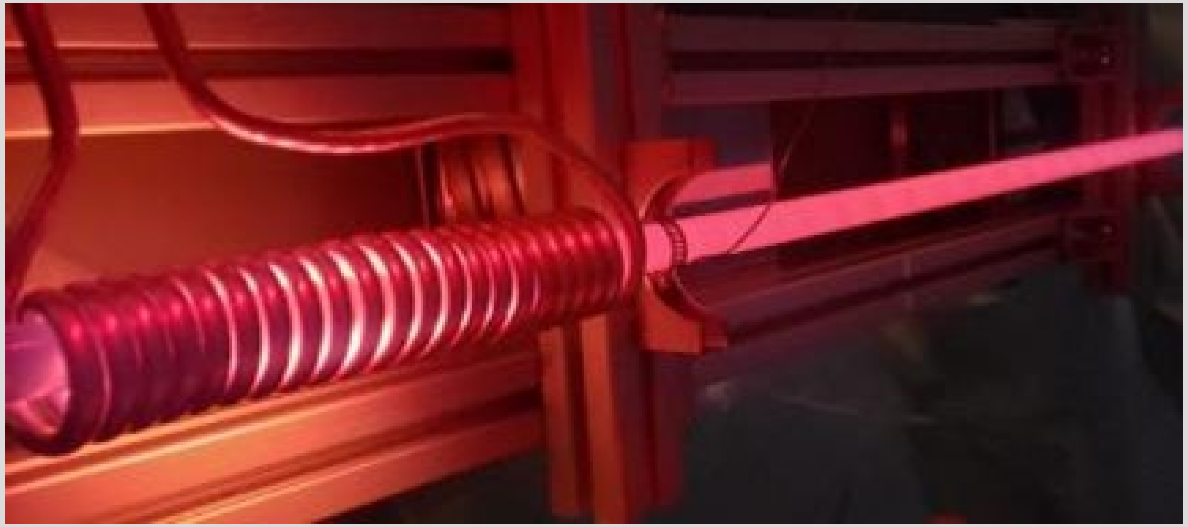
In collaboration with Urenco, Westinghouse was awarded a grant from the United Kingdom's Department for Business, Energy and Industrial Strategy (BEIS) to complete a Pre-Front End Engineering Design study for a secure and reliable supply of advanced TRISO to support a range of potential technologies in development.

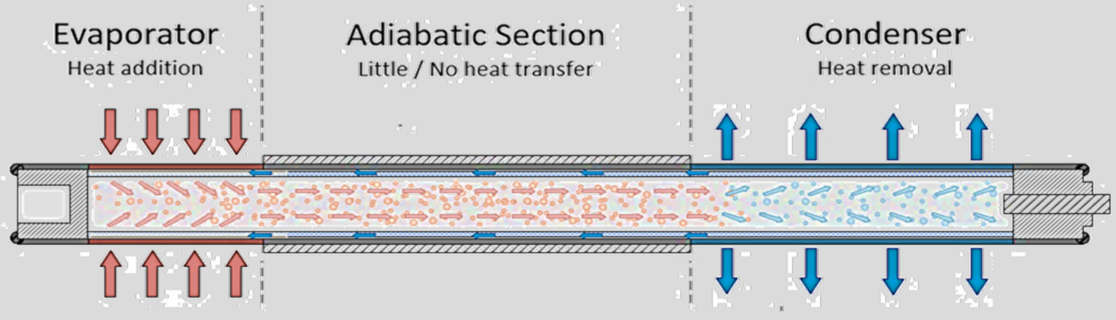
October 26, 2022

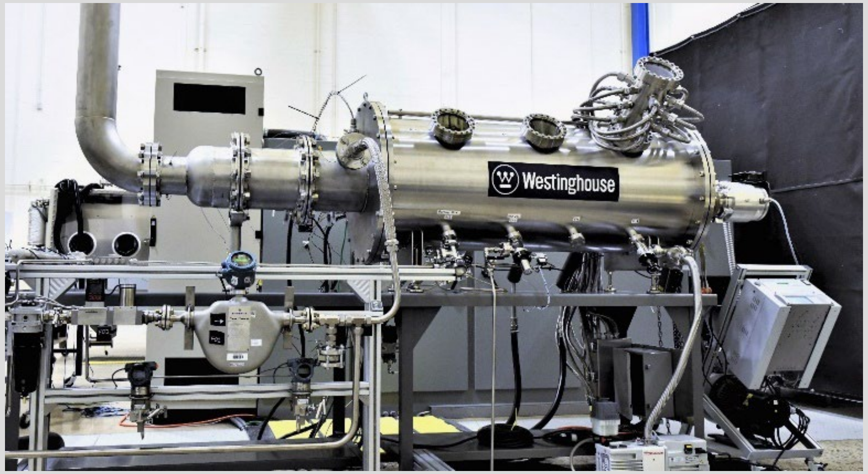




Heat Pipe Technology Development



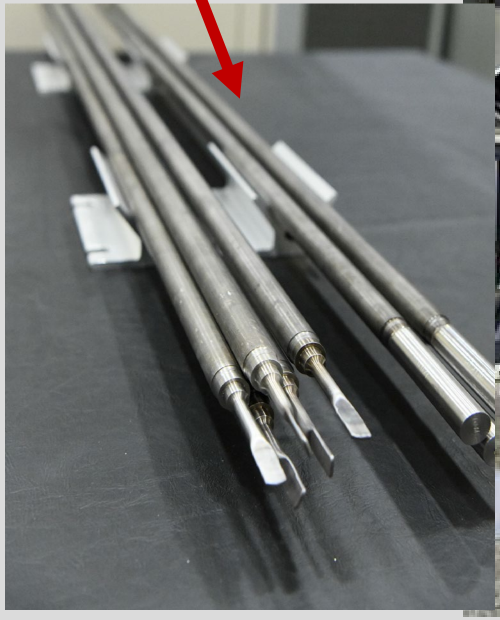


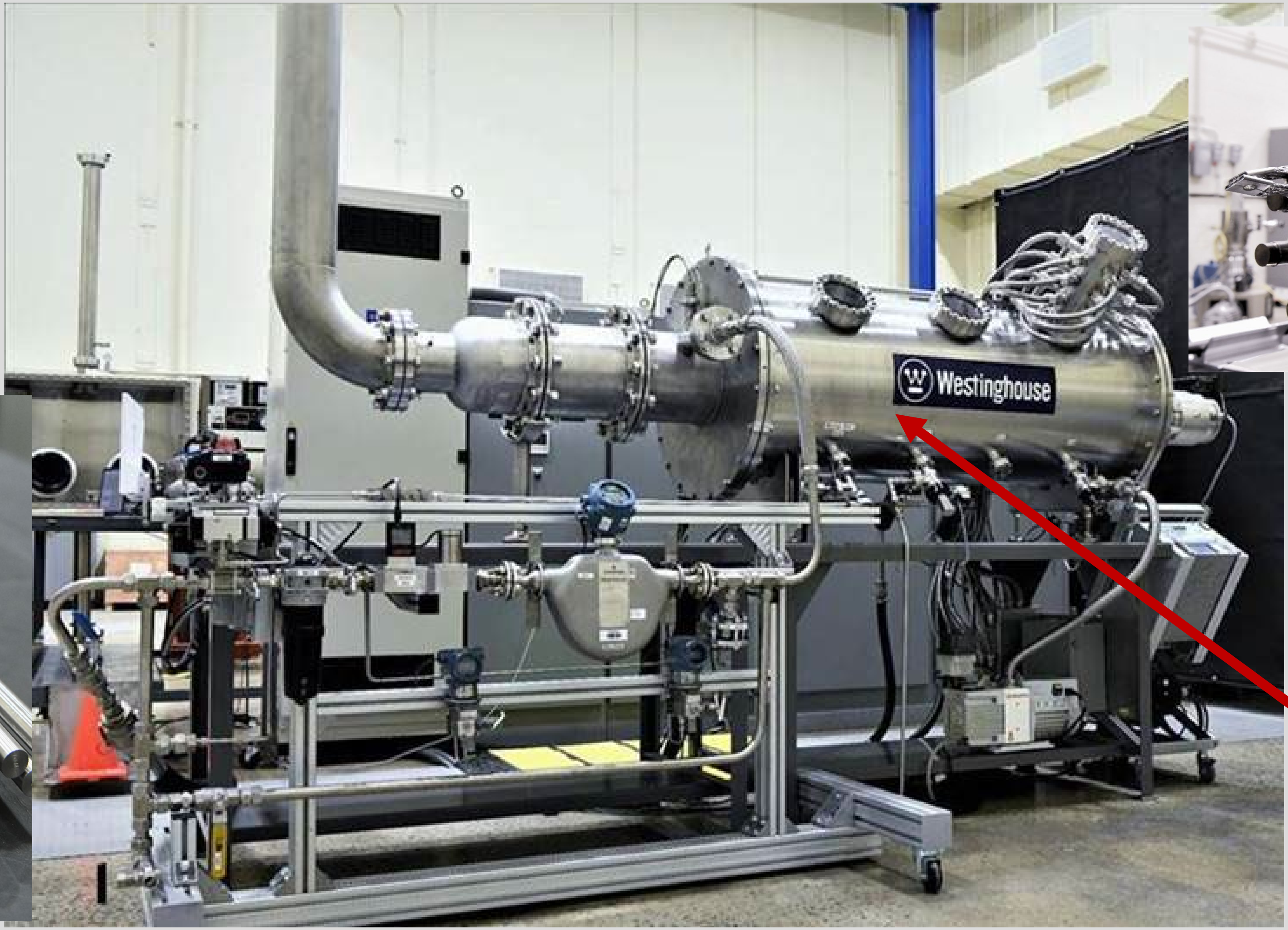


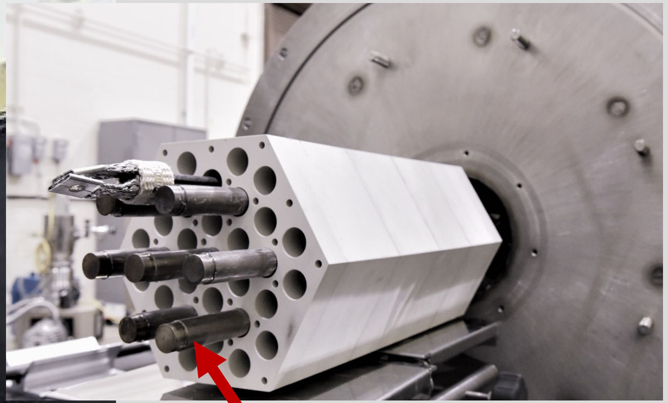
eVinci Integral Effects Test Program

Testing Program – 51 Bridge St & Waltz Mill

Heat Pipes





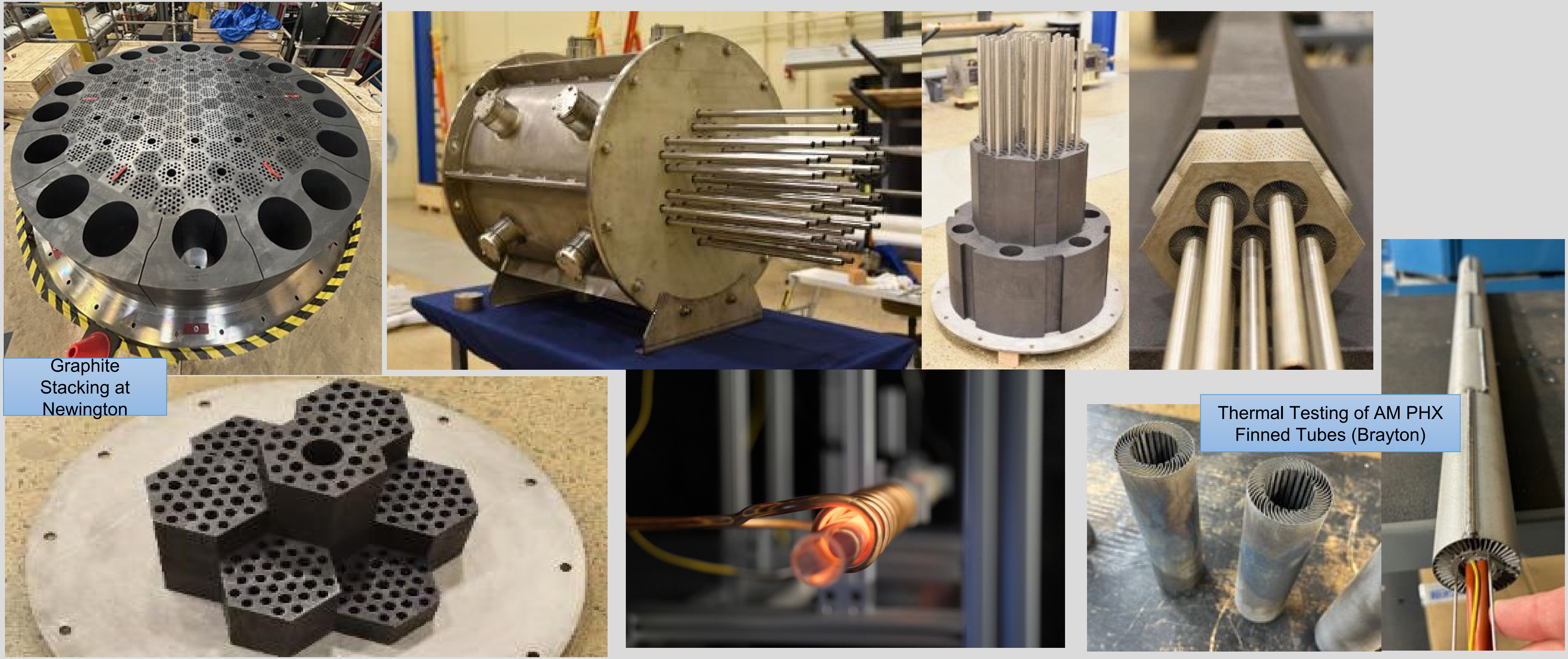


Heat Pipes

Test Chamber

eVinci NTR

Manufacturing Development and Demonstration Progress



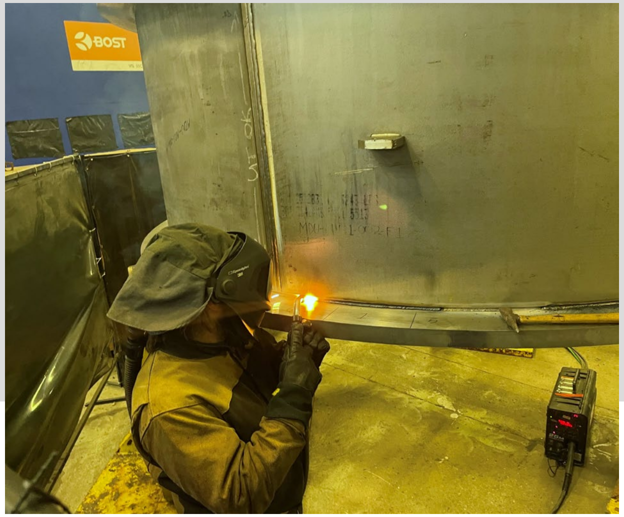
Graphite Stacking at Newington

Thermal Testing of AM PHX Finned Tubes (Brayton)

eVinci NTR
Manufacturing Progress








Hardware and Prototyping Continues

Control Drum and Shutdown Rod Assemblies under active prototyping

Westinghouse

Technology Components – Peterborough, ON office

Shut down rod and control drum component manufacturing and testing

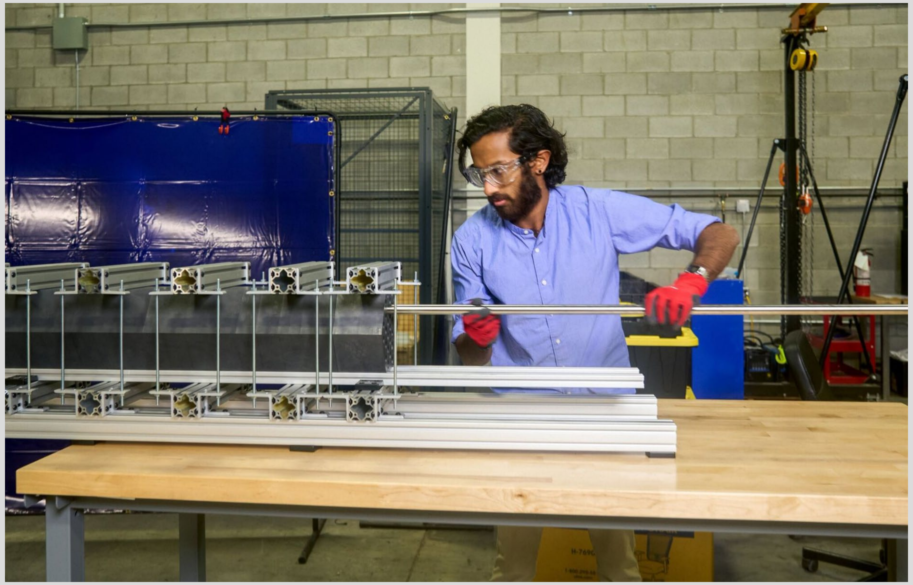
Collaborations with Ontario Tech University

