INL/CON-24-76436-Revision-0

Special Considerations for the Removal and Disposal of Microreactor Experiments

March 2024

Kristy Diane Yancey Spencer, Evans Damenortey Kitcher, Brett D Welty, Mitchell S Woolf, Andrew J Smith, Jared Harper, James A King, Nicholas Vise Smith

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Special Considerations for the Removal and Disposal of Microreactor Experiments

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Molten Chloride Reactor Experiment (MCRE) Mission Statement

To measure key reactor physics phenomena and test hypotheses about Molten Chloride Fast Reactor (MCFR) behavior, to reduce uncertainty and provide foundational knowledge to support the development of the MCFR Demonstration Reactor (MCFR-D).

Objective 1 Safely **achieve criticality** with the first fast spectrum molten salt fueled reactor

Objective 2 Experimentally determine **reactor physics and kinetics parameters** to reduce uncertainty and gather data

Objective 3 Demonstrate the **fuel** loading, fuel salt sampling/analysis, offloading, and general **handling strategy** for chloride fuel salt

Objective 4 Initiate development of industry **supply chain** for key molten salt components operated in a high temperature and radioactive environment

Objective 5 Collect operational/testing data to lay foundation for an operating license for MCFR-D under a risk-informed performance-based **(RIPB) licensing framework**

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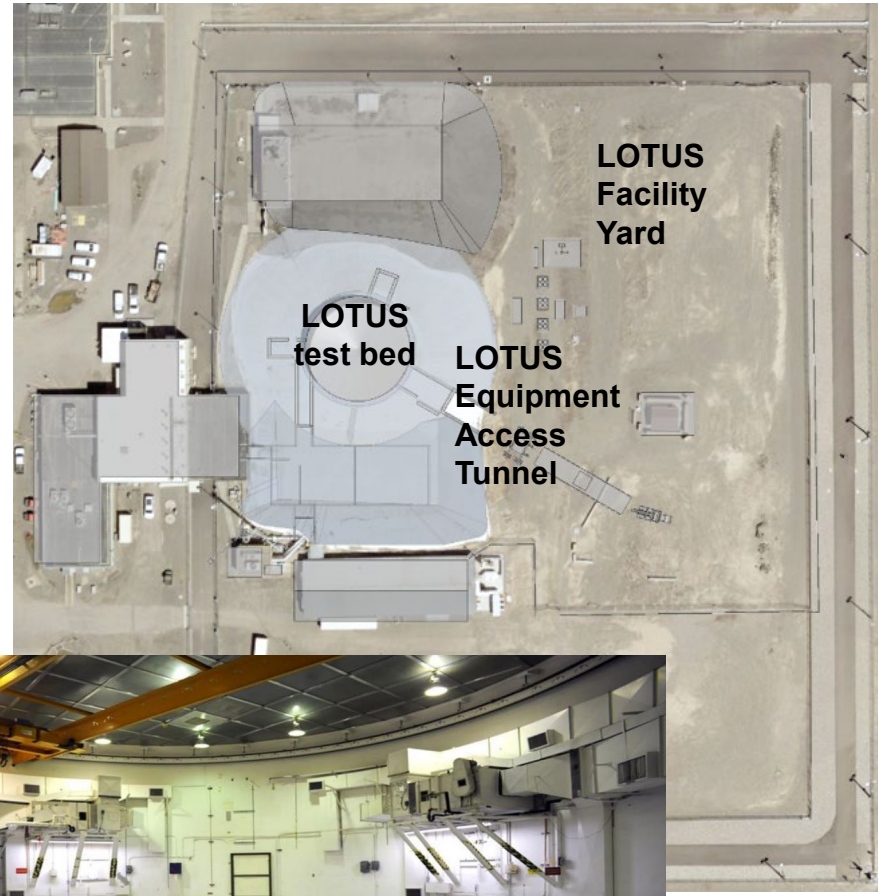
National Reactor Innovation Center (NRIC): LOTUS Test Bed

- **LOTUS** = Laboratory for Operation and Testing in the United States
- Established in the old Zero Power Physics Reactor (**ZPPR**) cell
- Designed to house nuclear experiments less than 500 kW_{th} with safeguards category I fuel quantities
- Designed for serialized experimentation → **rapid turnaround**
- Equipment Removal & Disposal (ERD) should leave clean slate for next experiment.



