Systems Analysis and Integration Microreactor Program Review

March 8, 2023

David Shropshire, Idaho National Laboratory

Agenda

- Technical Area Background
- **Technical Area Developments**
  - Licensing and Transportation
  - **Market Analysis and Economic Optimization**
  - Systems Analysis and Source Term Tools
- Path Forward
- Discussion/Questions

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FY23 (FY22 c/o) Activity: Market Analysis and Economic Optimization

- Task 1. An assessment of the opportunities and barriers for microreactors in emerging markets will be performed and reported.
- Task 2. A review of current and prospective state policies under consideration for carbon reduction will be evaluated and reported.
- Task 3. A cost reduction investigation will be evaluated on the microreactor system and structure through adoption of a functional containment approach.

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Tasks 1 & 2 Updates

- Work is conducted as part of EMA, the Emerging Energy Market Analysis Initiative, led by the INL with collaborators from the U of Alaska, U of Wyoming, U of Michigan, MIT, and the Energy Policy Institute at Boise State University (BSU).
- Draft report (9/30/22) is currently being updated with inputs from the performing organizations.
- Project review conducted Jan. 30-31, 2023 at INL.
- Final report due 3/31/2023


INL/RPT-22-02756

Microreactor Applications in U.S. Markets

September 2022

Evaluation of State-Level Legal, Regulatory, Economic and Technology Implications

DOE Microreactor Program

ema
Emerging Energy Markets Analysis Initiative

INL Idaho National Laboratory

Program Highlight

Emerging Energy Market Analysis / Integrated Energy & Market Analysis

Collaboration with Universities to Support Microreactor Program

INL & University Partners meeting Jan. 30-31.

- The Emerging Energy Markets Analysis (EMA) initiative met to review research supporting the Microreactor Program and to strategize ways to help states like Alaska and Wyoming position themselves to attract the low-emissions industry as part of a regional-to-global strategy.
- The EMA team led by INL, is a collaboration with the University of Michigan (UM), University of Wyoming (UW), Massachusetts Institute of Technology (MIT), University of Alaska (UA), and Boise State University (BSU).
- The initiative is dedicated to advancing the understanding of energy market options as the work transitions to new clean energy futures.
- For more information about EMA visit: *https://ema.inl.gov/*

Left-to-right standing: David Shropshire (INL) ,Dr. Todd Allen (UM), Dr. John Parsons (MIT), Selena Gerace and Tara Righetti (UW), Alex Huning (Oak Ridge National Laboratory), Donna Kemp Spangler (INL).
Left-to-right seated: Richelle Johnson (UAA), Paul Kjellander (EMA), Dr. Steven Aumeier (INL), Marcio Paes Barreto (Wyoming Energy Authority) and Eugene Holubynak (UW)
Virtual attendance: Dr. Kathleen Araujo (BSU), Christi Bell (UAA), Cassie Koerner (BSU), and Jessica Lovering and Michael Craig (UM)

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Assessment of Barriers and Opportunities for Microreactors

- Includes an assessment of the opportunities and barriers for microreactors in emerging markets, including applications in energy-intensive industries, e.g., urban fueling nodes, mineral extraction, chemical processing (Trona), etc.
- Initial focus is on Alaska (AK) and Wyoming (WY) energy markets serving location-specific energy needs for electricity and heat.
- Methods include literature review and expert and stakeholder elicitations.
- Research seeks to define key preconditions for microreactor deployment including economic, environmental, workforce, government intervention/regulatory, and tax revenue implications.
- Topics include:
  - Energy System Changes and Energy-Intensive Developments (led by Boise State)
  - Wyoming Market Assessment (led by U Wyoming)
  - Interior-Alaska Market Assessment (led by U Alaska)
  - Economic Assessment of Market (led by MIT)

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Review of Carbon and Nuclear Policies