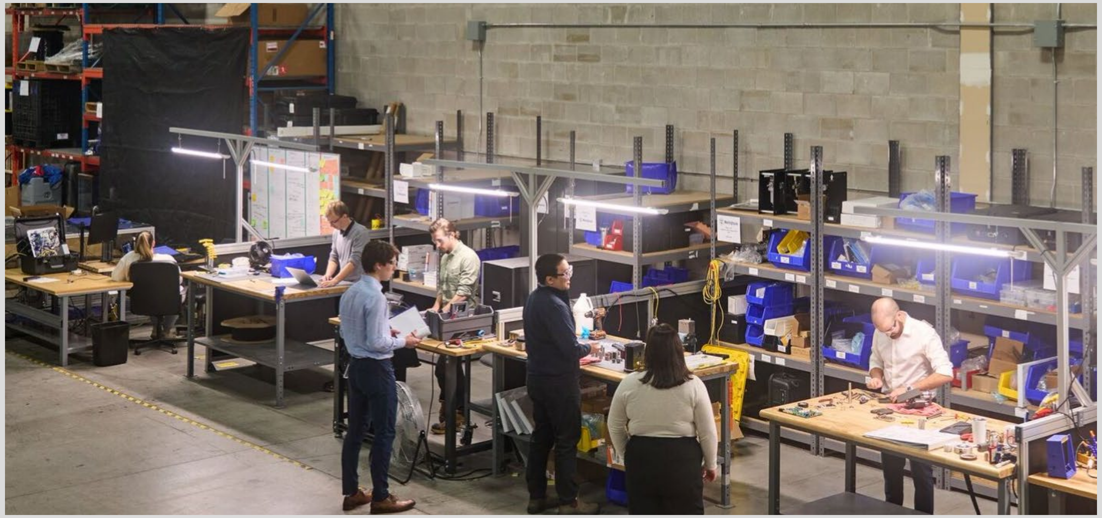
Technology Components- Burlington, ON Office

Reactor fueling and de-fueling component manufacturing and testing

Office expansion

McMaster University, Uwaterloo, Queens U

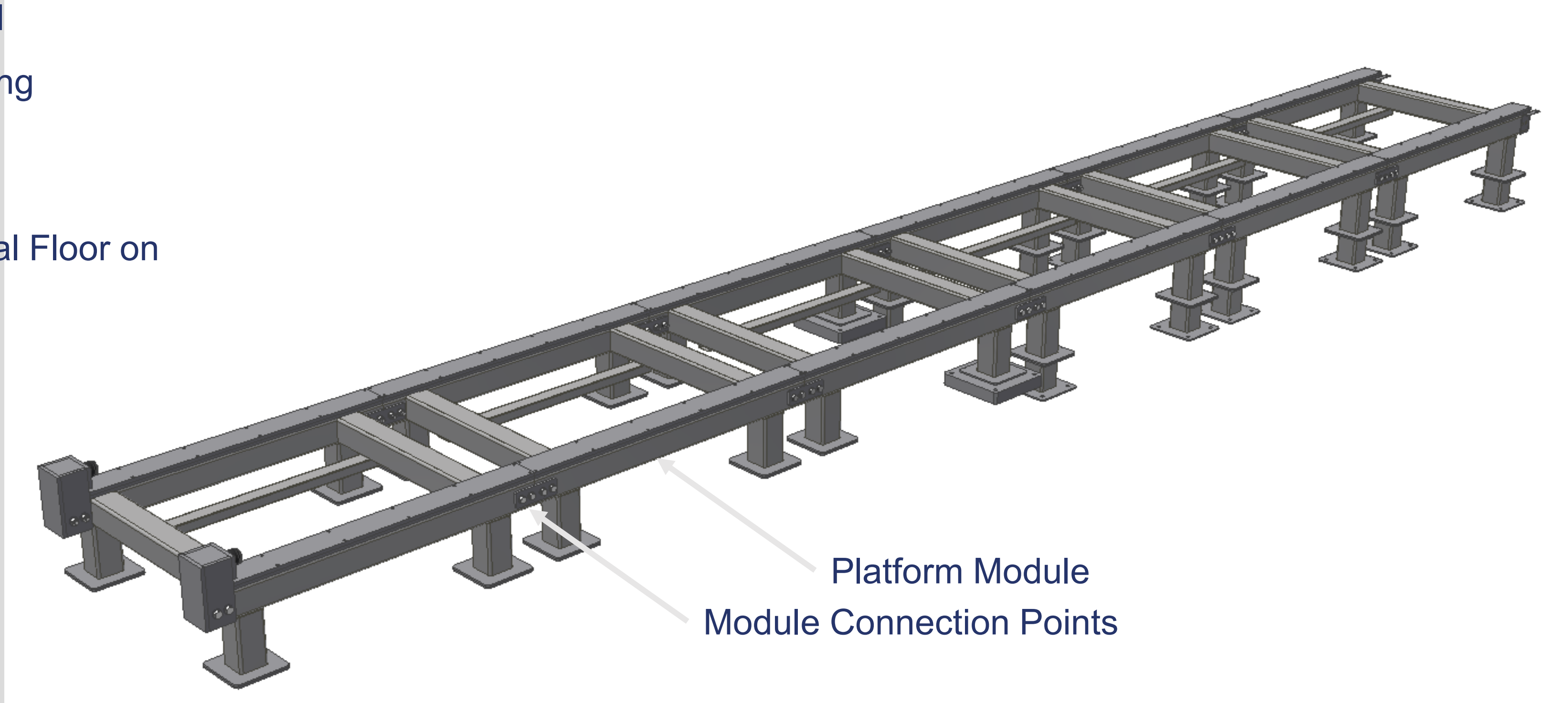




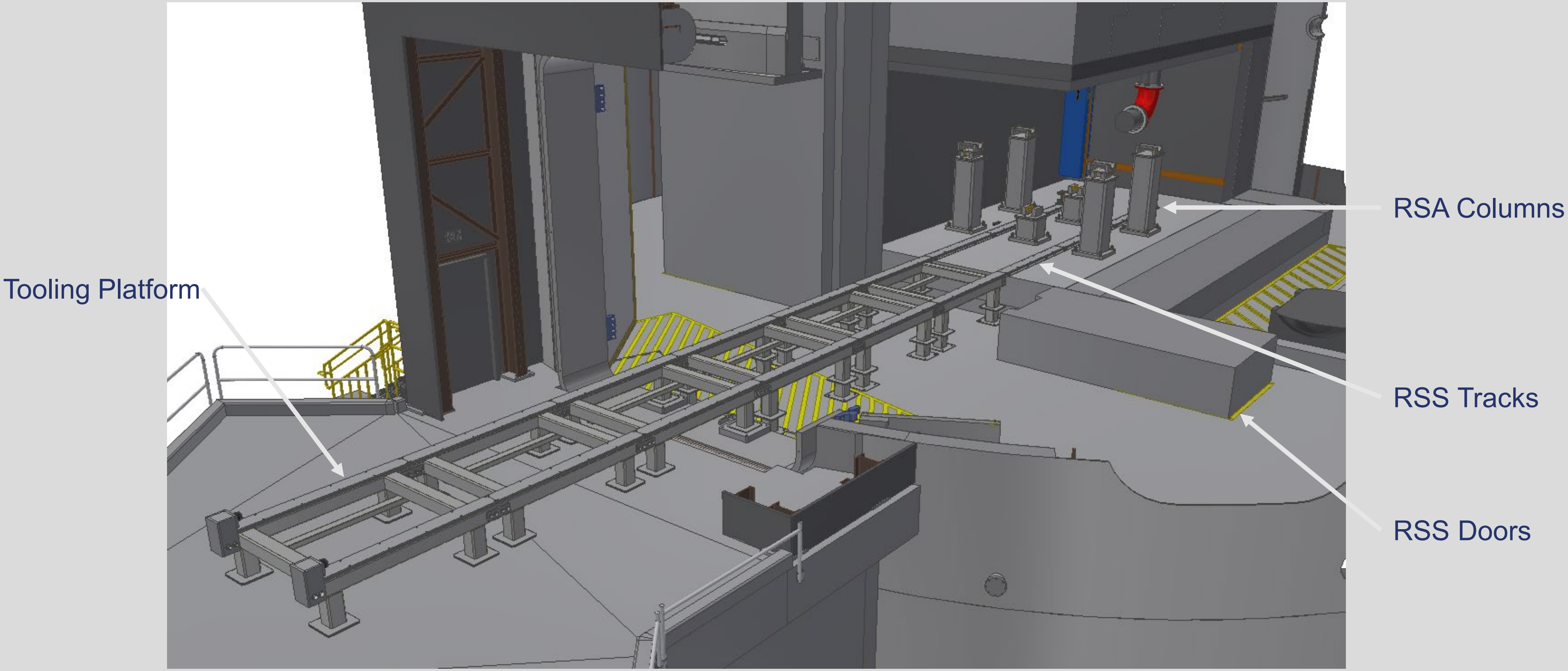
Westinghouse

Tooling Platform and RSS Tracks

- Flat continuous surface for tools to traverse into and out of the DOME.
- Modular platform sections for easy installation
- Stretches from INL Ramp to RSS Pedestal
- RSS Tracks are a continuation of the Tooling Platform
- Platform is secured to the DOME Floor
- RSS Tracks are bolted to the RSS Pedestal Floor on the provided bolt pattern

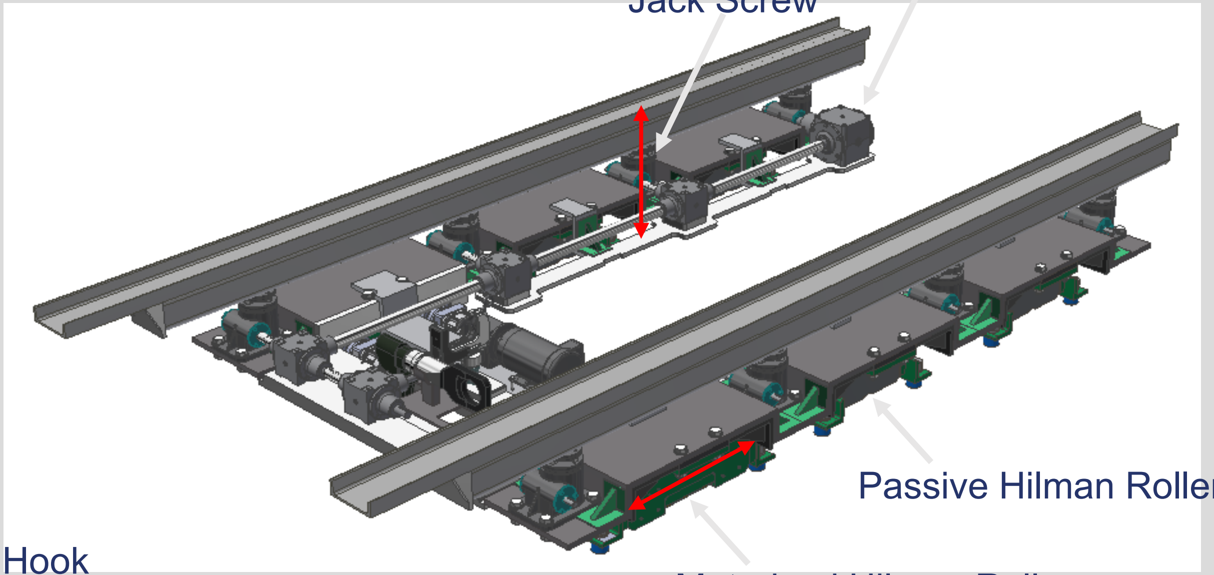


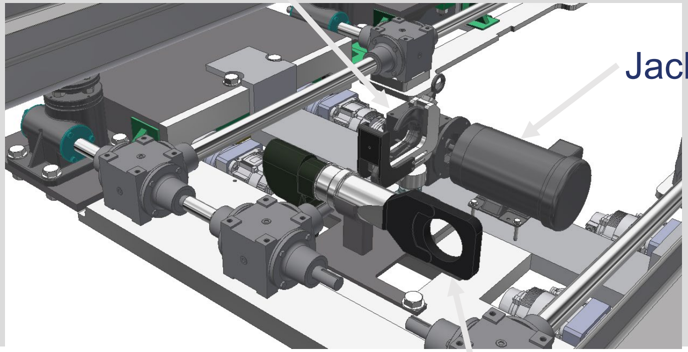
Tooling Platform and RSS Tracks Installed



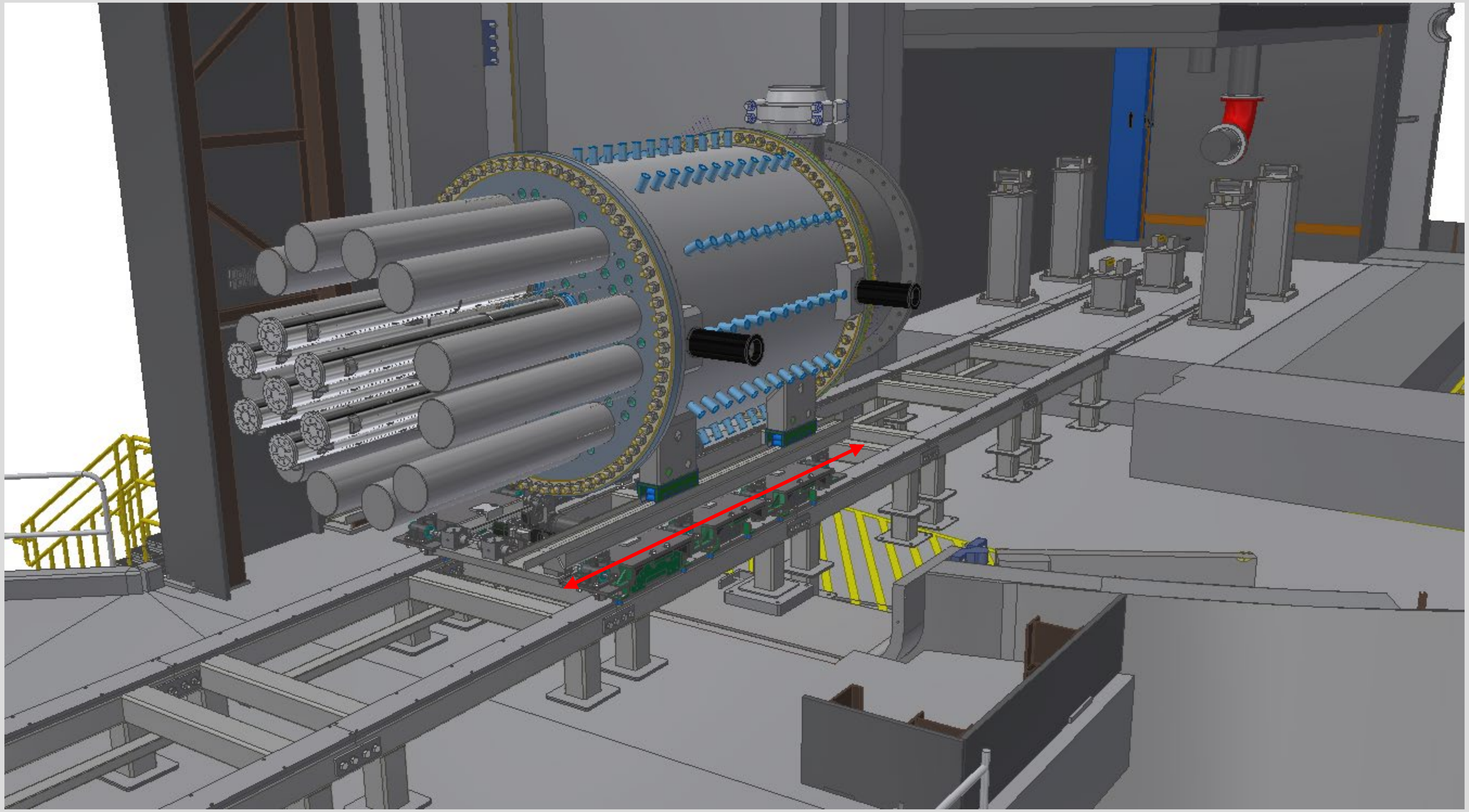
Delivery Trolley

- Dedicated tool for transporting the NTR within the DOME
- Features two motorized Hilman Rollers, and two passively driven rollers to facilitate the motions
- Jack screws to lift and lower the NTR as needed
- Navigates on the Tooling Platform and RSS Tracks
- Includes a winch hook mechanism to attach a winch hook for NTR removal
  - Also include a cable cutting tool for cutting the control cables after the NTR is in the RTC.
- Designed to be used for both installation and removal
- Interfaces with the Transportation Skid for initial NTR Transfer.