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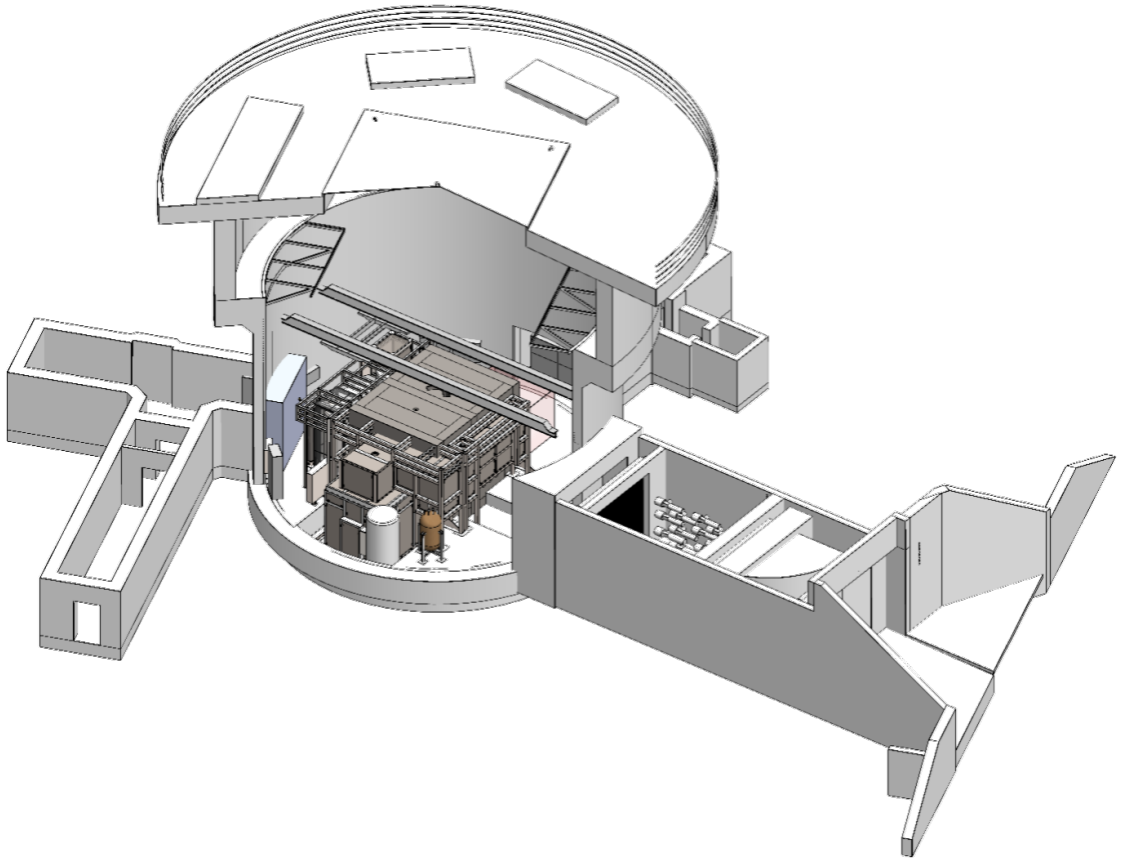
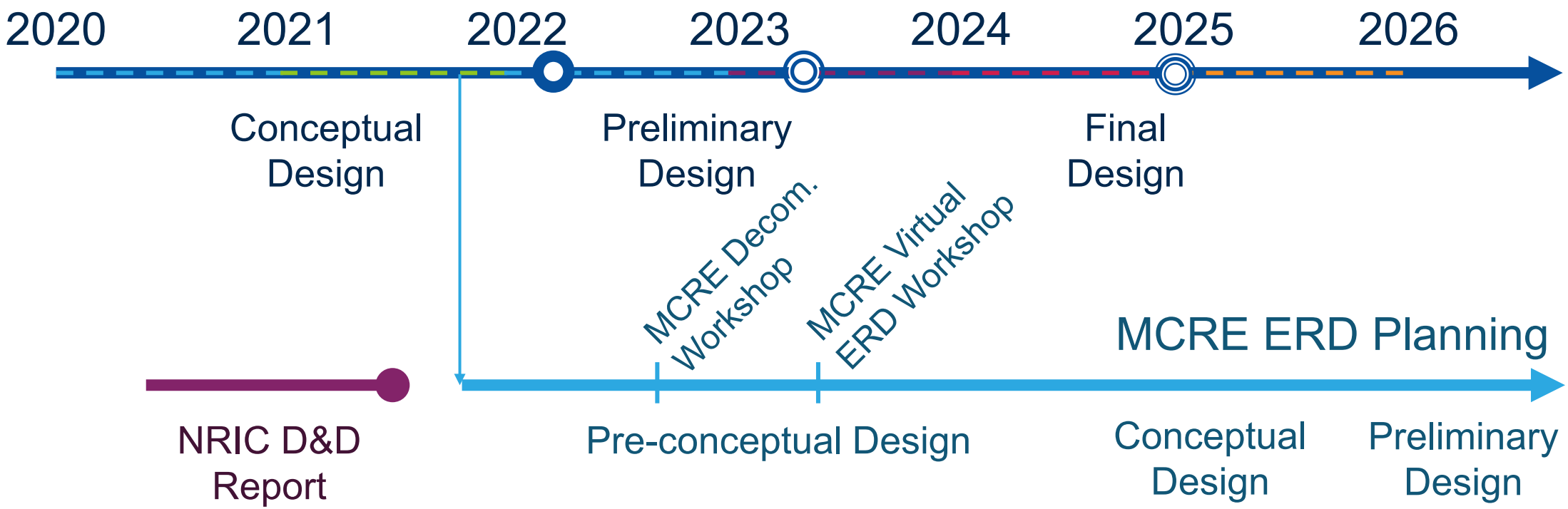
Molten Chloride Reactor Experiment

Parameter	Value
Rated Thermal Power	150 kW
Design Temperature	700°C
Design Pressure	500 kPa-g
Fuel Salt Mass Flow Rate	25 to 100 kg/s
Operating Temperature	600 to 650°C
Fuel Salt Melting Temperature	525°C
Fuel Salt Composition	NaCl-UCl_3 (67–33mol%)
Fuel Salt Volume	0.302 m^3
Fuel Salt Mass	~1000 kg
Neutron Reflector	82% dense MgO
Reactivity Control	Four rods w/ B_4C 80 wt.% B-10



MCRE is in Preliminary Design.
ERD Planning is still pre-conceptual.



- Safety Design Strategy (SDS) submitted to DOE
- Conceptual Safety Design Report (CSDR) submitted to DOE
- Preliminary Documented Safety Analysis (PDSA) planned to be submitted to DOE

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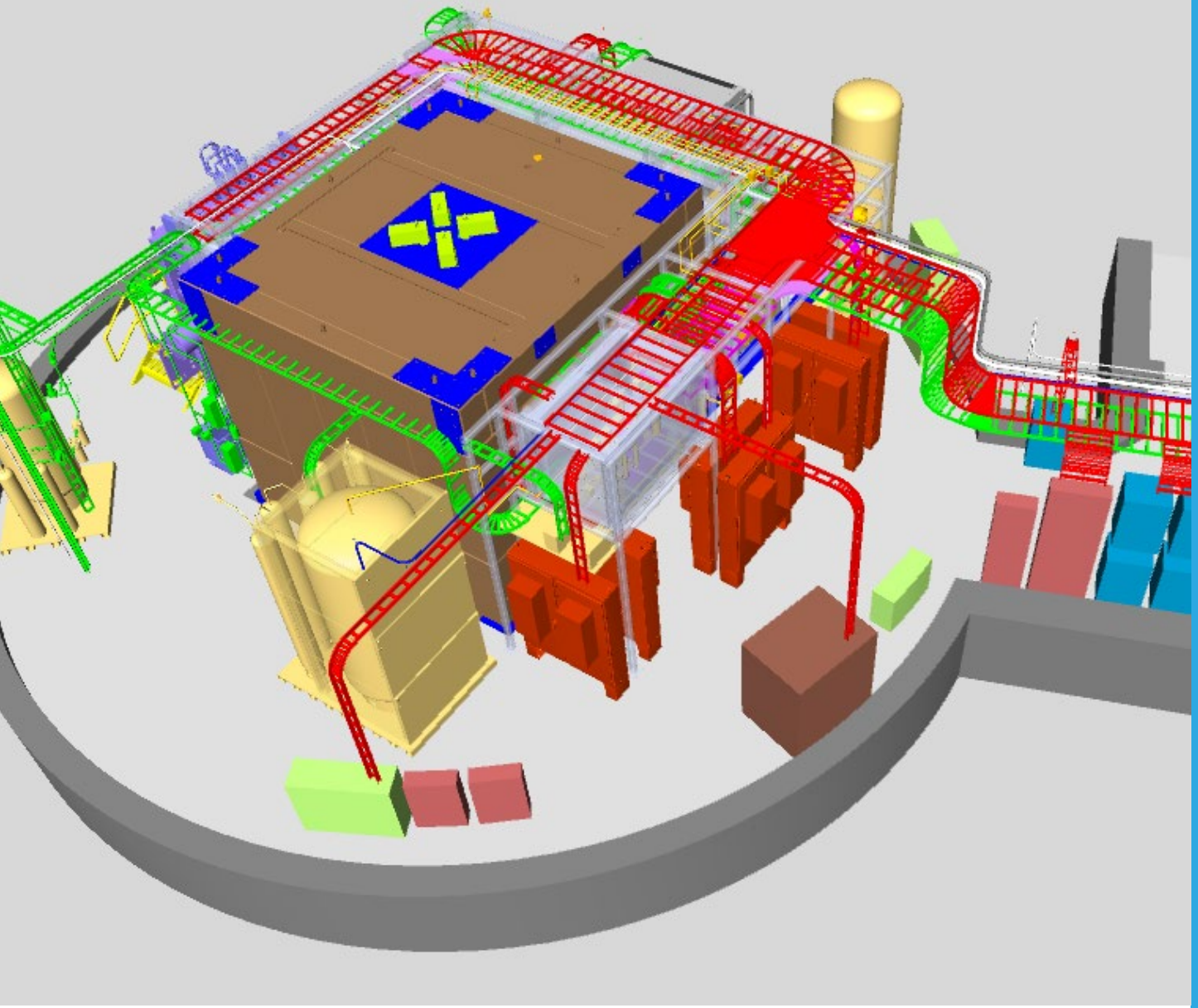