- Federal and State Policy Focus.
  - Current and prospective state policies (50 states), emphasizing Alaska and Wyoming, with a focus on Renewable Portfolio Standards, Clean Energy Standards, carbon-reduction targets, and nuclear adoption/extension support.
- Carbon Policies/Carbon Targets.
- Nuclear Adoption/Life Extension Support.
- Research on Energy Transition.
  - Uses methods including interviews and focus groups to assess industry awareness of- and sensitivity to- carbon governance including carbon regulations, carbon markets, ESG (Environmental, Social, Governance) disclosures, procurement requirements, supply chain or contract provisions.
  - Research seeks to identify which areas of carbon governance have the most impact on state industries and to what extent industries are motivated to make new investments to decarbonize. Analysis will identify informational requirements, barriers, and opportunities for microreactor applications in established state industries.

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Future Study Areas

- Define MR capabilities (mobility, etc.) to support specific types of industries (e.g., Trona mining in WY) and operate within existing energy systems.
- Identify strategies for low-carbon transition, including interim planning in advance of MRs availability in the market.
- Explore public perceptions on nuclear energy to determine how stakeholders/decision maker’s value and prioritize issues important for MR deployment.
- Explore new markets, particularly in the oil and gas industry and mining applications that can tap funding streams in recent passed laws (IRA, IIJA, CHIPS, DPA, etc.).
- Assess key areas in regulatory space related to licensing a facility, access to and interconnection with the grid or ability to sell excess power in deregulated markets.
- Additional study areas forthcoming in March 31 report (TBD).

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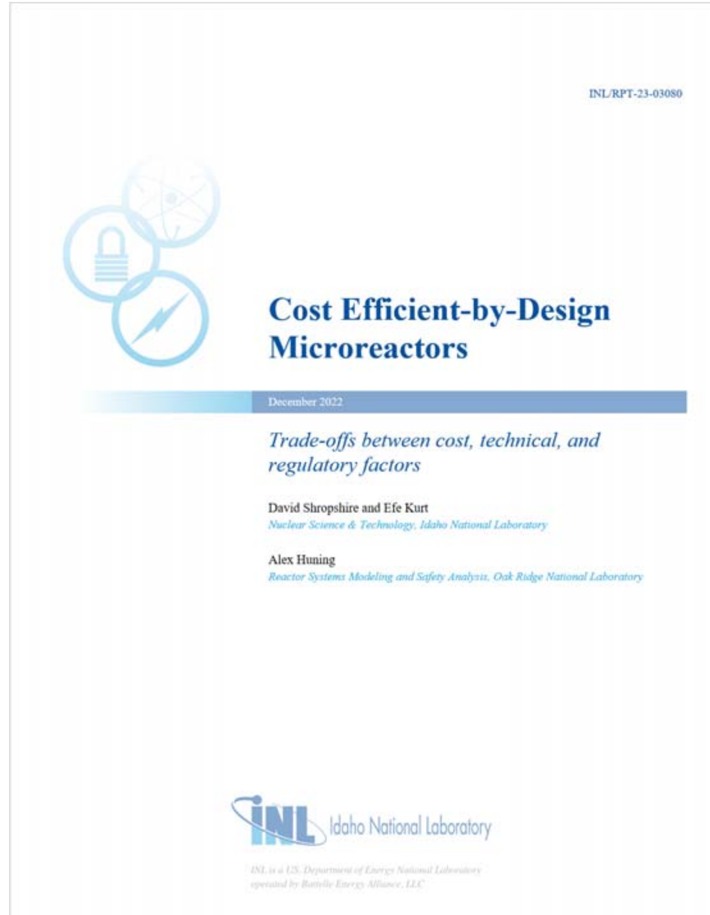
Tasks 3

- Final report submitted 12/30/2022
- Technical reviews conducted and final report was submitted to PICS.