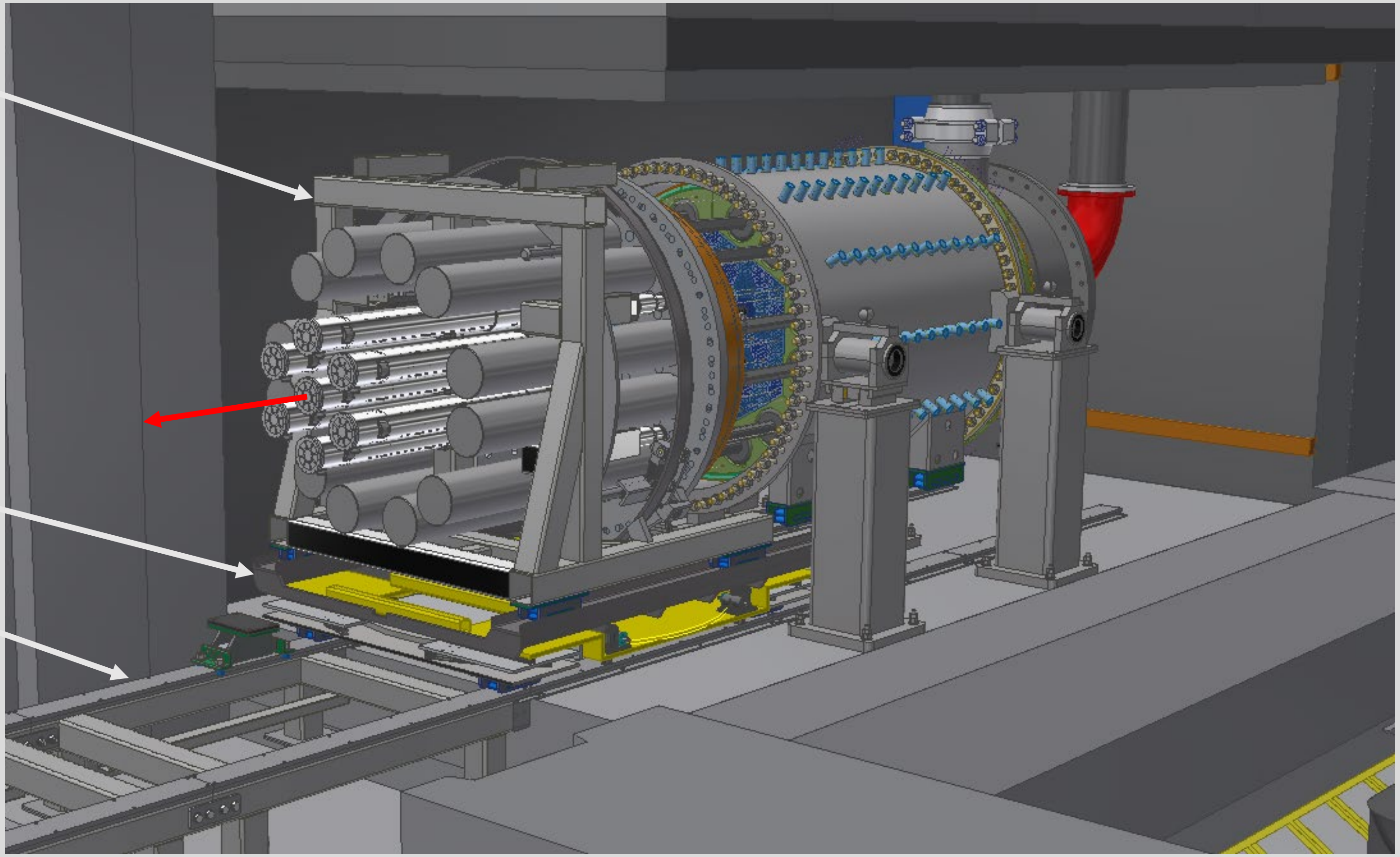


Delivery Trolley on Route to RSA



*Head configuration still undetermined

Closure Head Removal



Head Handling Tool

Tool Positioning System

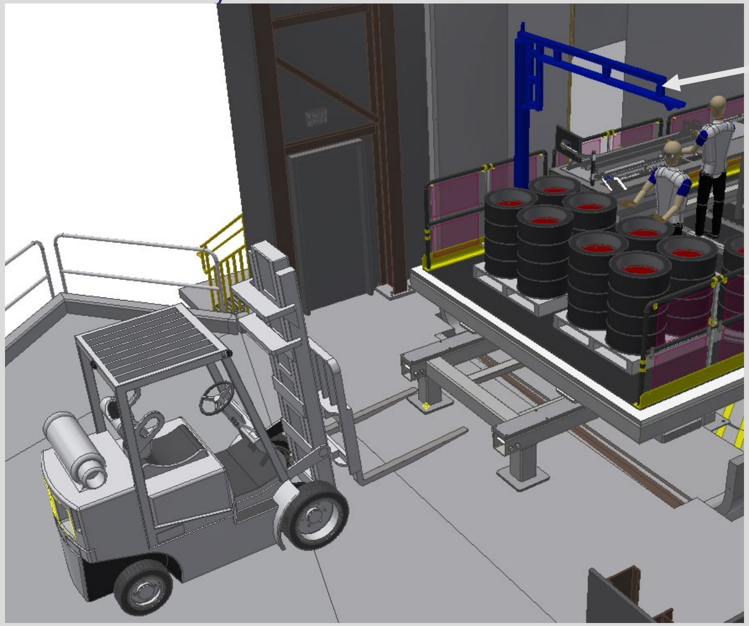
Tooling Platform

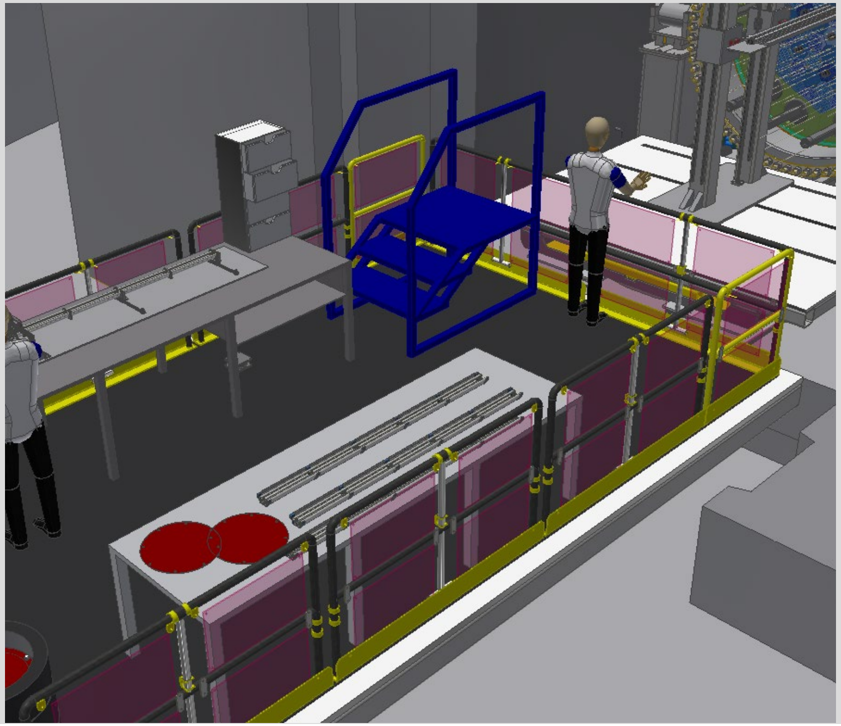
Fueling Platform continued…

- Fuel Drum Receival:
  - Area features two dedicated spots for fuel drum pallets
  - Work area will include all hand tools required to remove the various layers of the fuel drum
  - A turntable or rotating mechanism to turn the pallets for the operators to get access to every drum

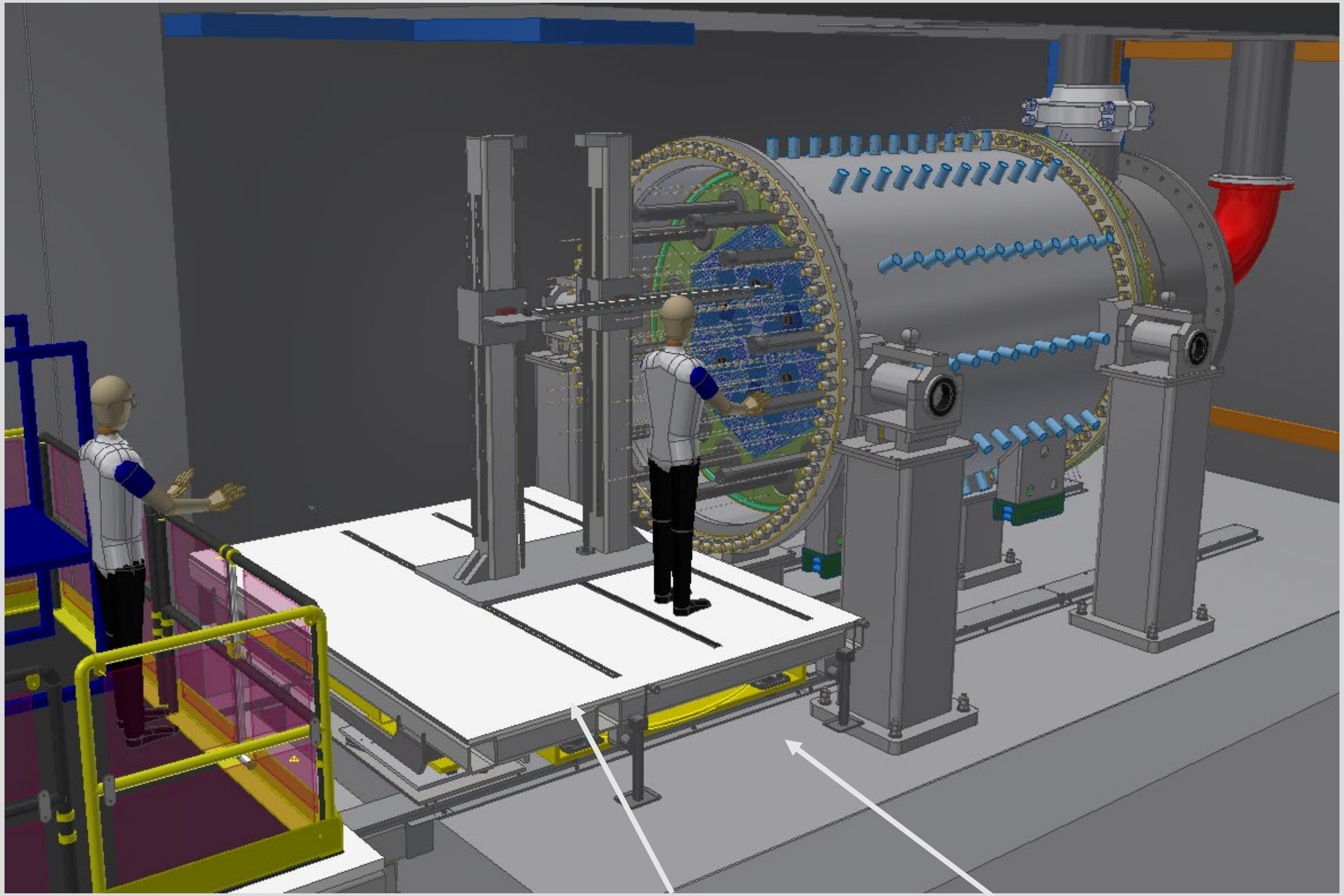
- Supplemental Worktable:
  - Includes all hand tools required to remove the various layers of the Fuel Drums
  - Small jib crane to assist with component removal
  - General lay-down area for components as they are being removed.

- Fuel Cartridge Hand-Off Area:
  - Dedicated space for operators to pass fully loaded fuel cartridges to the operators on the operators on the Fueling Machine
  - Potential space for in-process fuel cartridges