Challenge: Complexity

- First of a kind system
- Complex, evolving design
- Coordination between Southern Company, TerraPower, INL, etc.
- Balance experimental design goals with LOTUS constraints and ERD needs.

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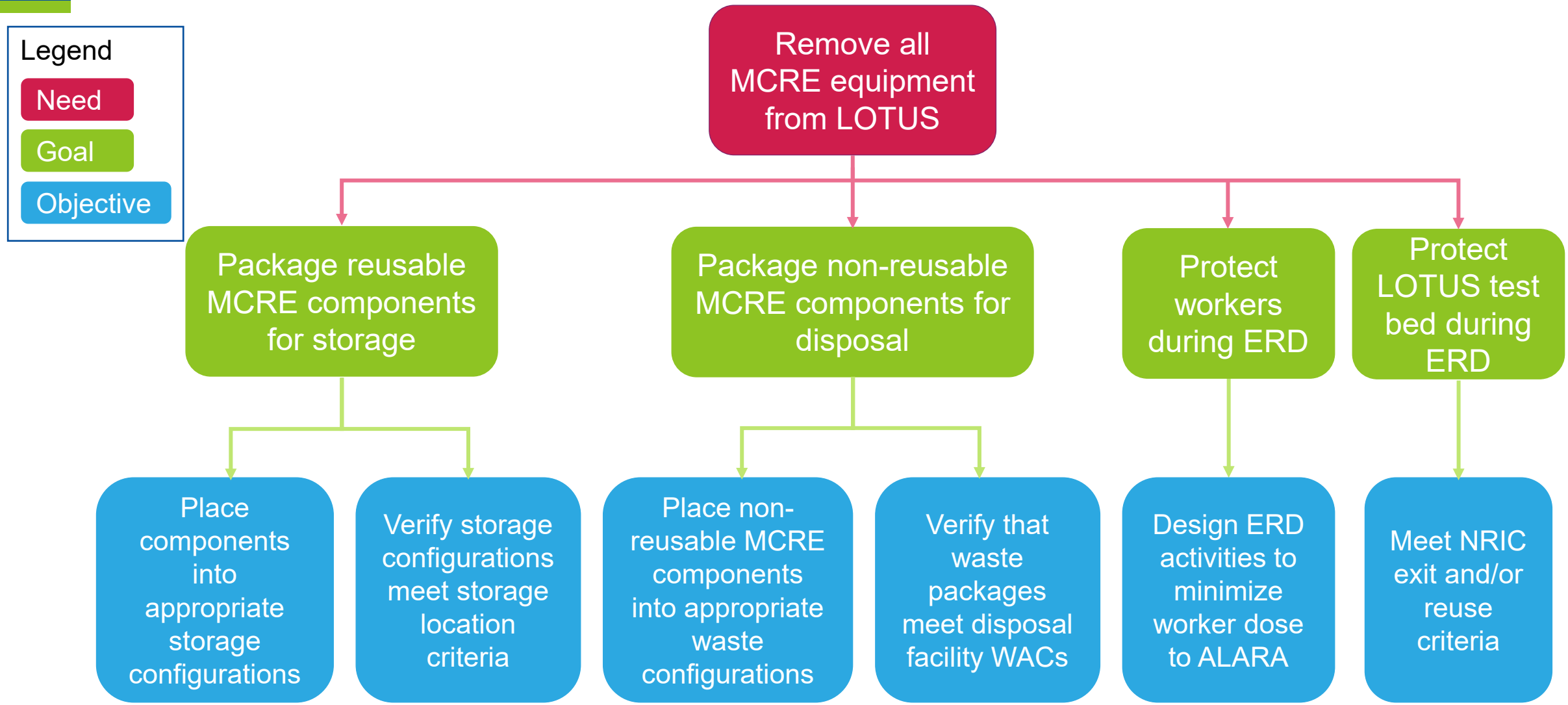
Systems Engineering Approach