INL/RPT-23-03080

Cost Efficient-by-Design Microreactors

December 2022

Trade-offs between cost, technical, and regulatory factors

David Shropshire and Efe Kurt
Nuclear Science & Technology, Idaho National Laboratory

Alex Huning
Reactor Systems Modeling and Safety Analysis, Oak Ridge National Laboratory

INL Idaho National Laboratory

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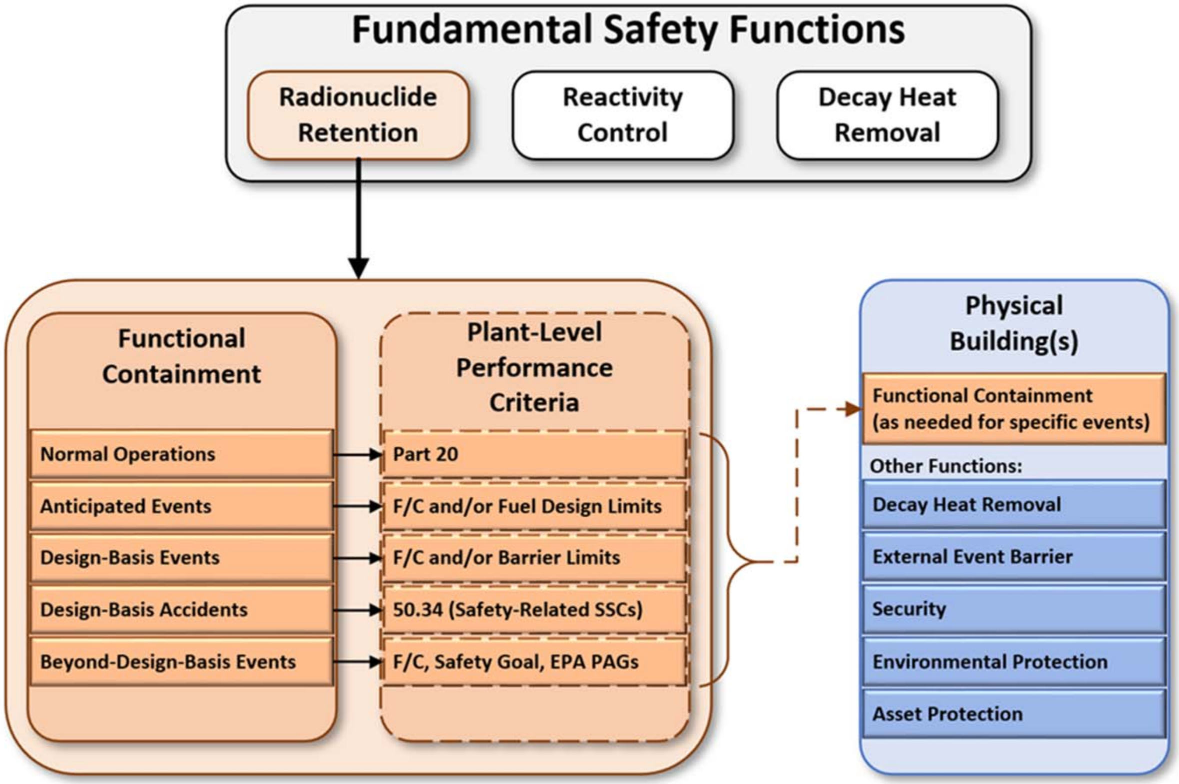
Functional Containment



Note: F/C refers to frequency/consequence targets

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Functional Containment design is based on a technology-inclusive, risk informed, and performance-based (TI-RIPB) approach:

1. Establishes objective criteria for evaluating performance,
2. Develops measurable or calculable parameters for monitoring system and licensee performance,
3. Provides flexibility to determine how to meet the established performance criteria in a way that will encourage and reward improved outcomes,
4. Focuses on the results as the primary basis for regulatory decision making.

The risk insights from a probabilistic risk analysis (PRA) also form the basis for identifying and setting up decisions regarding anticipated operational occurrences, design-basis events, and beyond-design events.