Fueling Machine continued…

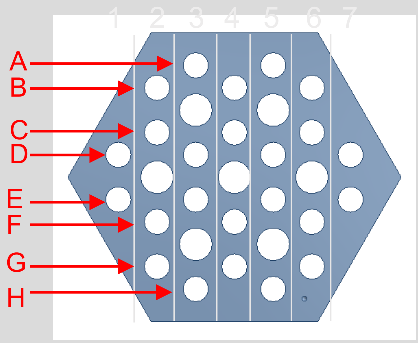


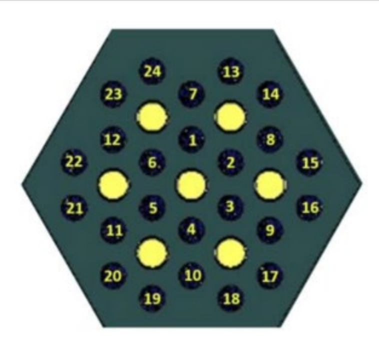
Fueling Machine

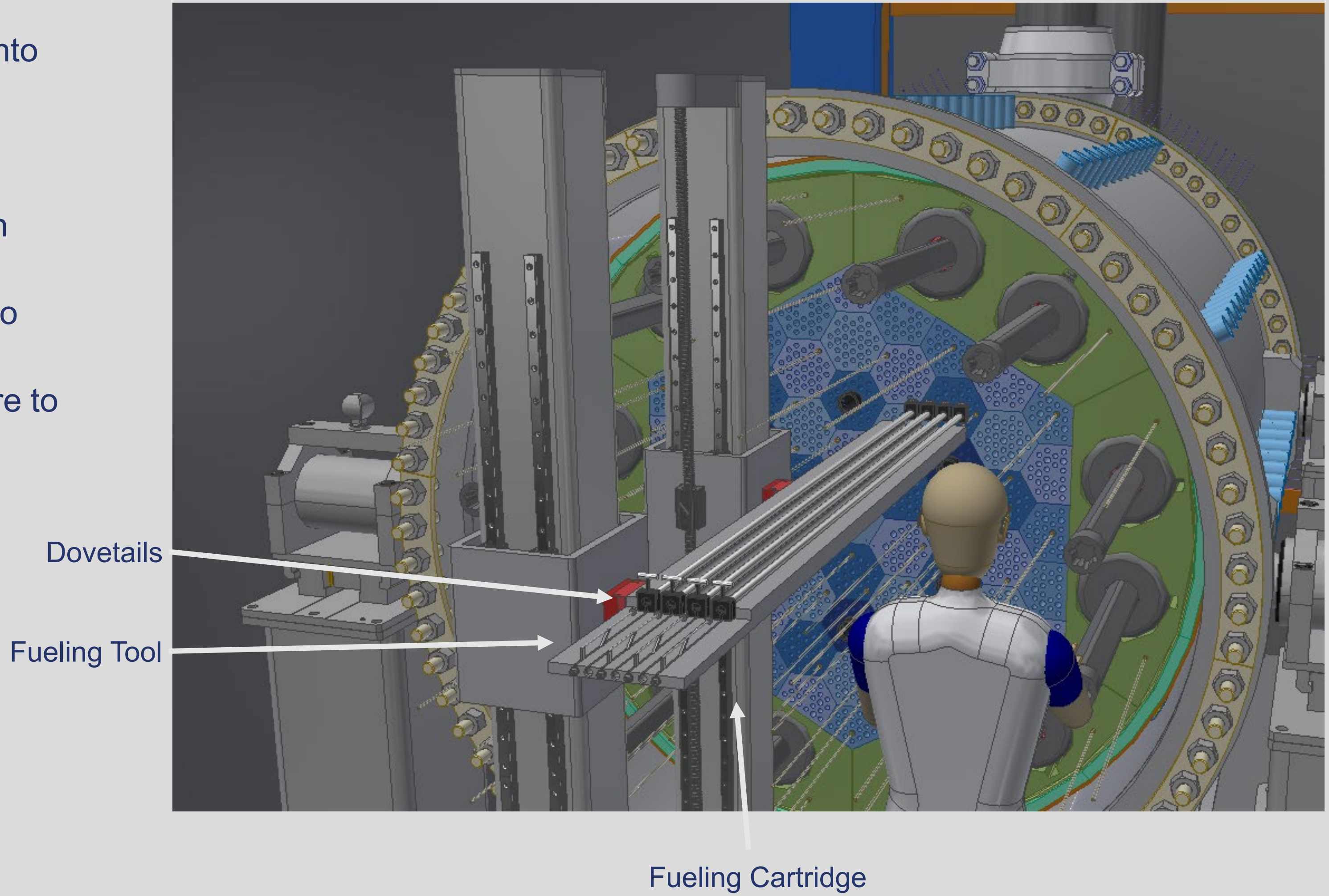
Tool Positioning System

Fueling Tool

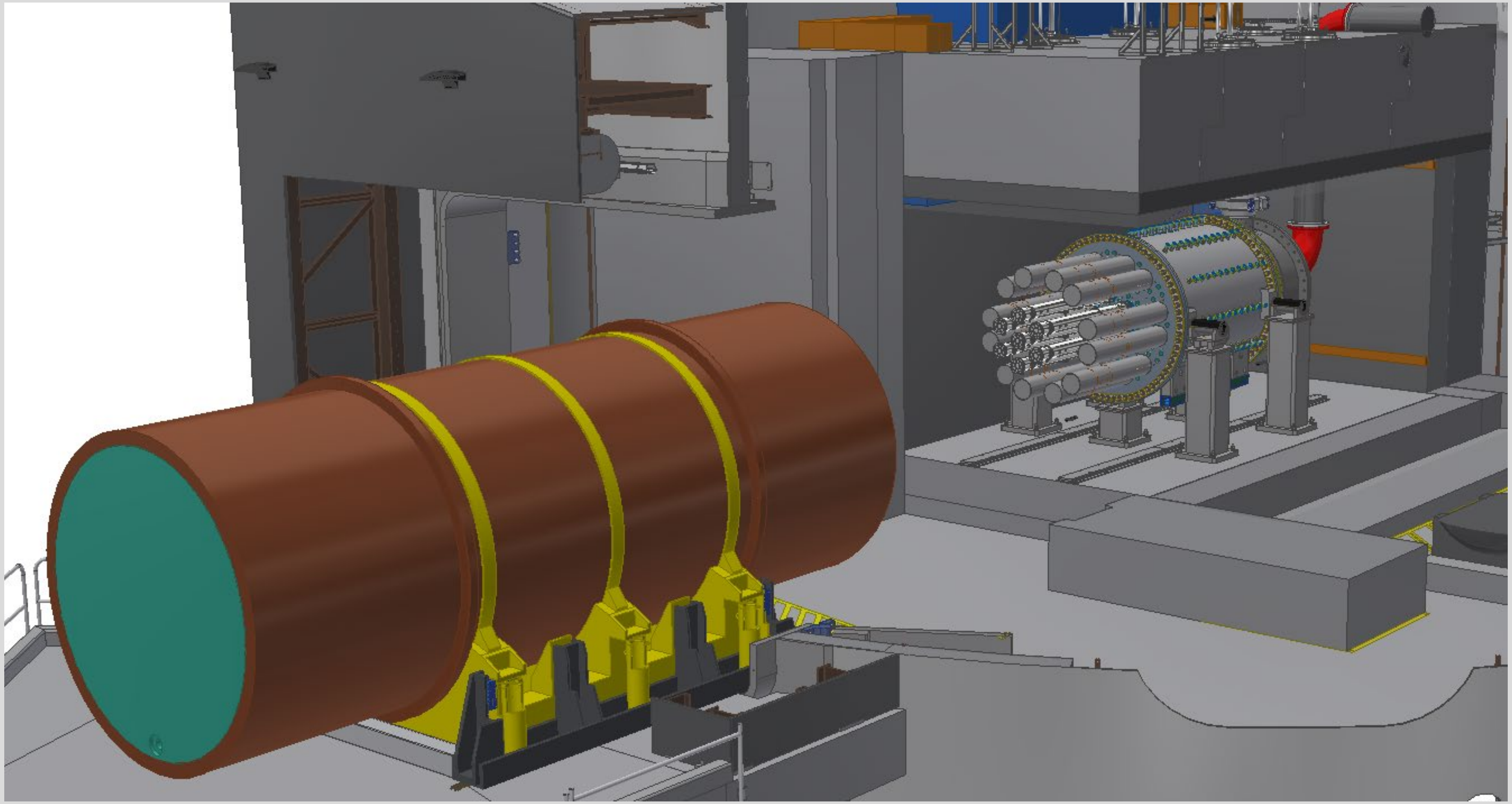
- Tool designed specifically to handle and load fuel into the core.
- Integrates with the Tooling Columns of the Fueling Machine
- Integrates with the fuel cartridges to secure them in place during fuel loading.
- Allows the operator to either manually push fuel into the core or make it an automated process
- Provides the operators with access to the NTR Core to manage the In-Core Thermocouples during operations.



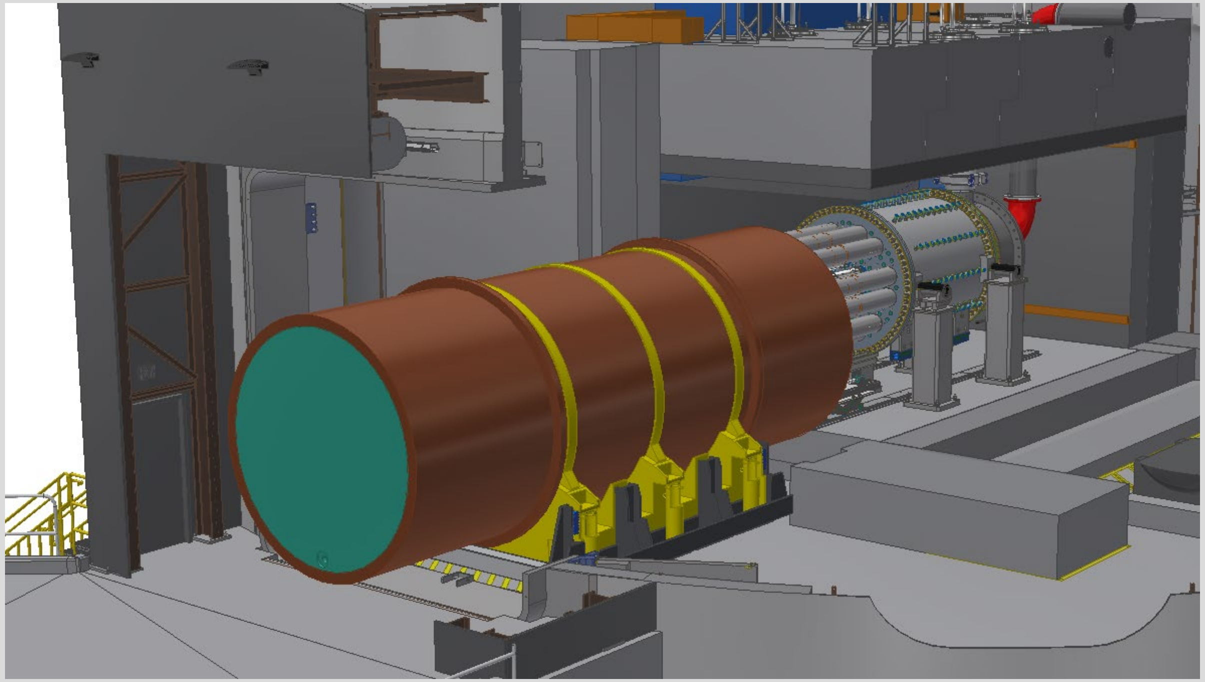


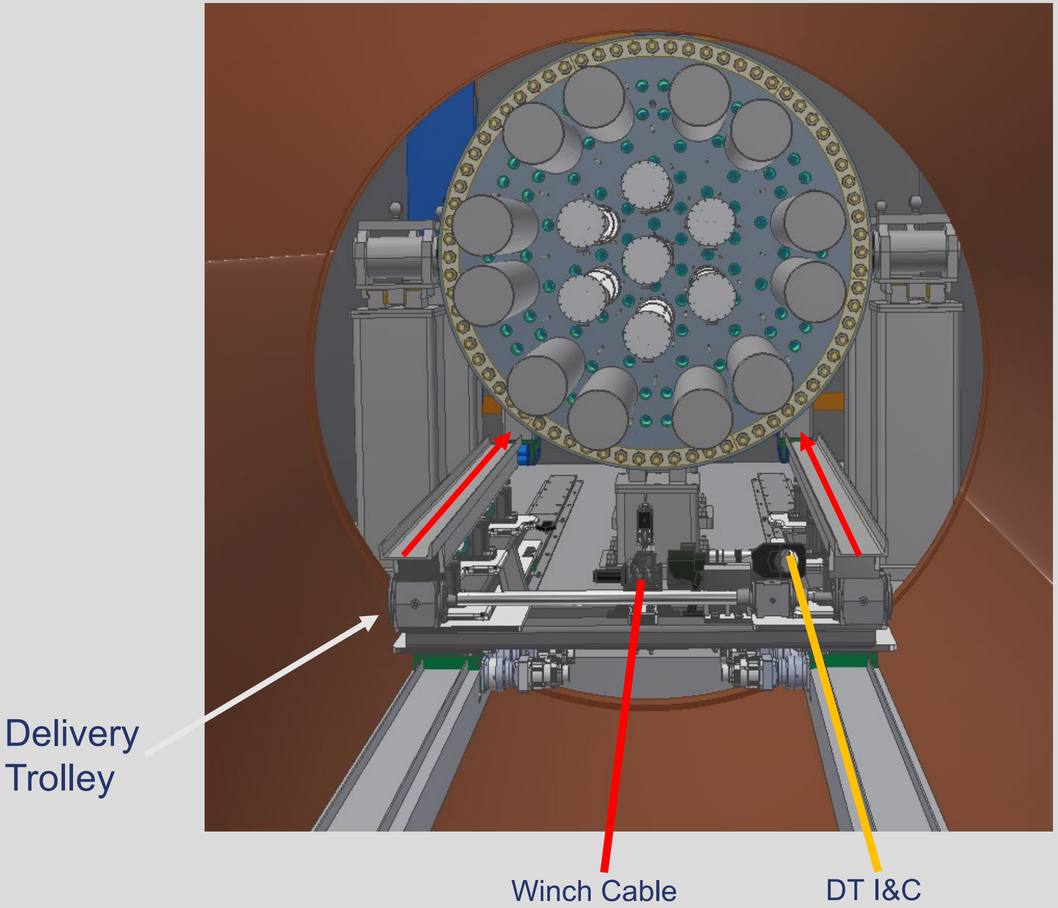


RTC Entering through DOME Hatch



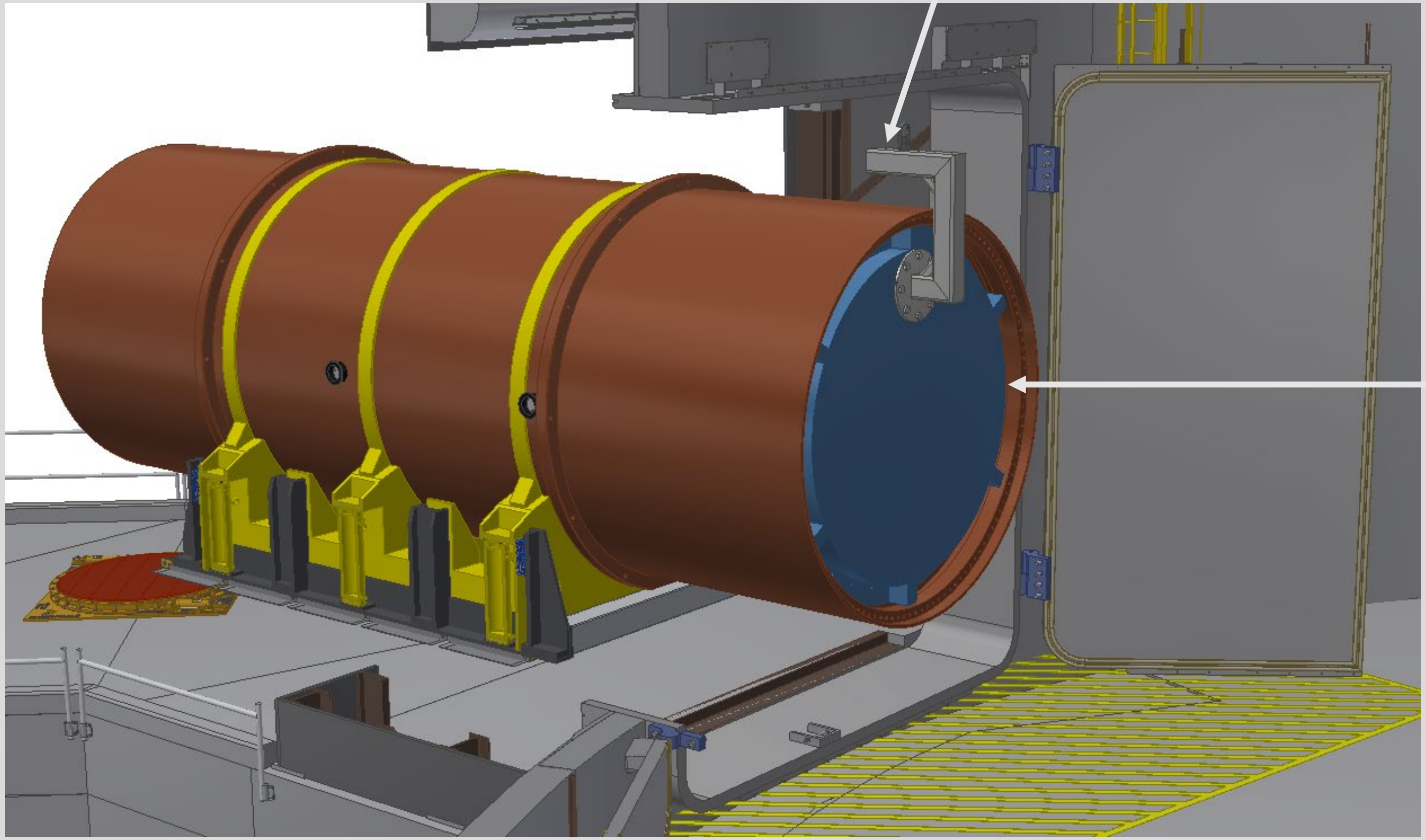
RTC at NTR





RTC Closure – Shield Plate Install

- J-Hook for Shield Plate and Closure Head installation.
- Simple bolt on tool
- Once installed, operators can operate directly in-front (with sufficient protection)



University Engagements

- **Penn State**
  - Evaluating potential site locations
  - Determining use case/research applications
  - Considering follow on power reactors for campus heating/electricity
- **McMaster (Canada)**
  - Materials
  - Potential reactor irradiation
  - Research reactor product development
- **University of Pittsburgh**
  - Materials
  - Modeling and simulation
  - Sensors
- **Carnegie Mellon**
  - Public and international policy
  - Space, materials, cyber security, AI
- **MIT, Wisconsin, Texas A&M, Oregon State**, + others

Taking nuclear energy to **new frontiers**

Westinghouse is excited about our technology's promise for the Fission Surface Power project seeking 40 kWe for 10 years.

Our space reactor is designed for lunar surface operation under NASA's Artemis program and leverages eVinci microreactor technology, Uranium Nitride fuel, a hydride moderator and our vast experience across terrestrial and space nuclear fission systems.

Thank You

Westinghouse Electric Company

@WECNuclear

Westinghouse Electric Company

wecchinanuclear

westinghousenuclear.com

Westinghouse

ULTRA SAFE NUCLEAR

Nuclear Fuel Production for Pylon D1

Presentation to 2024 NRIC Program Review

Wesley Deason, Pylon Program Manager
w.deason@usnc-tech.com

RELIABLE ZERO-CARBON ENERGY ANYWHERE

Who We Are

USNC
ULTRA SAFE NUCLEAR

Intrinsically safe nuclear power for reliable zero-carbon energy anywhere

Intrinsically Safe Micro Modular Nuclear Batteries

High Temperature Heat

Multiple Use Cases

Vertical Integration + High Volumes = Accelerated Learning Rate

Reactor and Fuel Factories with Rapid Deployment

Manufacture / Delivery

Active Development Pipeline with Projects in Advanced Stages

Development / Execution / Operation / Service

Supportive Regulatory Pathway

First to Market with Full-size Demos in Canada and US

ULTRA SAFE NUCLEAR

Full-Stack Nuclear

Nuclear hardware and services to provide reliable energy anywhere.