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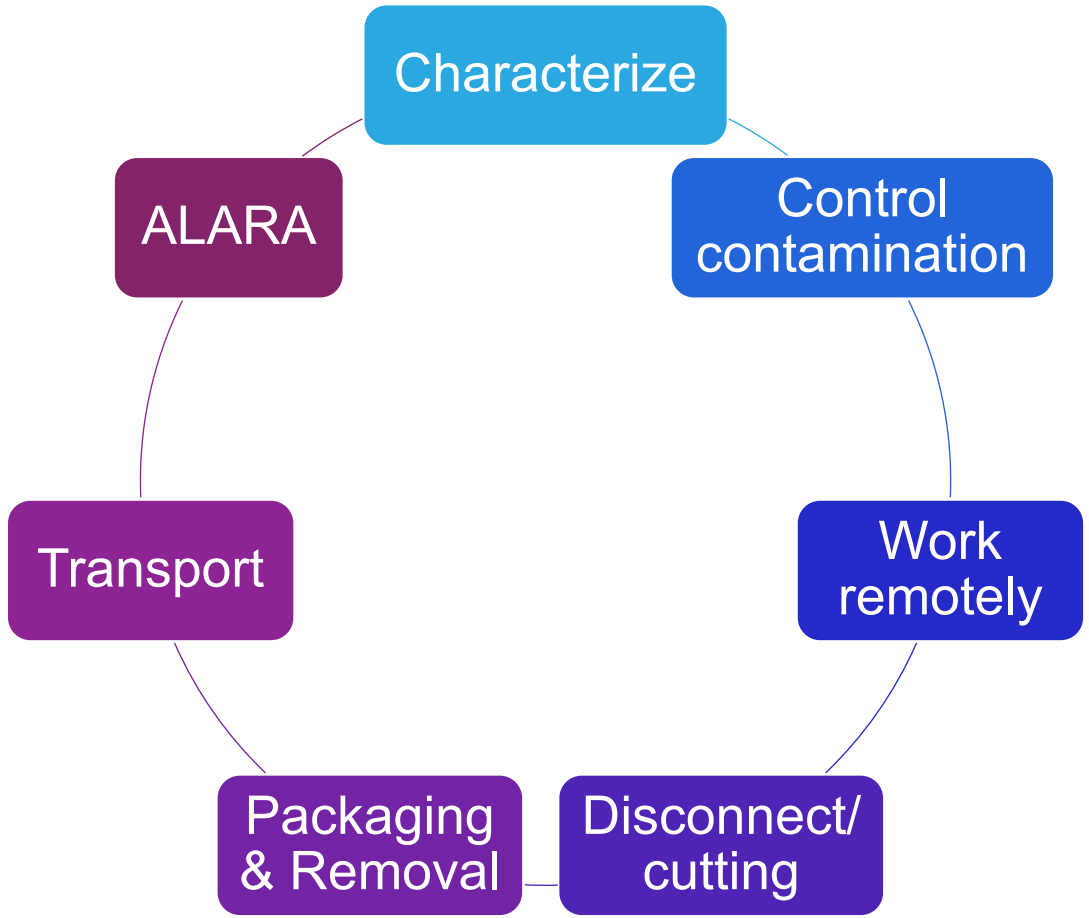
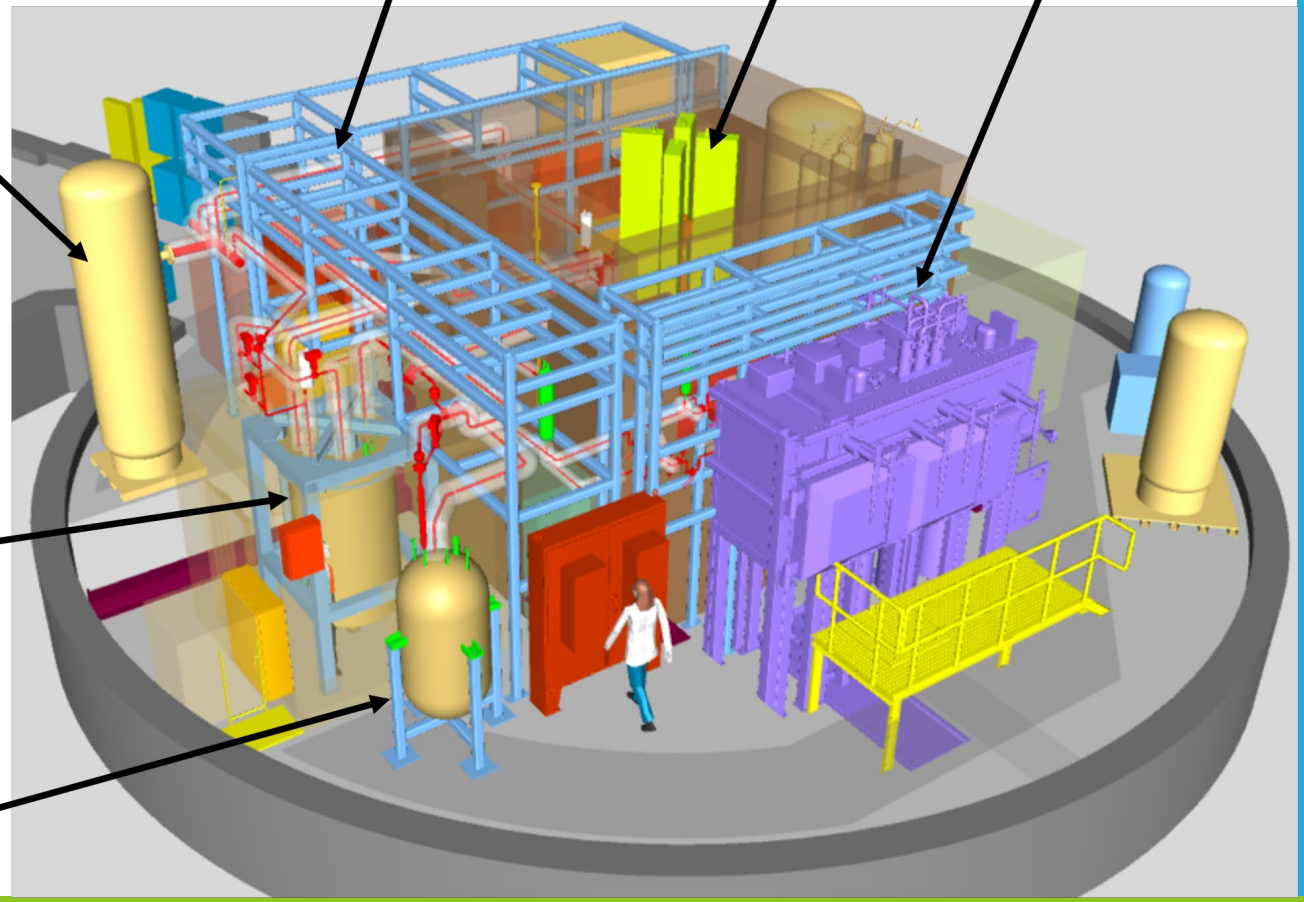
ERD Functions & Characteristics

- **Reliability** –perform identified tasks and survive operational environment.
- **Redundancy** – provide options to mitigate unexpected conditions or changes.
- **Recoverable** – recover from upset conditions to complete ERD activities without significant work stoppages.