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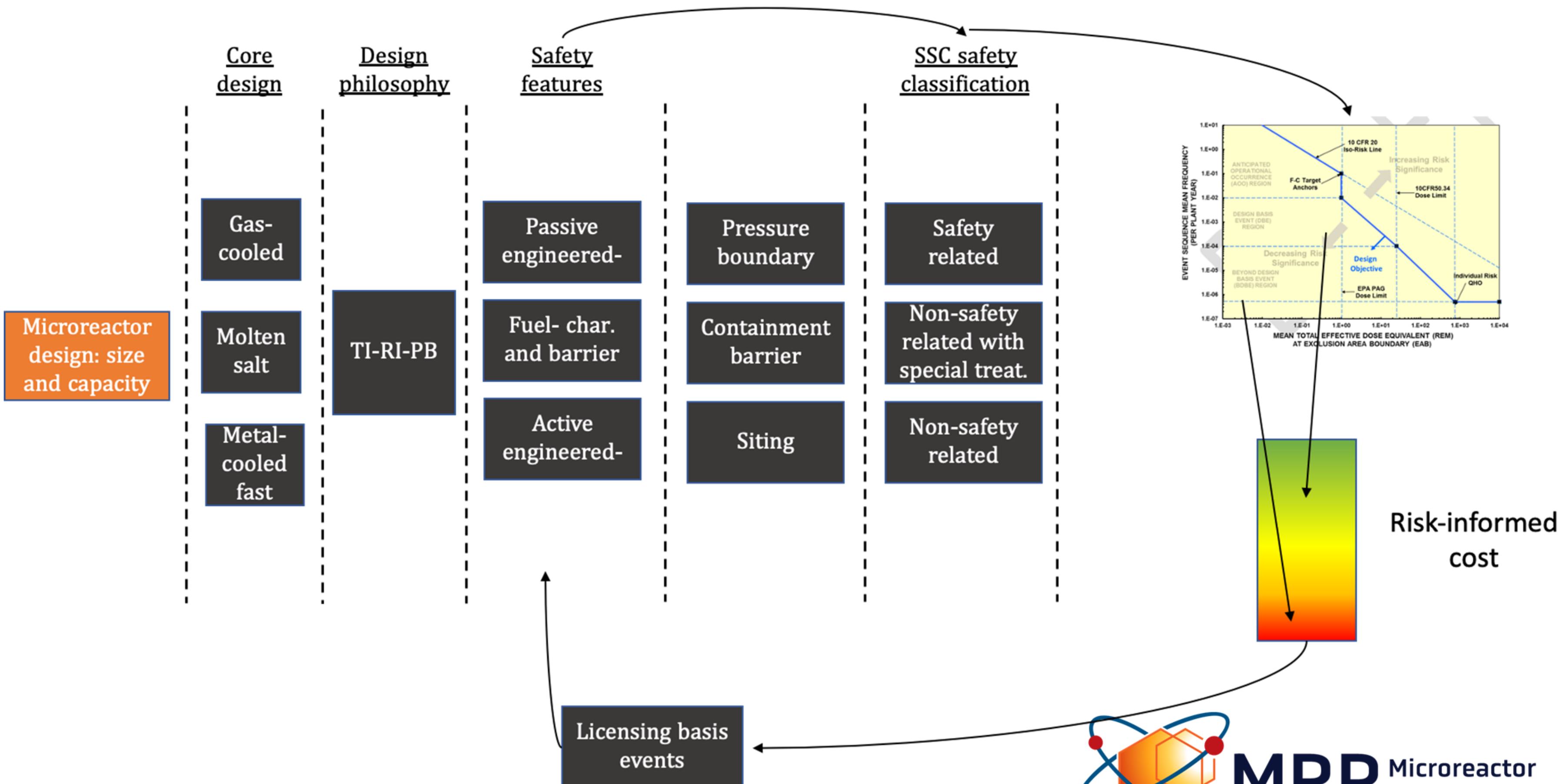
Possible economic benefits from functional containment