CORE GROUP
Nuclear Fuels + Materials

NUCLEAR GROUP
Manufacture + Deploy

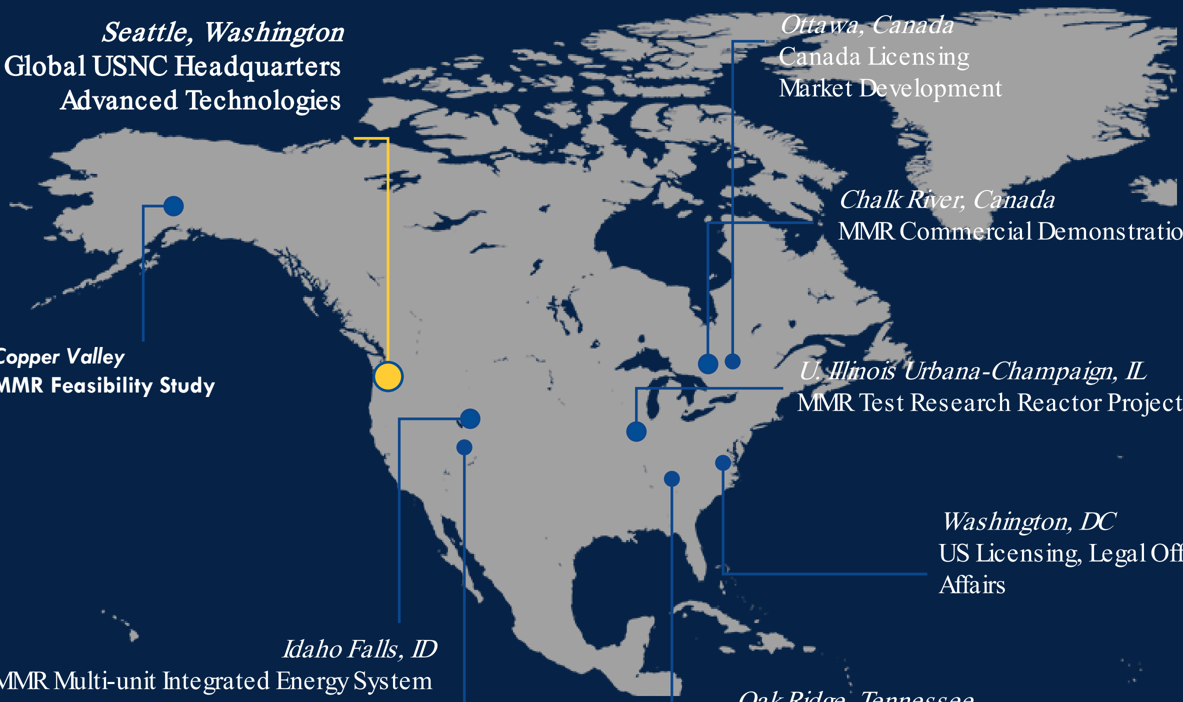
ADVANCED TECHNOLOGIES GROUP
Future Looking Product Development

INNOVATION GROUP
MMR Technology Development

2011
Founded

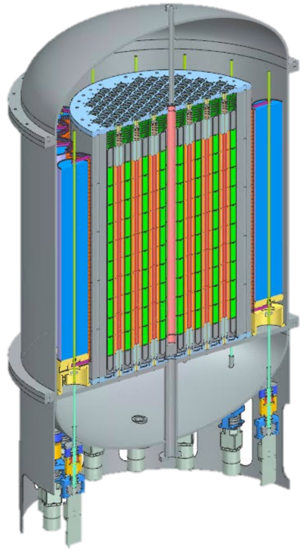
240+
Employees

2028
First MMR Demo



Overarching Characteristics

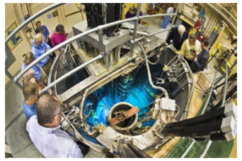
- FCM Fuel in geometry only possible with additive manufacturing
- Hydride moderator with regenerative cooling
- Gas coolant
- 9.9% U^{235} "LEU+" or 19.75% U^{235} HALEU
- Control drums and control rod for reactivity control



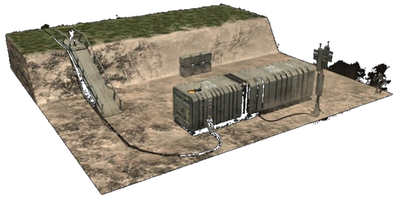
Development Philosophy

- Pylon D1 leverages extensive DOE investment and facilitations for a rapid and cost-effective technology demonstration.
- Use of MMR Fuel and systems enables leveraging of fuel irradiation and qualification and synergy with MMR design and licensing experience
- Start with low-hanging markets with straight-forward and achievable performance requirements and grow into larger and more aggressive applications

2027 | 2028 | 2029 | 2030 | 2031+

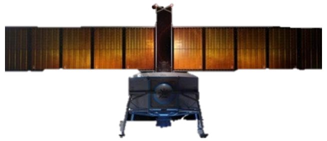


PYLON R1
Research

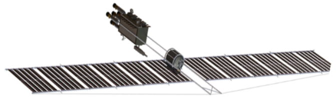


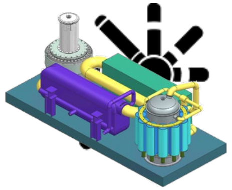
PYLON T1
Transport

PYLON L1
Lunar



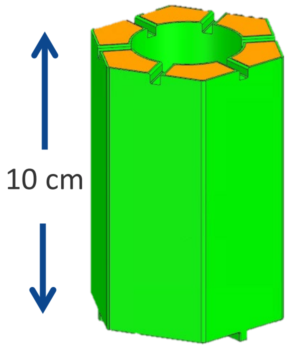
PYLON S1
Space



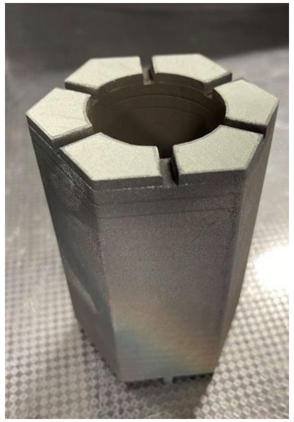


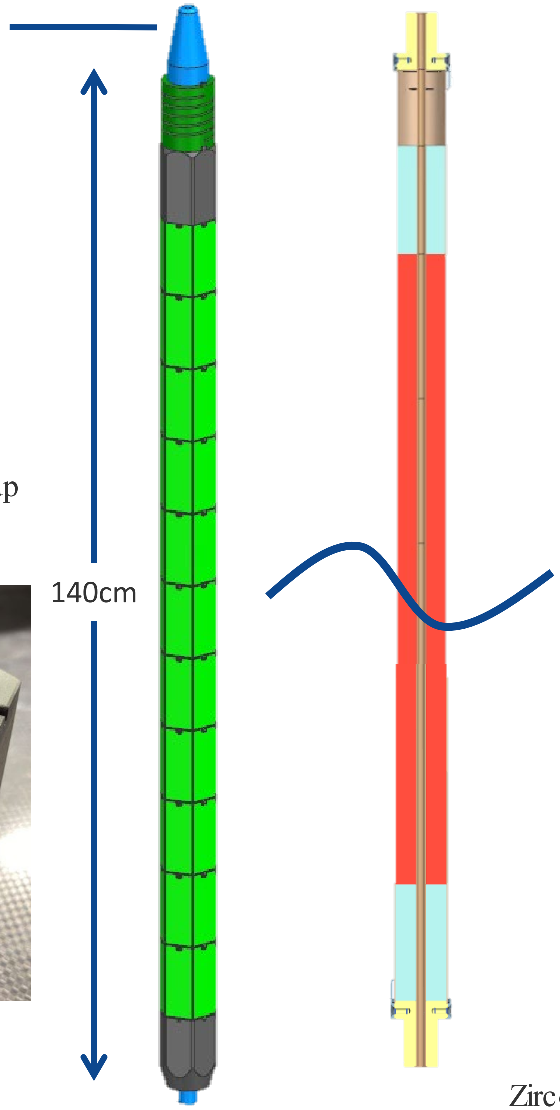
PYLON D1
Demo

Pylon Reactor Architecture

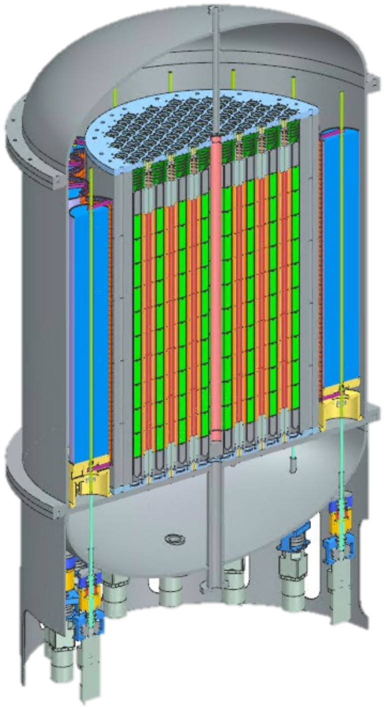


Individual Fuel Cup





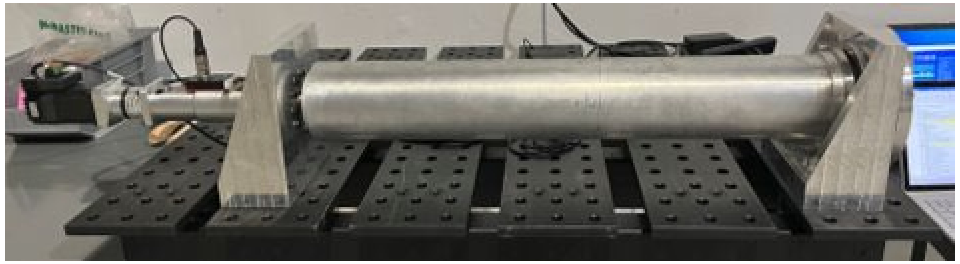
Fuel Stack Assy   Moderator Assy

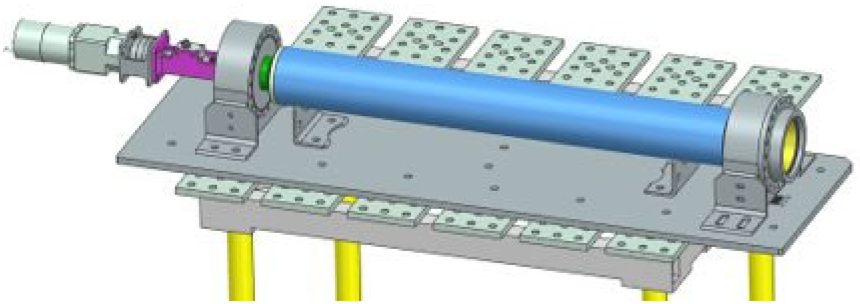


Zirconium Hydride 1.59 samples next to Zircaloy-4 control

Overarching Characteristics

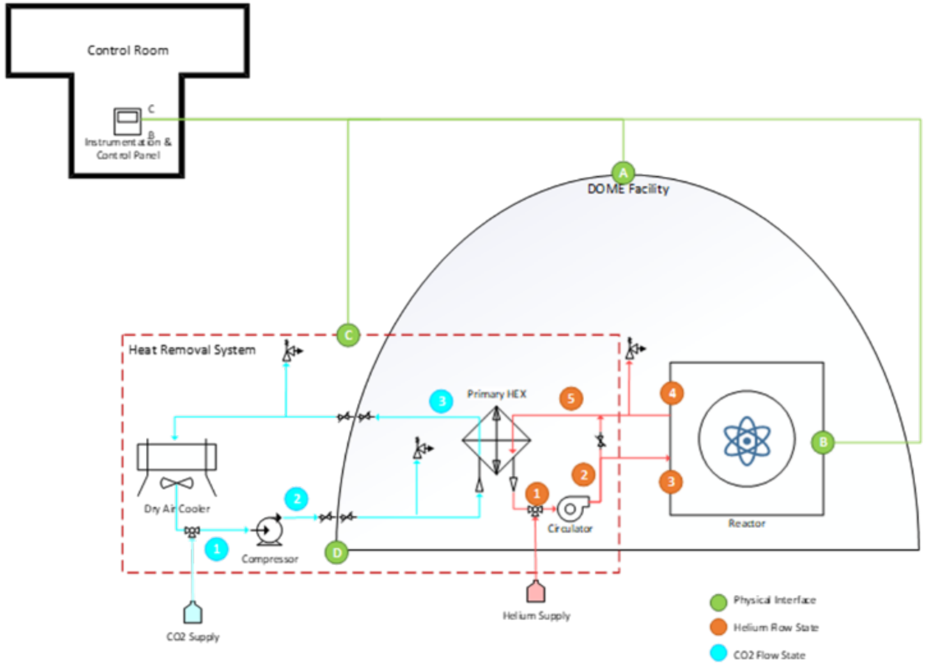
- FCM Fuel in geometry only possible with additive manufacturing
- Hydride moderator with regenerative cooling
- Gas coolant
- 9.9% U^{235} "LEU+" or 19.75% U^{235} HALEU
- Control drums and control rod for reactivity control





Program Overview

- A derivative reactor is being developed to be tested at the NRIC DOME facility at Idaho National Laboratory as early as possible
    - Verify licensability and key performance, operations, safety and cost aspects.
- Reactor-focused: increase TRL of key nuclear technologies, minimize cost and schedule



Technical Performance Requirements

- Demonstration Requirements: 1 MWth @ 1000 K reactor outlet, 2.5MW-yr core energy
- Use of 9.9% Enriched U (LEU+) (<500 kg) allows demo with **currently available fuel**
- Metal Hydride moderator

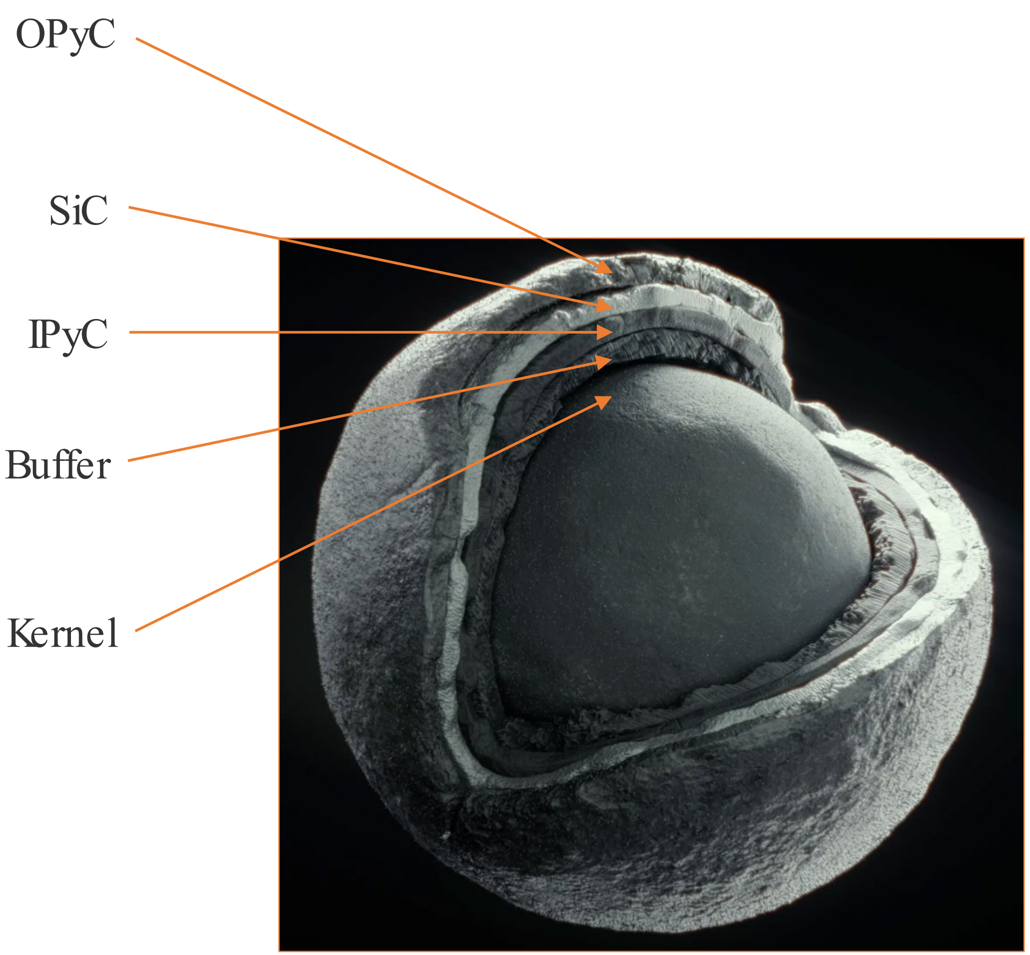
Pylon D1 **1 MWth**	**Pylon T1** **5-10MWth (1-3 MWe)**
Graphite Reflector Lower-Cost	Beryllium Reflector Lower-Mass
<500 kg of 9.9% Enriched (LEU+) Available Now	19.75% Enriched (HALEU) Available Soon
Helium based Heat Removal Focus on Nuclear Demo	He-Xe Brayton Power Cycle Focus on Strong Partnership

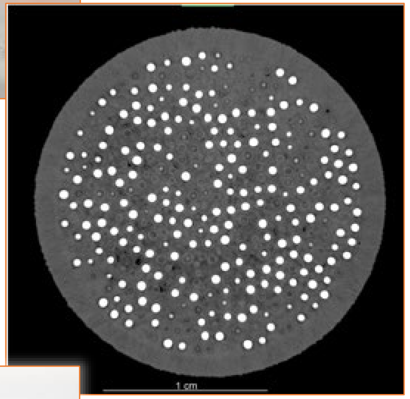
ULTRA SAFE NUCLEAR

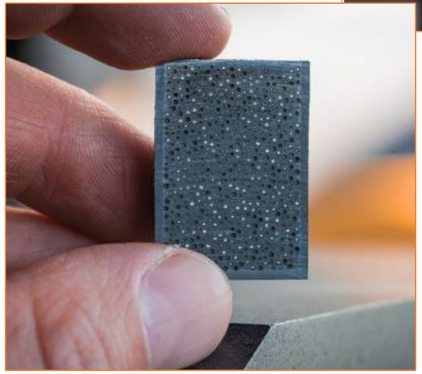
FCM® Fuel Technology for MMRs Comprises TRISO Coated Fuel Particles Embedded inside Silicon Carbide

Fully Ceramic Microencapsulated (FCM®) Fuel

- Tri-structural isotropic (TRISO) fuel particles embedded inside an impermeable SiC matrix
- Very high fuel loading fraction owing to the unique manufacturing methodology leveraging additive techniques
- Manufacturing technology agnostic to fuel element geometry







Patent: U.S. 9.299.464 B2
Patent application: U.S. 2020/0156282 A1

USNC Core Technology: TRISO Fuel Embedded in Silicon Carbide - Fully Ceramic Micro-encapsulated ("FCM") Fuel

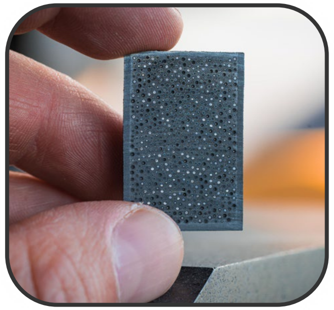
Employing the same team that made high performance TRISO fuel for the US DOE, we've developed special techniques and knowledge to steadily improve the TRISO manufacturing process. We do not rely on any other commercial or governmental entity as we own the entire vertical chain of manufacturing downstream from uranium feedstock to the fueling the final reactor core blocks

Built on TRISO

A Uranium bearing microsphere is coated with multiple special **ceramic layers designed like tiny pressure vessels**. These carbon and silicon carbide layers contain fission products inside and ensure mechanical and chemical stability during irradiation at high temperatures.