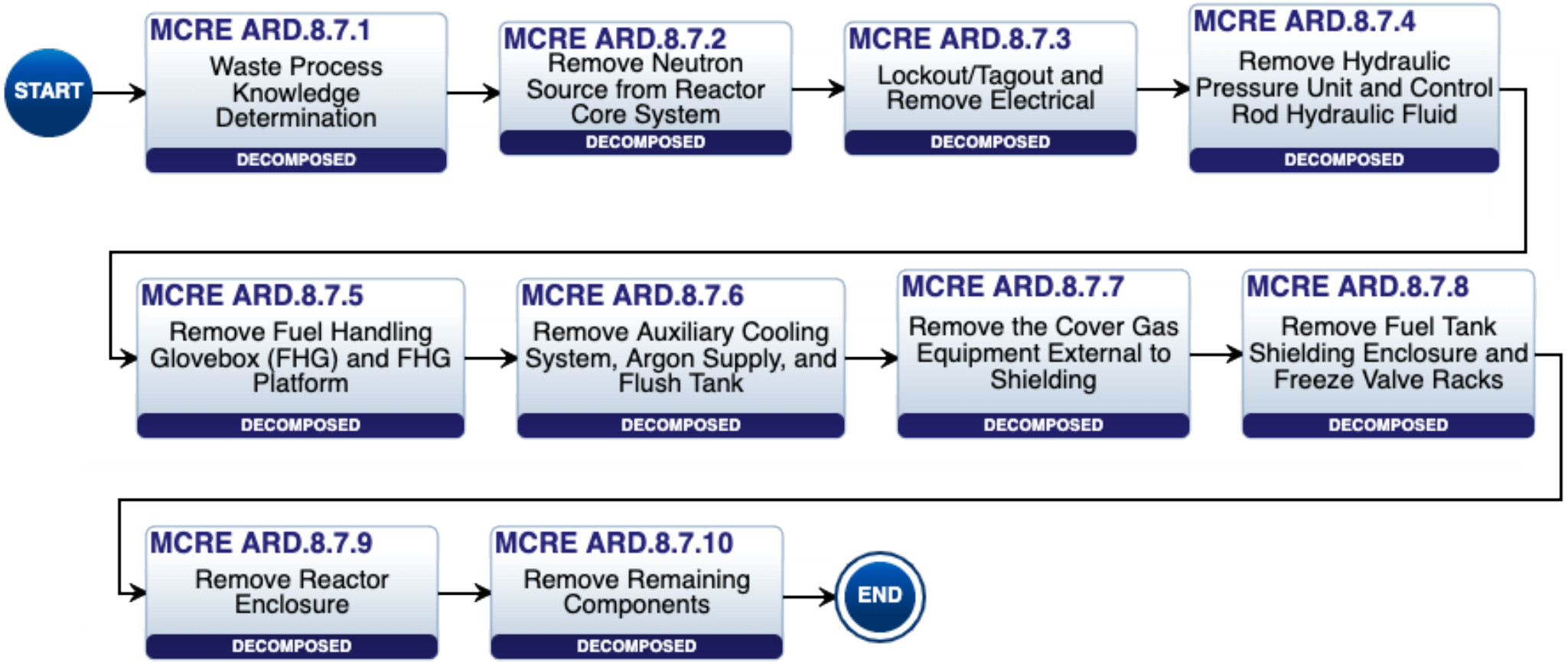




Challenge: Space

- Limited space with many subsystems
- LOTUS floor loading limit
- LOTUS tunnel loading limit.

Systems Engineering Approach: Innoslate



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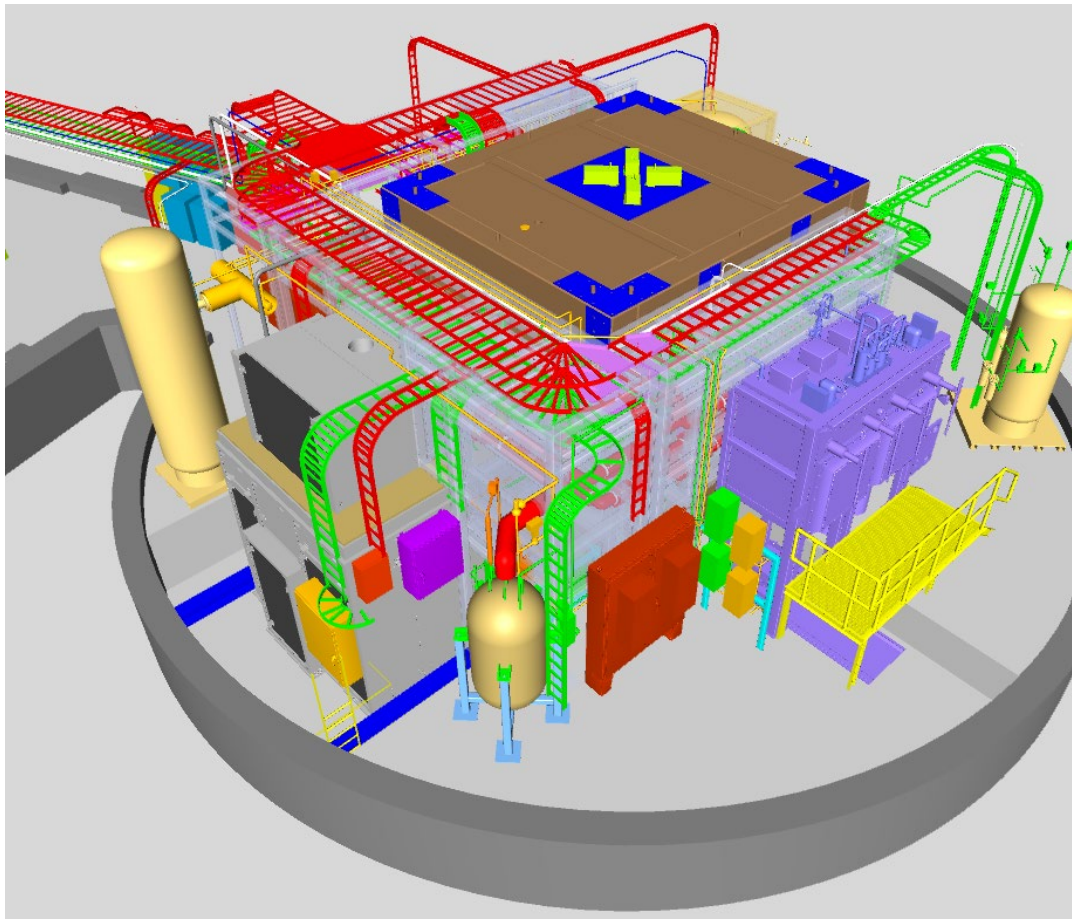
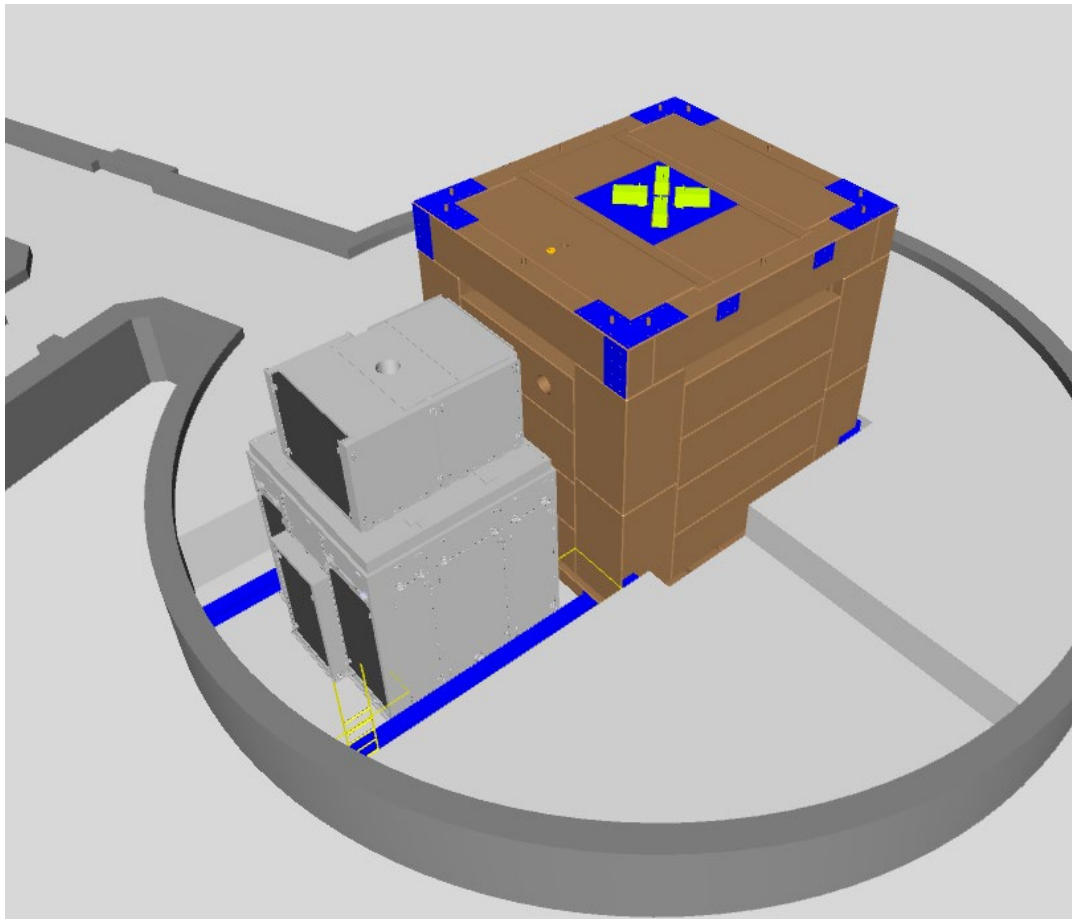
Sizing and Sequencing