Functional containment economic evaluation approach

- Different microreactor technologies were analyzed and assessed based on their safety systems, release fractions, and radionuclide release rates. Generic dose and radionuclide dispersion calculations were performed for:
  - GCRs,
  - MSR (liquid fuel),
  - Heat Pipe Reactors.
- For all technologies at very small capacities, e.g., 1 MWt, the microreactors would be unlikely to challenge any limits on radiological release during an accident.
- GCRs using TRISO fuel have the lowest “worst case” or bounding release from the fuel.
- MSRs and HP microreactors can particularly benefit from using a functional containment approach to improve safety performance.
- A systematic approach is recommended for further evaluation of microreactor specific conditions to determine potential benefits from various design options (e.g., stack and exhaust fans, embedment).

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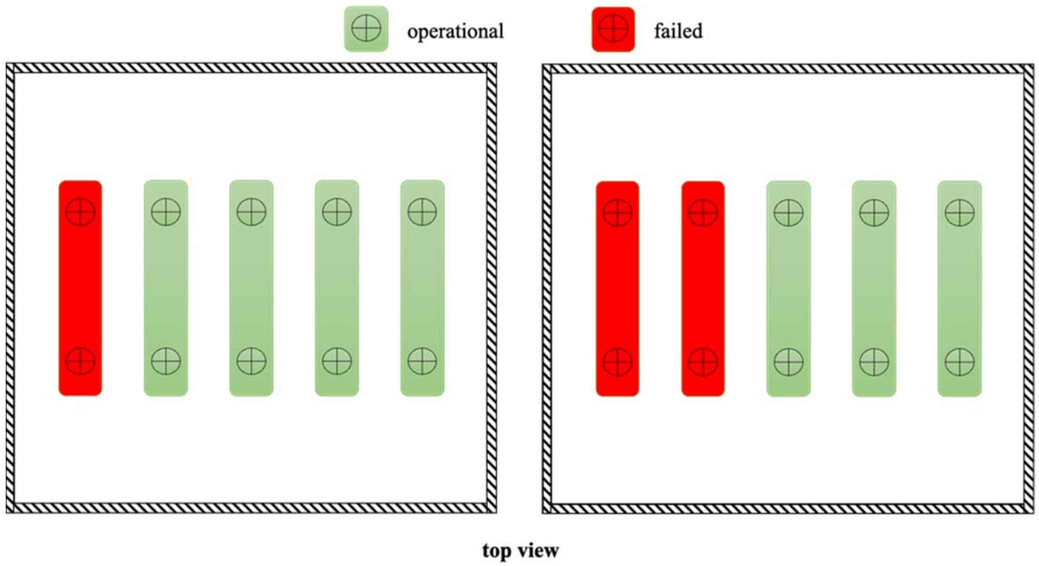
Cost Trade-offs and Relationships (Example)

Hypothetical case studies using F/C curves showed that:

1. For 10 MWt reactors, an additional barrier may not be needed.
2. As individual reactor capacities were increased from 10-50 MWt, high-performance structures were increasingly necessary to stay within safety limits.
3. Normalized delta costs ($/MWt) for the structures decreased as microreactor capacity increased.



Schematic representation of operational (green) and failed (red) MRs sharing a common barrier/structural enclosure.

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Future Study Areas

- New methodologies of TI-RIPB from an economics perspective as topical reports to NRC based on the existing literature, codes, and standards.
- Investigation of composite materials for retention barriers that are both resilient to internal and external hazards and have good retention capabilities.
- Testing and evaluating the performance of new microreactor containment designs under multi-hazard conditions (earthquake, flood, tornado, impact and similar).
- Assess the cost/risk/proliferation tradeoffs from using a high confinement barrier system for microreactor transport, operation, refueling, and decommissioning as an alternative to approaches using CONEX boxes and on-site reactor facilities/infrastructure.

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