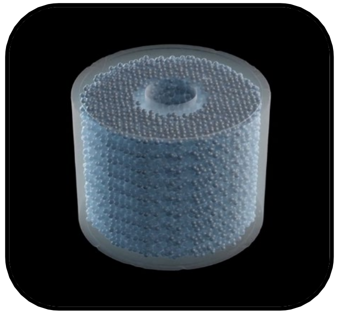
TRISO + Silicon Carbide (SiC) Matrix

FCM Fuel is a new approach to inherent reactor safety by providing an ultimately safe fuel. TRISO Fuel, which contains the radioactive byproducts of fission within layered carbon and Silicon Carbide (SiC) coatings. Doubling down on SiC as the main containment, these particles are then encased within a fully dense SiC matrix resulting in an extremely **rugged and stable fuel with extraordinary high temperature stability.**



Fuel in Any Shape

Our fuel production process leverages additive manufacturing to form the SiC matrix and as such allows for a wide variety of **fuel shapes beyond simple pins**. We can produce annular cylinders, hollow pebbles, Y-compacts and any other arbitrary shapes or particular specifications.



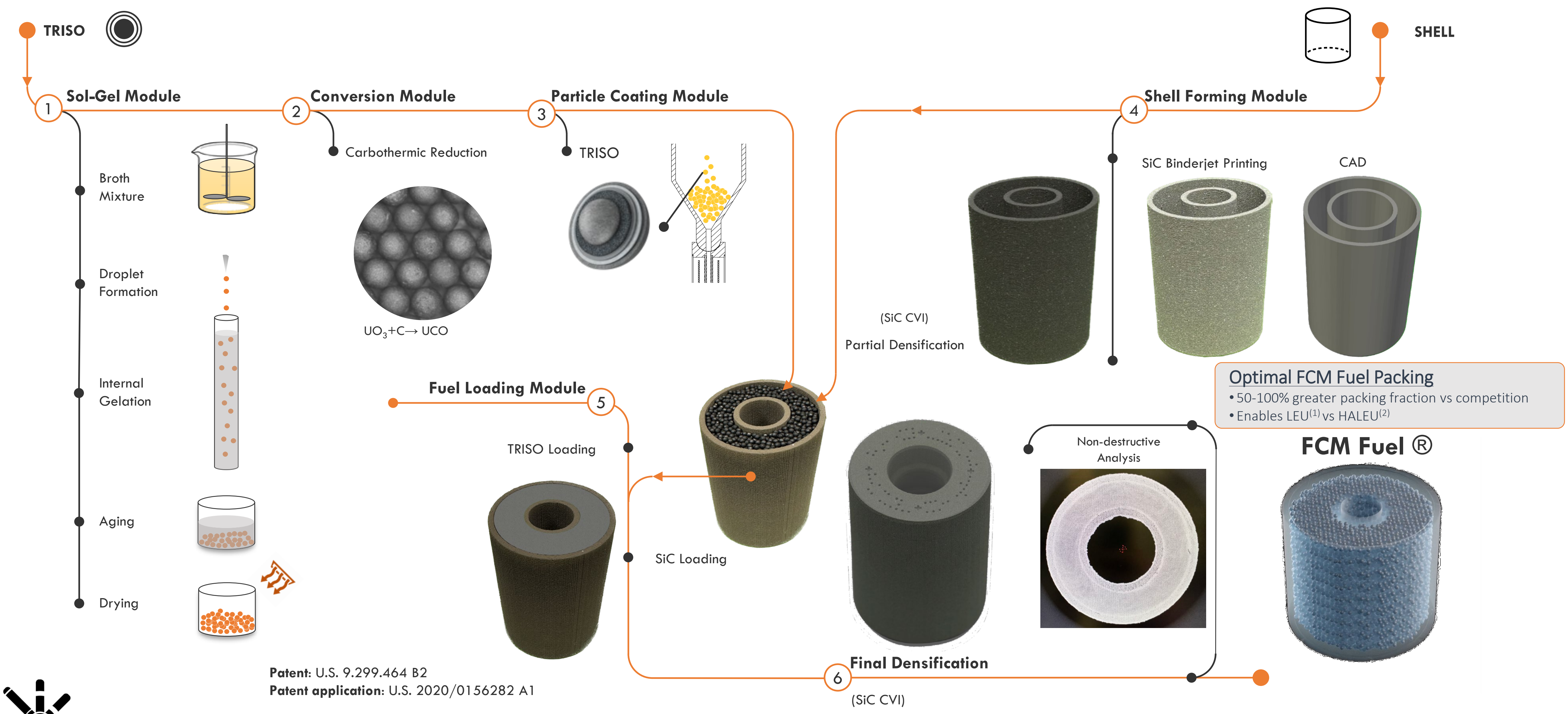
3D Print High-Purity Silicon Carbide

We use the same suite of manufacturing technologies to **3D print customized components** in highly pure, fully crystalline, and stoichiometric Silicon Carbide including both simple and complex parts for turbines or heat exchangers. Silicon Carbide offers extreme performance for many applications including nuclear reactors, aerospace, and defense.

Source: Management Information.

TRISO and Fully Ceramic Microencapsulated (“FCM”) Fuel Manufacturing Process

ULTRA SAFE NUCLEAR



Optimal FCM Fuel Packing

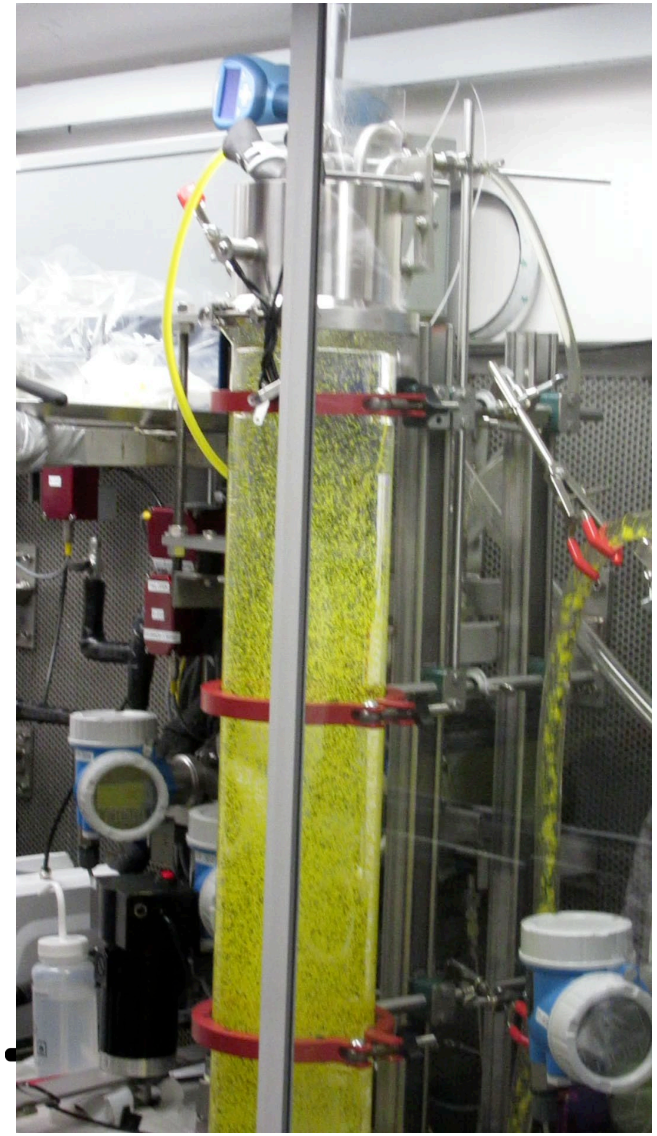
- 50-100% greater packing fraction vs competition
- Enables LEU[1] vs HALEU[2]

Patent: U.S. 9.299.464 B2
Patent application: U.S. 2020/0156282 A1

Source: Management Information.
Note: Images contain hyperlinks to online video clips.
(1) Low Enriched Uranium.
(2) High Assay Low Enriched Uranium.

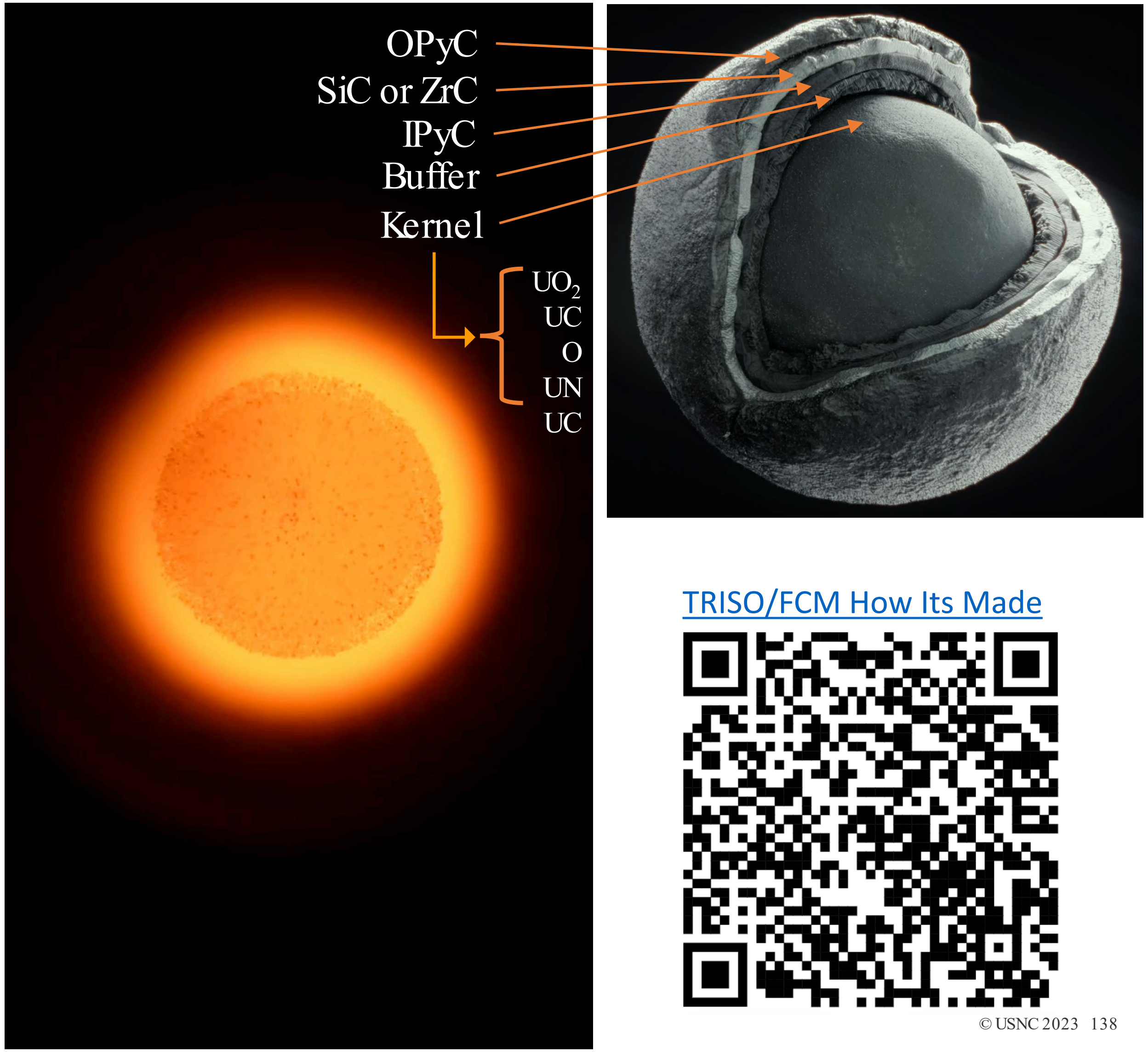
TRISO Manufacturing Steps: Sol-Gel, Kernel Conversion, TRISO Coating

① Sol-Gel Module



② Kernel Conversion Module

③ Particle Coating Module

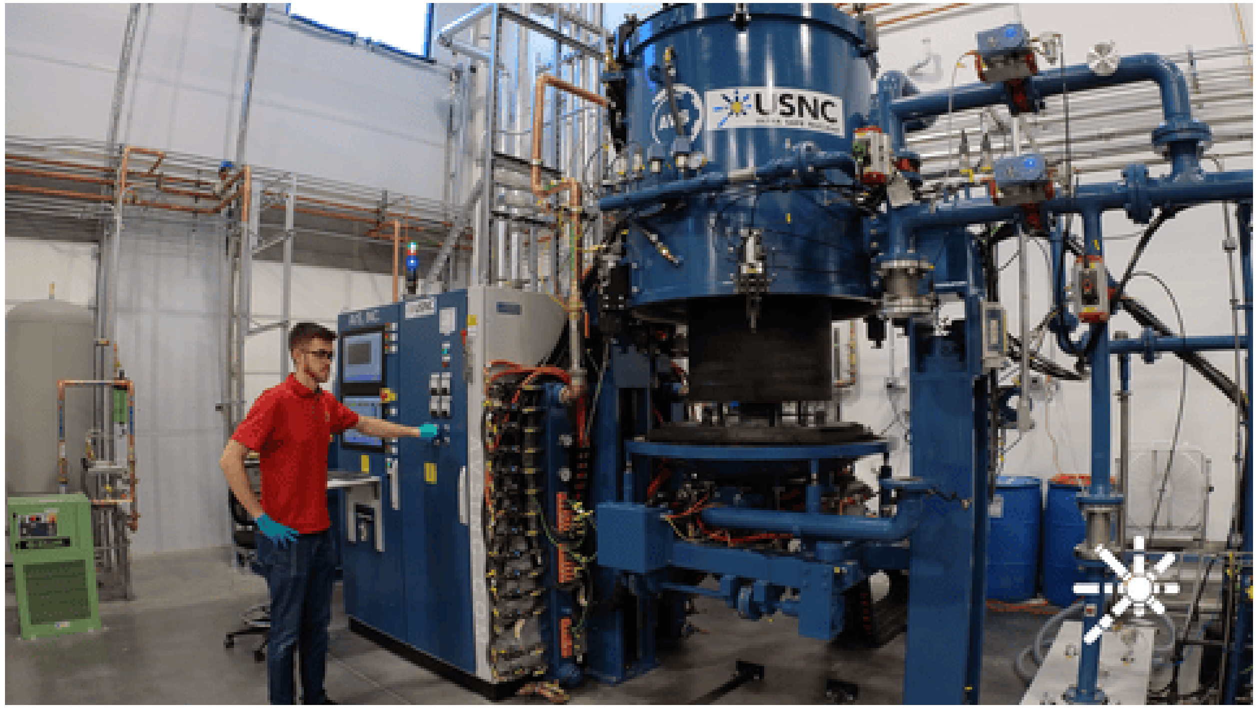


[TRISO/FCM How Its Made]