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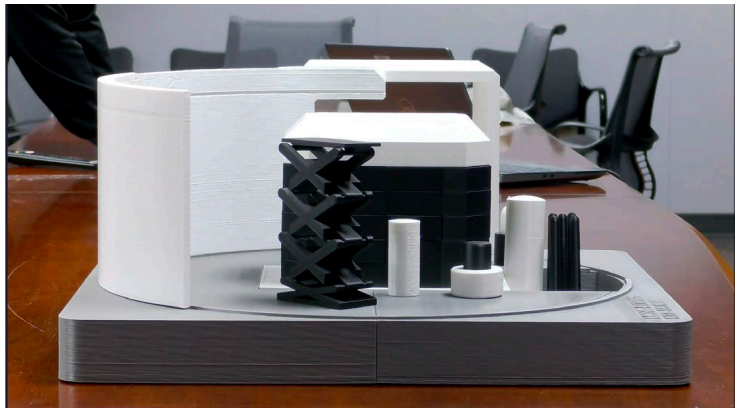
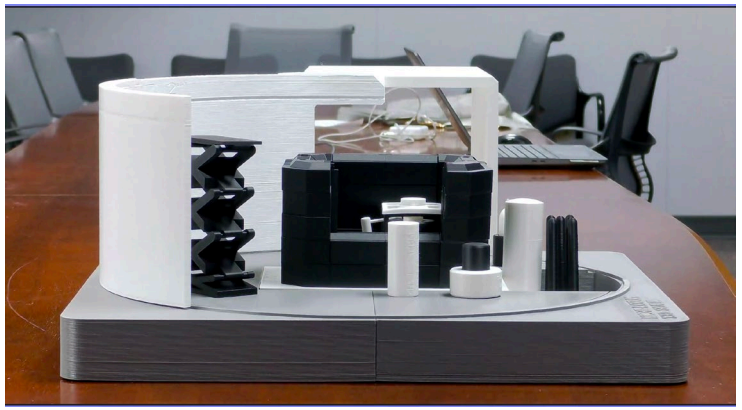
Usage of Small 3D-Printed Models





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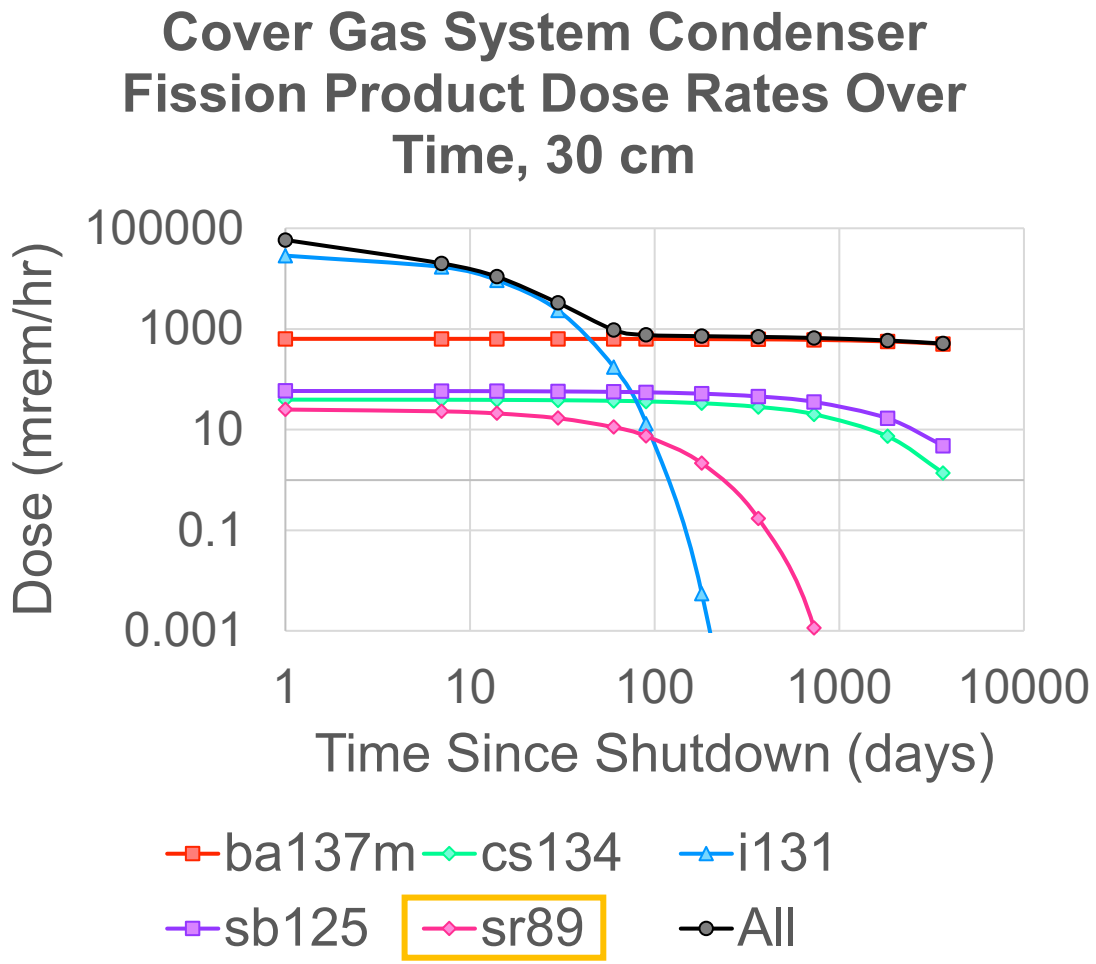
Challenge: Rapid Time Frame

- Components will be more radioactive.
- Presence of uncommon short-to-medium-lived isotopes in system at the time of packaging and removal.
- Solutions:
  - ALARA optimization
  - Usage of remote or semi-remote systems
  - Supplemental shielding.