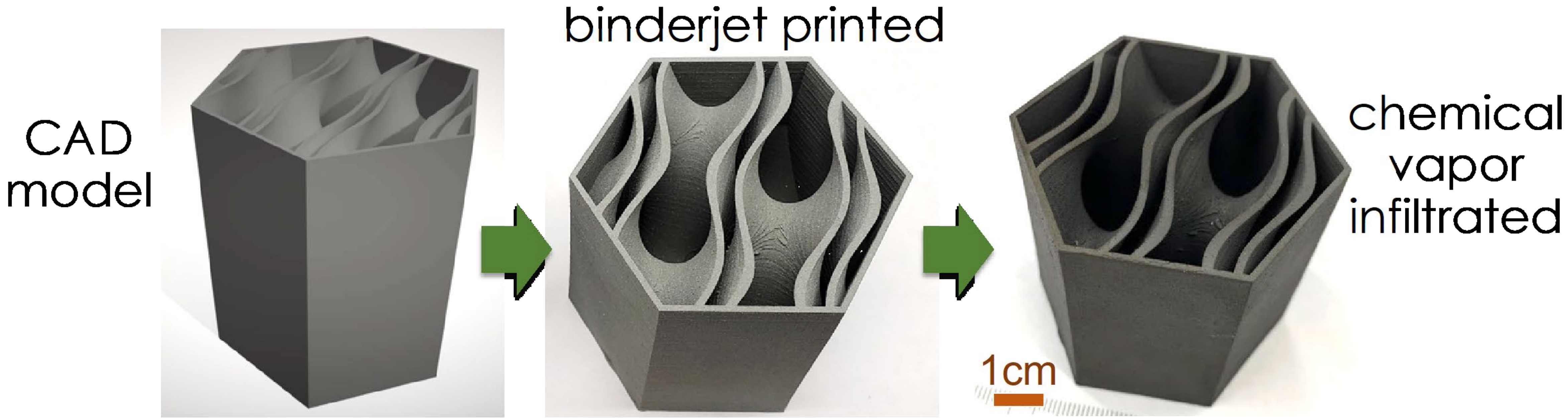
Large-Scale Binderjet Additive Manufacturing follow and Chemical Vapor Processing

SiC 3D printing via binderjet additive manufacturing

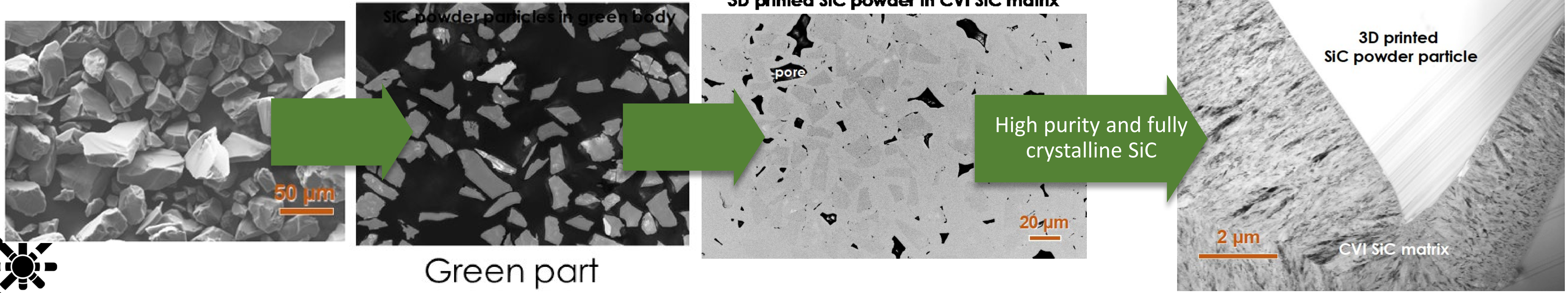
Final part densification via chemical vapor infiltration (CVI)



The Combination of Binderjet and CVI facilitates 3D printing of nuclear-grade SiC in complex geometries



Patent application: U.S. 2020/0156282 A1

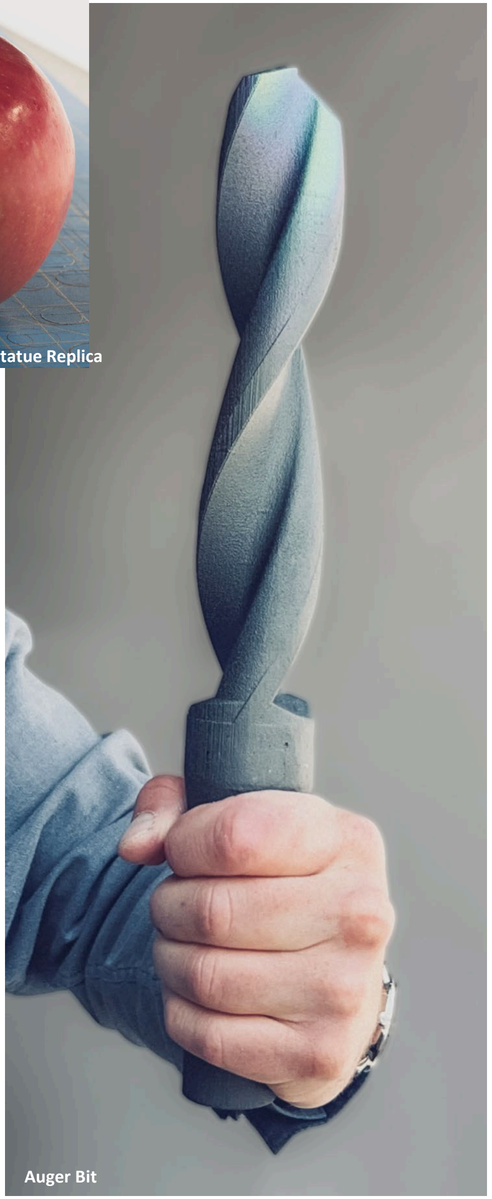


K. Terrani, B. Jolly, M. Trammell, "3D printing of high-purity silicon carbide" *J. Am. Cer. Soc.*, (2019) DOI: 10.1111/jace.16888

Additive Manufacturing Snapshot

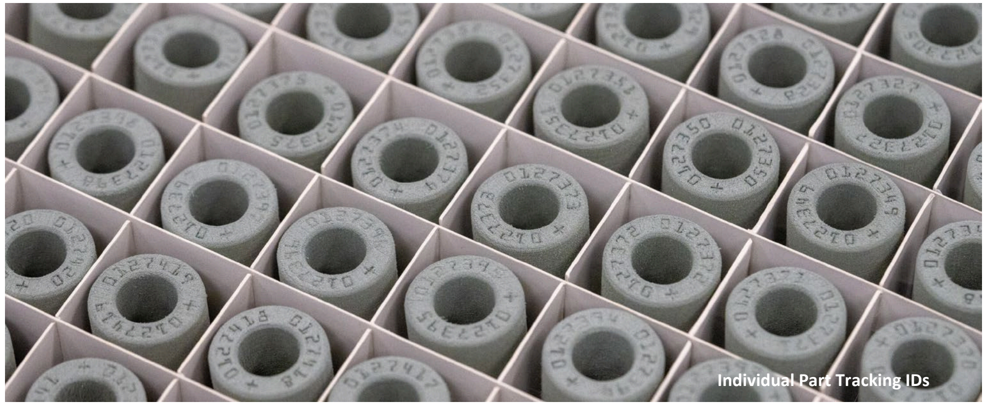
- USNC uses binder-jet additive manufacturing for SiC and ZrC
    - High dimensional tolerance, geometry impossible by other means
- Post-print chemical vapor infiltration and/or deposition to yield parts very near as-designed


Laocoon Statue Replica

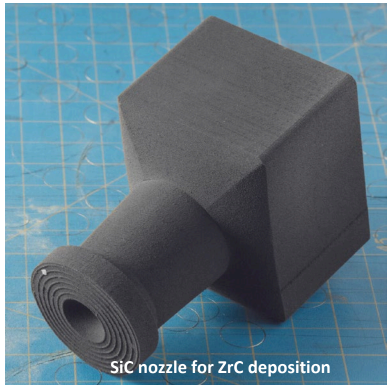

Auger Bit

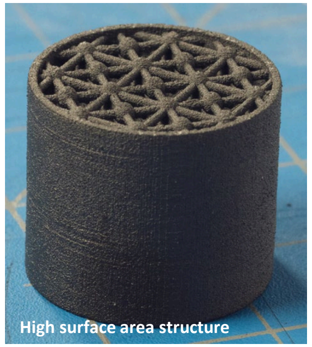

Fuel Qualification Pellet

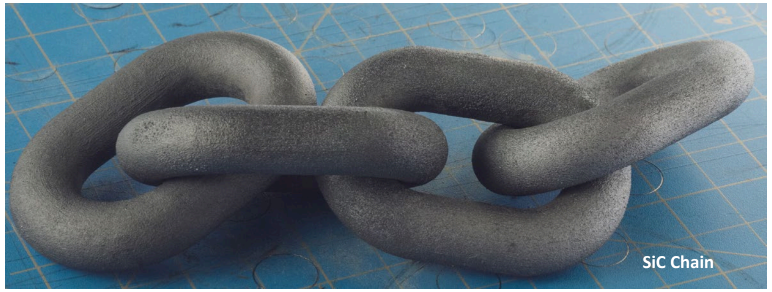

FCM Shell Concept


Individual Part Tracking IDs


FCM Shell Concept

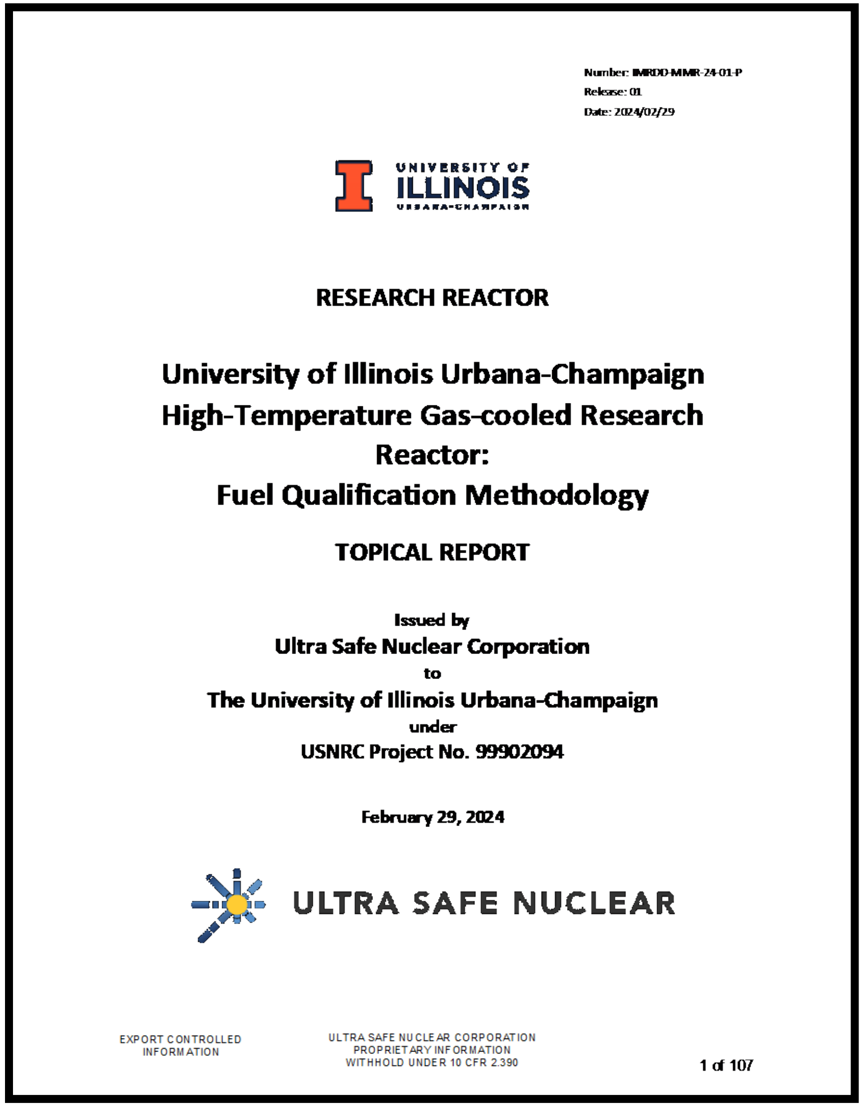

SiC nozzle for ZrC deposition


High surface area structure


SiC Chain

USNC Fuel Qualification

- As defined in NUREG-2246, "Fuel Qualification for Advanced Reactors":
  - Fuel Qualification is the overall process (planning, testing, analysis, etc.) used to obtain qualified fuel.
  - Fuel is qualified when reasonable assurance exists that the fuel, fabricated in accordance with its specification, will perform as described in the **safety analysis**.
- Assessment framework From NUREG-2246:
  - Fuel is manufactured in accordance with a specification
  - Margin to safety limits can be demonstrated
    - Experimental data used for assessment is appropriate
    - Evaluation model is acceptable for use
- USNC submitted and NRC accepted for review our Fuel Qualification Methodology Topical Report



Number: IMRDD-MMR-24-01-P
Release: 01
Date: 2024/02/29

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

RESEARCH REACTOR

University of Illinois Urbana-Champaign High-Temperature Gas-cooled Research Reactor:
Fuel Qualification Methodology

TOPICAL REPORT

Issued by
Ultra Safe Nuclear Corporation
to
The University of Illinois Urbana-Champaign
under
USNRC Project No. 99902094

February 29, 2024

ULTRA SAFE NUCLEAR

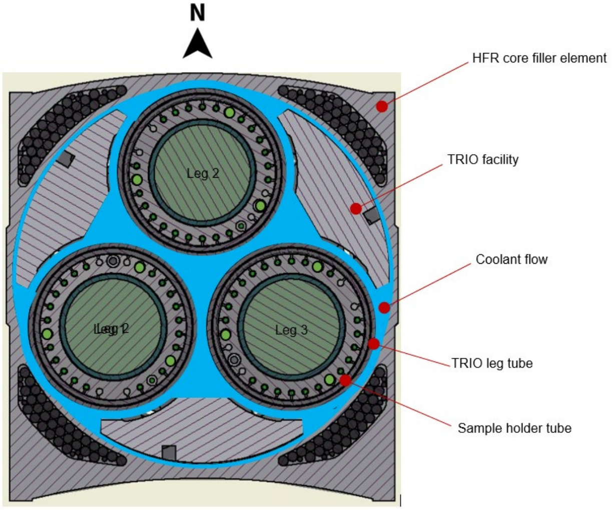
EXPORT CONTROLLED INFORMATION

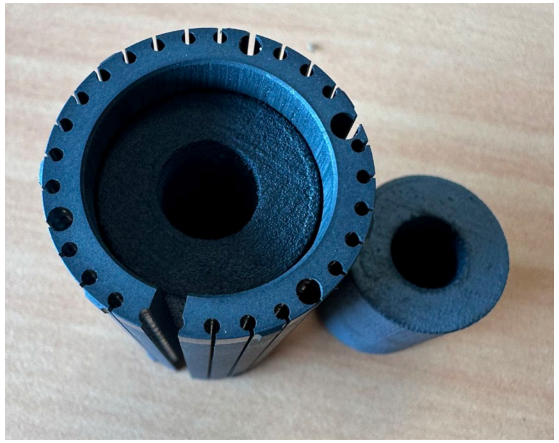
ULTRA SAFE NUCLEAR CORPORATION
PROPRIETARY INFORMATION
WITHHOLD UNDER 10 CFR 2.390

1 of 107

Fuel Irradiation Plan

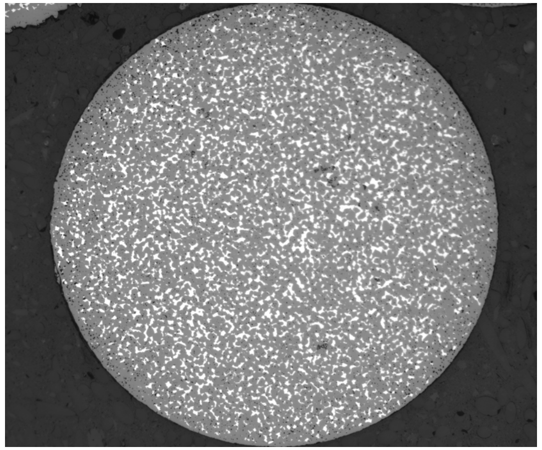
- Fuel qualification strategy largely unchanged, but will require irradiation of an annular pellet smaller than nominal MMR pellet
  - Enables higher enrichment and higher power density, resulting in faster accrual of required burnup
- Steady-state irradiation test: **High Flux Reactor in Petten (NL)**
  - Testing of USNC TRISO, FCM fuel, ODSL, and other non-fuel samples
  - Planning, experiment design, etc., currently underway
  - Testing performed on slightly smaller pellets with simplified geometry
  - Stress levels in irradiation experiment bound those in MMR
- Short-duration irradiation test: **MITR**
  - Testing of characteristic MMR FCM pellets beyond power densities and stress levels in MMR
  - No need for long-duration testing in MITR as nuclear heated stresses are highest at BOL
  - Reactor power will be increased incrementally to determine power and stress conditions that cause failure