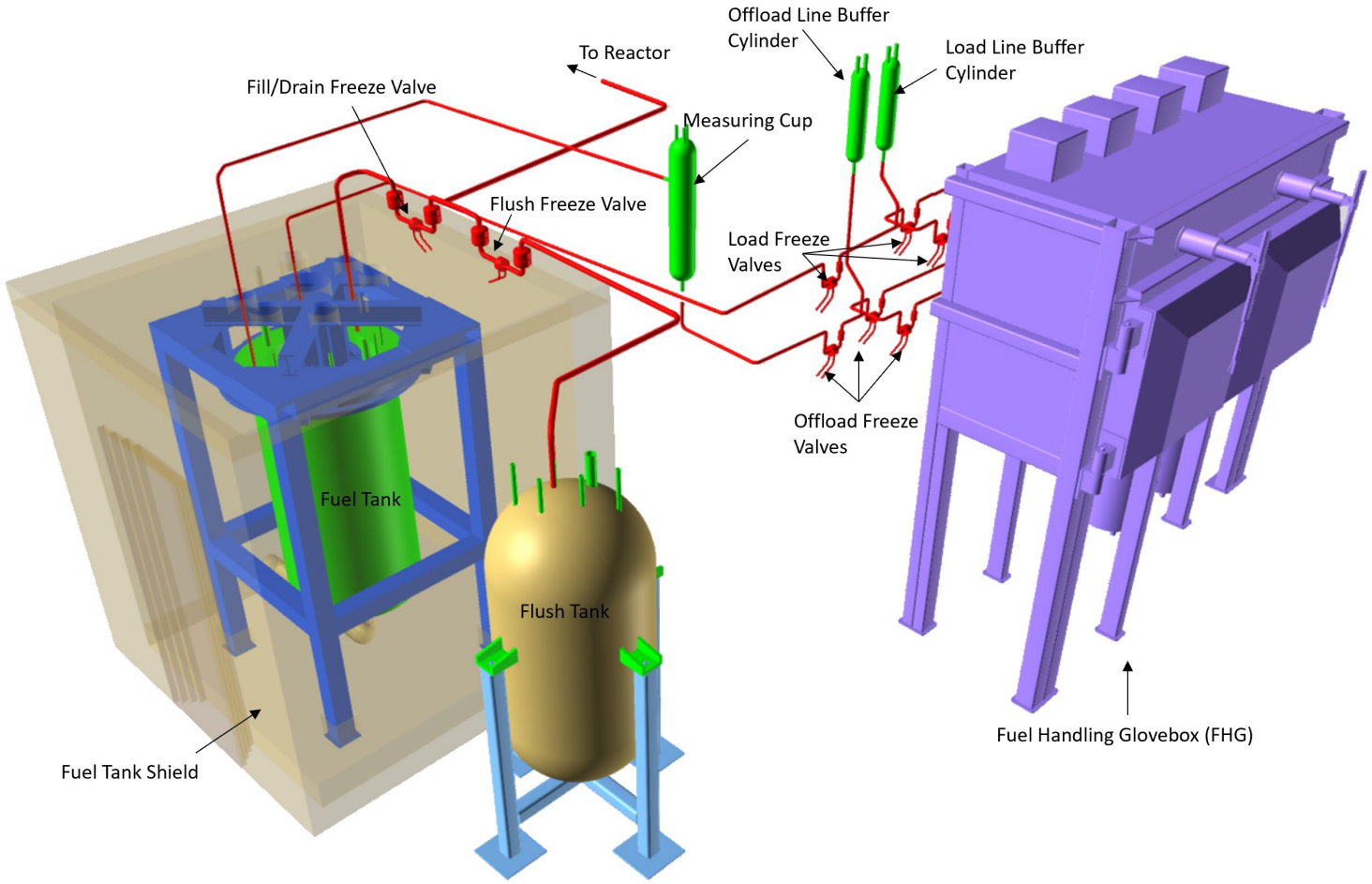
*Dose based on mid-2022 design, shown here as representative

Remote Solutions: Robots, Portable Containment, etc.

Note: these are examples of considered technologies. Decisions about specific solutions have not been made.

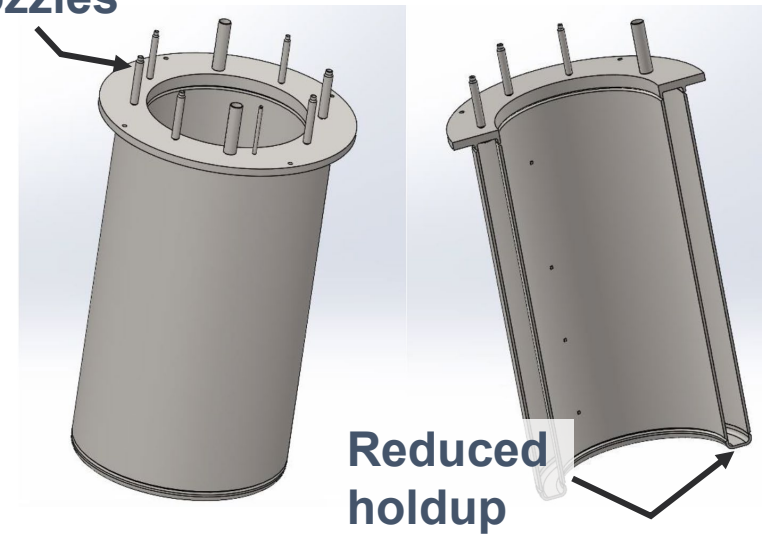
Figure credits: Abraflex, Azo-Grout, Brokk, D&D KM-IT, International Attachments

Challenge: Residual Contaminated Material on Salt-Wetted Surfaces (Holdup + Uranium Plating).



- **Solutions:** working w/ designers, isolating collections in fuel handling system (FHS), sizing, grouting.

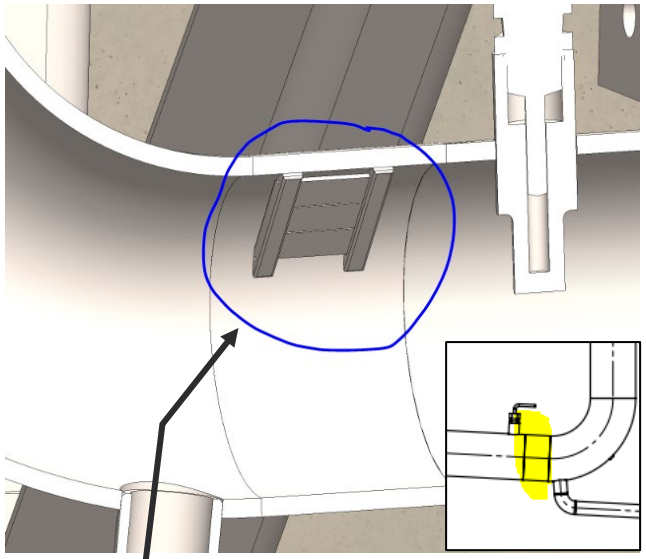
Custom nozzles

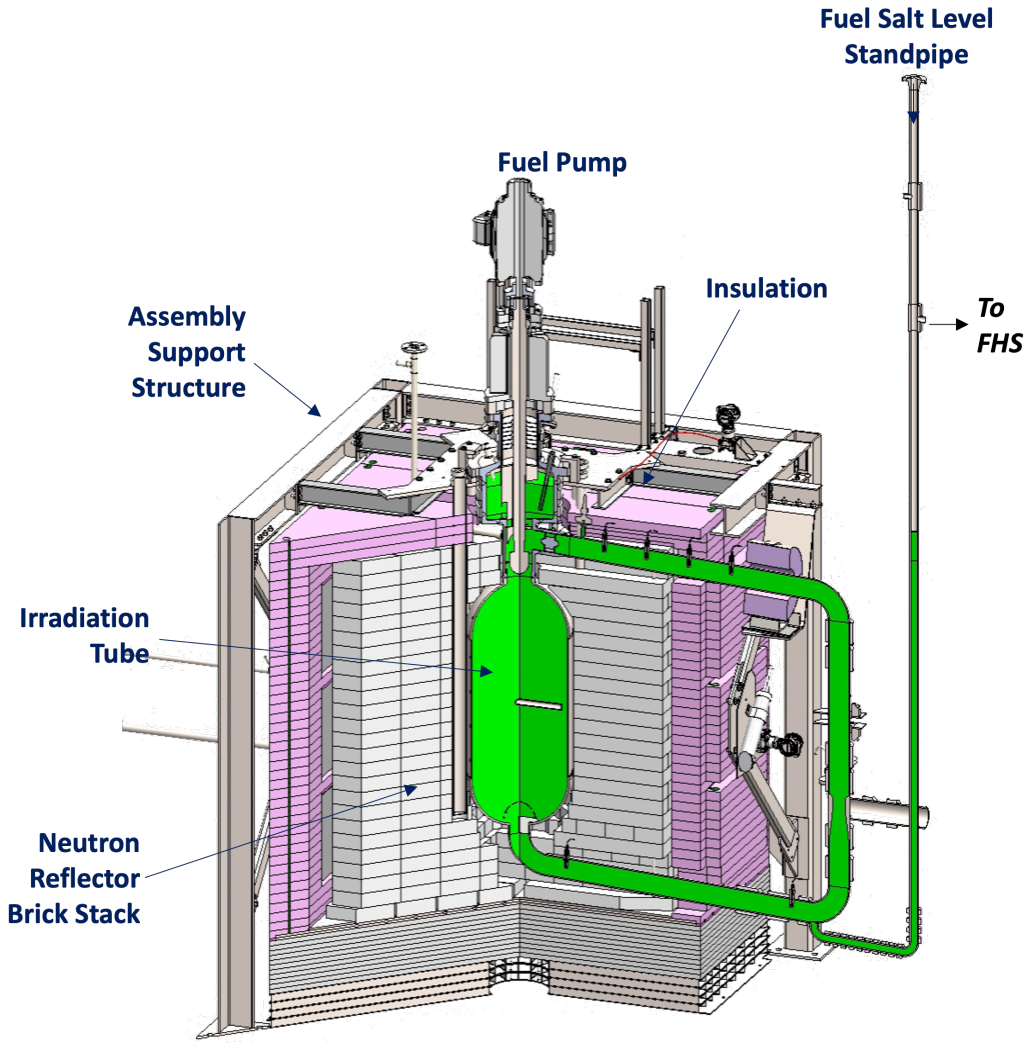


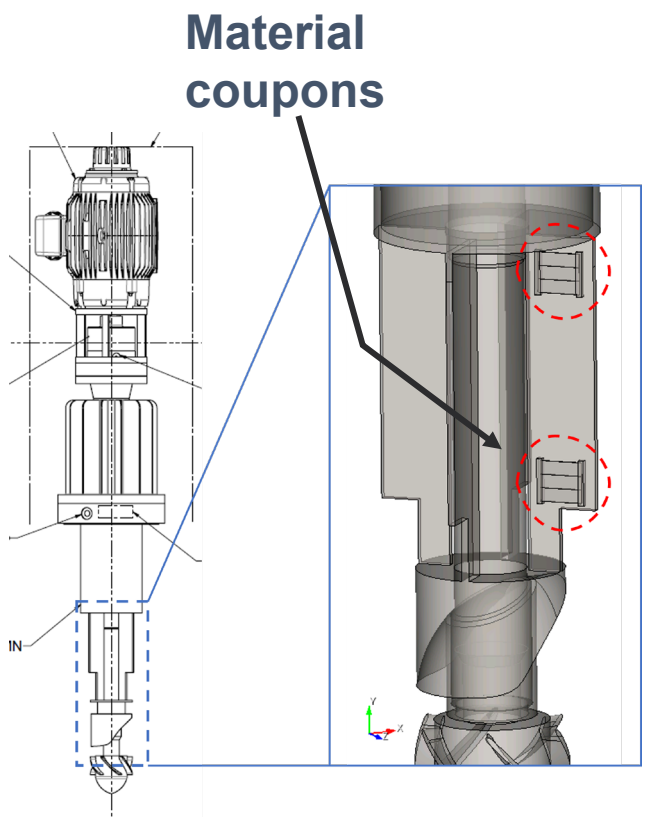
Reduced holdup

Challenge: Post-irradiation Examination Sample Extraction

- **Solutions:** working with designers, sequencing, selecting right tools.







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Future Work:
ERD System Technology Validation and Testing

- Demonstration of remotely operated reflector **brick handling techniques**.
- Investigation of component **sizing** and **pipe cutting** techniques.
- Development of frozen **salt sizing and handling techniques**, followed by demonstration of stability in a solidified grout-flush salt mixture.
- Demonstration of **vision system technology**, including possible augmented or virtual reality tie-ins with the remote technology.
- Investigation and demonstration of **radiation monitoring system**.
- Demonstration of **containment materials**, particularly for surfaces contaminated with flush salt.

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Conclusions

- ERD planning to continue in step with MCRE design.
- ERD or decommissioning planning early allows for design feedback.
- Micro-reactor and nuclear experiments provide opportunity to demonstrate, deploy, and test new removal and disposal capabilities to support the next generation of nuclear reactor technology.

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