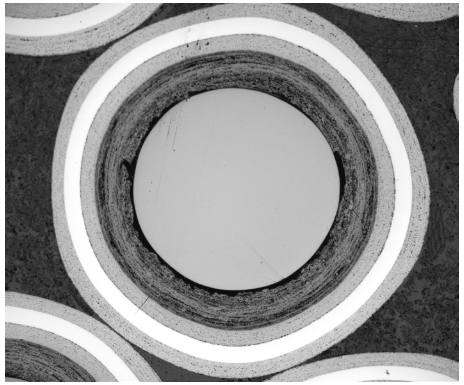
TRISO Sales: NASA, private space company, and newly started collaboration with a terrestrial developer

- TRISO Commercial Sales
  - Completed successful production of nuclear fuel to NASA’s Space Nuclear Power and Propulsion program.
    - UN kernel coated with buffer, iPyC, and ZrC
  - Additional production run of a similar product for a private company completed and tested in CFEET
  - Agreement and pending kickoff with a private terrestrial reactor developer
- Large-scale UCO production for MMR and Pylon ongoing
  - Produced ~30 kg UCO TRISO in recent months to optimize sol-gel, conversion, and coating parameters
  - Completion of 4.95% enriched TRISO particles for MMR fuel qualification

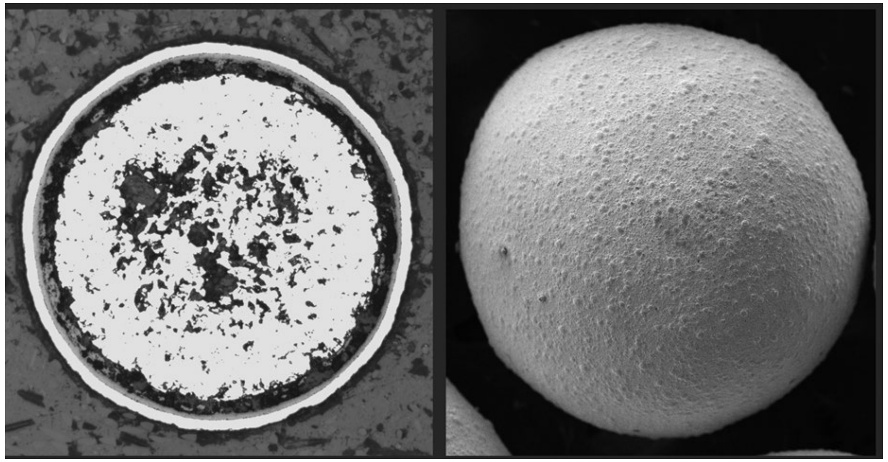


USNC UCO Kernel

UN/ZrC team with completed particles for NASA



USNC AGR-spec TRISO



UN/ZrC coated particle images

USNC and Framatome First to Navigate the Front End of the Fuel Cycle for Advanced Reactors

ULTRA SAFE NUCLEAR

Mining & Milling → Conversion → Enrichment → Deconversion → Fabrication → Reactor

We have signed a purchase agreement for <10% Enriched Uranium Product (EUP) feedstock from Urenco for Q1-Q2 of 2025

urenco
The Energy to Succeed

Framatome partnership to provide deconversion services and fabricate fuel via a Joint Venture

framatome

wnn
world nuclear news

Energy & Environment | New Nuclear | Regulation & Safety | Nuclear Policies | Corporate | Uranium

Urenco USA, USNC in advanced reactor uranium supply 'first'

02 March 2023

Share

A newly announced agreement under which Urenco USA will supply enriched uranium to Ultra Safe Nuclear Corporation to manufacture fuel for its Micro-Modular Reactor (MMR) has been described by the companies as the first commercial supply of enriched uranium product (EUP) for use in an advanced nuclear reactor anywhere in the world.

(Image: Urenco USA/USNC)

TRITONIC

TRITONIC will be deployed in three phases at Framatome's existing NRC-licensed Richland, WA site:

- Phase I – Manufacturing of approximately 2 MTU per year of <10% enrichment material ("LEU+")(1) by retooling and re-equipping an existing building on this site
- Phase II – Construction of a new building on this site with the partial installation of process equipment, increasing capacity by an additional ~10 MTU per year of <10% enriched FCM Fuel
- Phase III – license amendment for production of <20% enriched ("HALEU")(2) FCM Fuel and installation of process equipment, increasing total manufacturing capacity above 20 MTU per year

Phase 1 well underway

- ✓ Purchase agreement for LEU+
- ✓ Equipment delivery ongoing
- ✓ License amendment submittal in Q3 2024

ULTRA SAFE NUCLEAR

Thank you!

Presentation to 2024 NRIC Program Review

Wesley Deason, Pylon Program Manager
w.deason@usnc-tech.com

RELIABLE ZERO-CARBON ENERGY ANYWHERE

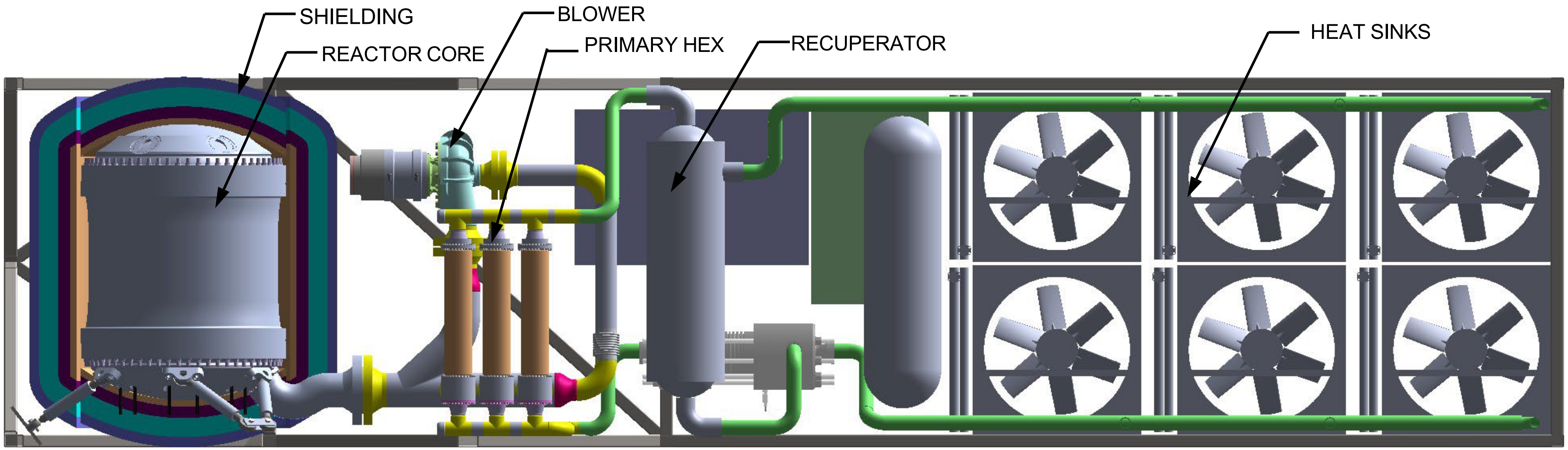
Radiant NRIC Program Overview

April 23, 2024

Agenda

- Kaleidos Overview
- Radiant Company Update
- Recent Engineering Progress
- Kaleidos Development Unit (KDU) Overview
- DOME Test Campaign

Kaleidos Overview



Representative image of commercial Kaleidos unit.

- 1 MWe portable high-temperature gas-cooled microreactor
- 20 year product life, refueled 3 times
- Key safety features: TRISO fuel, helium coolant, passive cooling air jacket

Since Last Year

- Raised $45M in April ‘23, $60M total
- $2.3M ➔ $8.7M in non-dilutive funding
- 29 employees ➔ 50 employees
- Renovated and moved into 38,000 sq ft HQ
- Safety Design Strategy approved by DOE-ID
- Successful Conceptual Design Review at INL
- In Pre-Application with NRC
- Significant design and hardware development progress

Leadership Team (unchanged)

Doug Bernauer, CEO and co-founder

SPACEX

Bob Urberger, CTO and co-founder

SPACEX

Tori Baggio, COO

McMASTER-CARR.

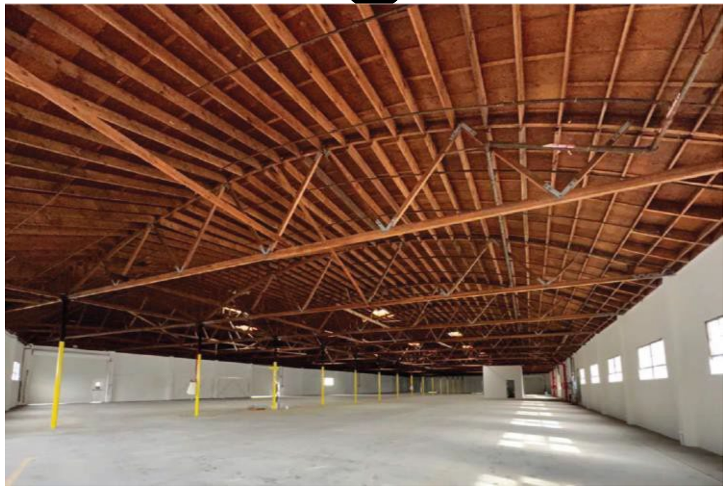
Ben Betzler, Head of Nuclear Eng.

OAK RIDGE National Laboratory

Chris Hansen, Head of Mechanical Eng.

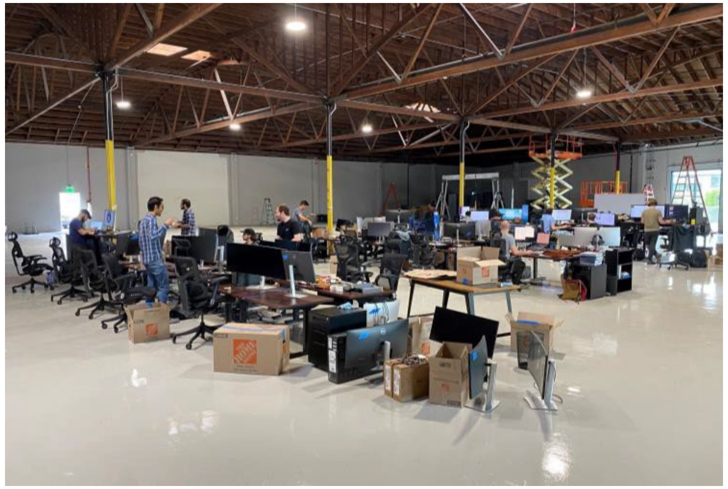
SPACEX

El Segundo HQ



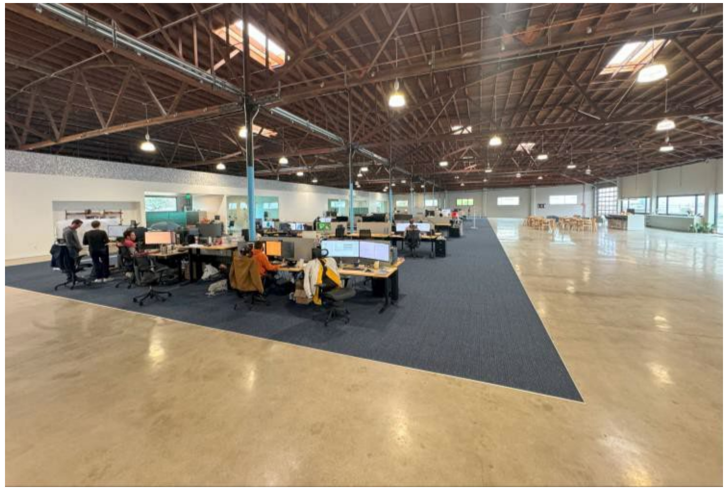
Lease commencement – July 1, 2023

Slab upgrade – August 8, 2023



Move-in (shop floor) – August 21, 2023

Exterior – Today



Office (23,000 sq ft) – Today

Shop floor (15,000 sq ft) – Today

Test Stands

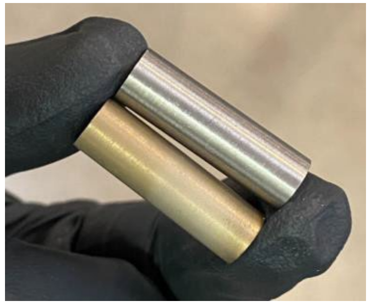
Air Jacket Test

Unit Cell Flow Test

Helium Circulator Loop Test

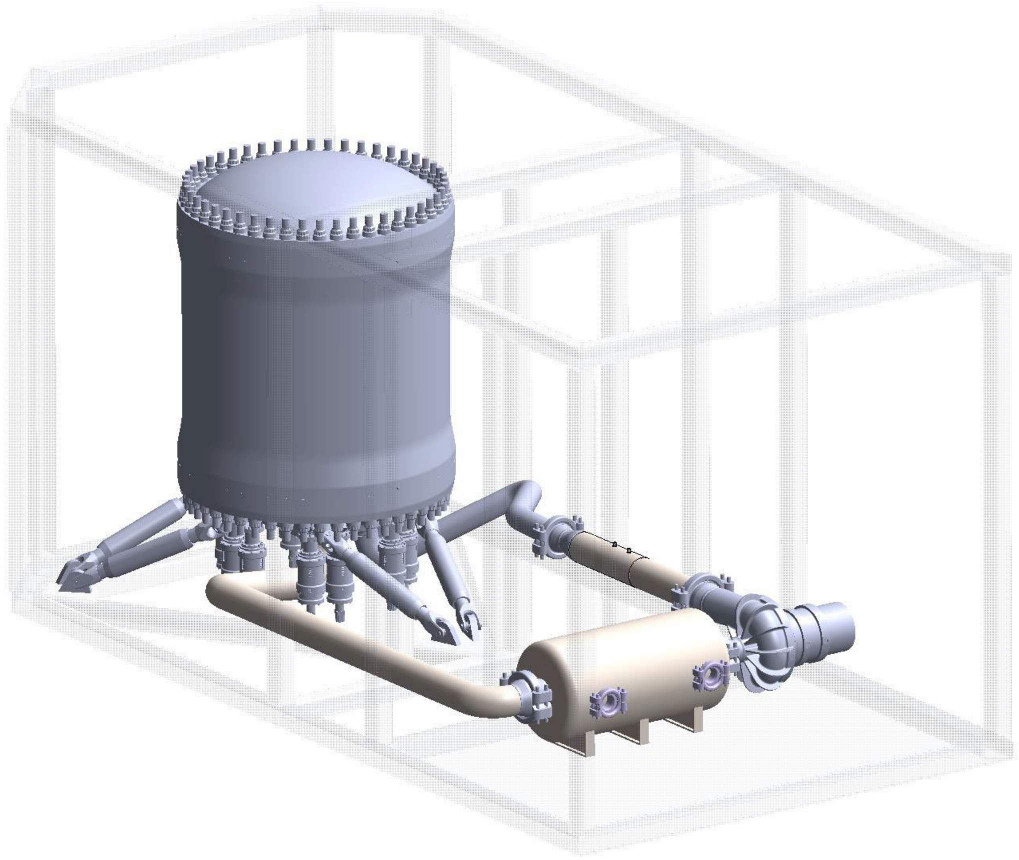
Engineering Milestones

- Zirconium Hydrides
  - Established repeatable process for hitting desired atomic ratio
- Pressure Vessel
  - Test article pressure vessel procured for passive cooldown test
- Graphite
  - Machining test of core internals complete
  - Long lead procurement for DOME test placed
- Helium Test Loop
  - Completed testing of helium circulator at operational temperatures and pressures


Kaleidos Development Unit

- Verifying performance of commercial product through real-world testing
  - Reactor core + shielding
  - Primary loop
  - Heat transfer loop



Reactor Core, Pressure Vessel and Primary Loop

RADIANT

NRIC and DOE Engagement

NRIC

- All FEEED deliverables submitted
- Held Conceptual Design Review
- On INL's Qualified Supplier List for design

DOE-ID

- Participation in CDR and frequent collaboration meetings
- Approval of Safety Design Strategy
- Delegation of approval for long lead bulk materials to INL

Next Steps

- Additional long lead procurements
- Phase 2 and 3 of INL NQA-1 audit
- Conceptual Safety Design Report
- Preliminary Design Safety Analysis
- Continued subsystem development and testing

Radiant remains singularly focused on the development of Kaleidos. Agile and creative problem solving will be key to maintaining our timeline for a successful test in the DOME.