



Development of Codes and Standards Solutions to Streamline Regulatory Review and Approval of Microreactor Applications

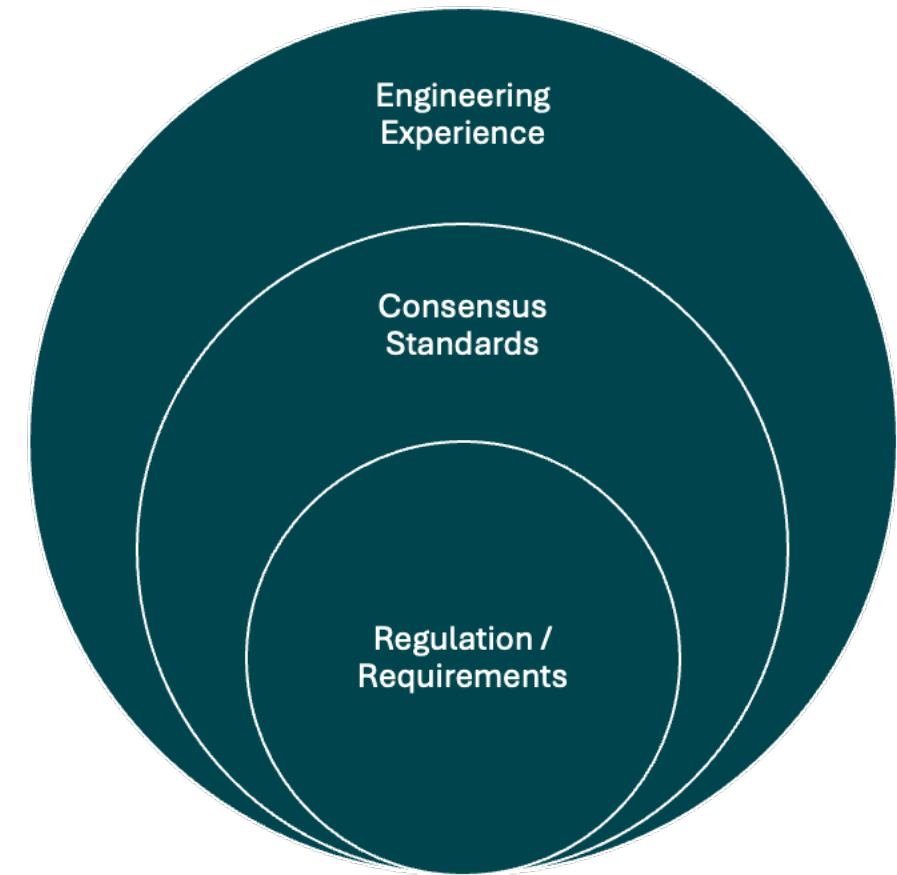
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Codes and standards are a representation of industry consensus

- Technical requirements that govern activities such as welding, fabrication, testing, construction, and non-destructive examination to ensure safety and reliability
- Developed by non-governmental standard development organizations (SDOs) like ASME and endorsed by NRC
- Advanced Reactor Codes and Standards Collective (ARCSC) curated a list of **>1000 nuclear codes and standards written by 17 SDOs**
- No special considerations for microreactors in any code or standard (yet)



How standards become required in practice

Voluntary Use

Company chooses to adopt a standard
Referenced in contracts or design basis

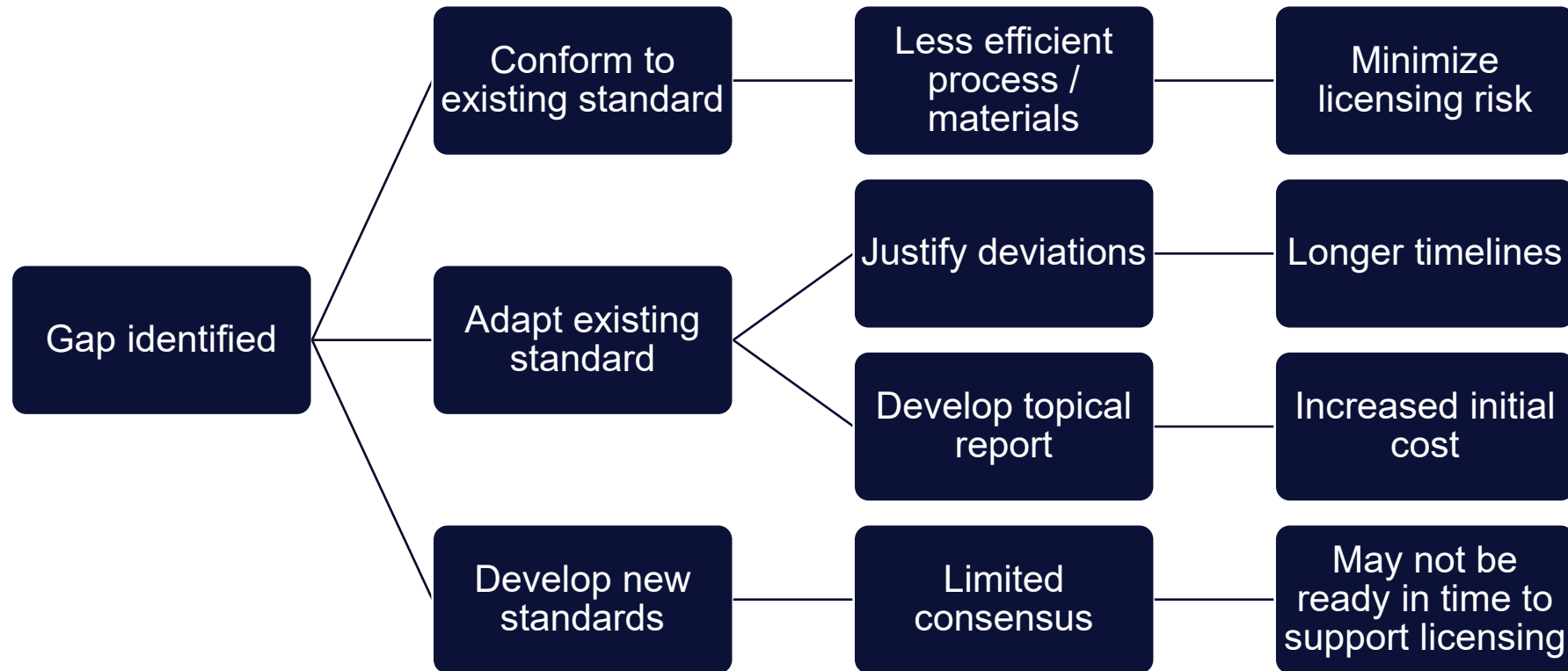
Regulatory Endorsement

NRC or agency references the standard
Used as an accepted method of compliance

Becomes Enforceable

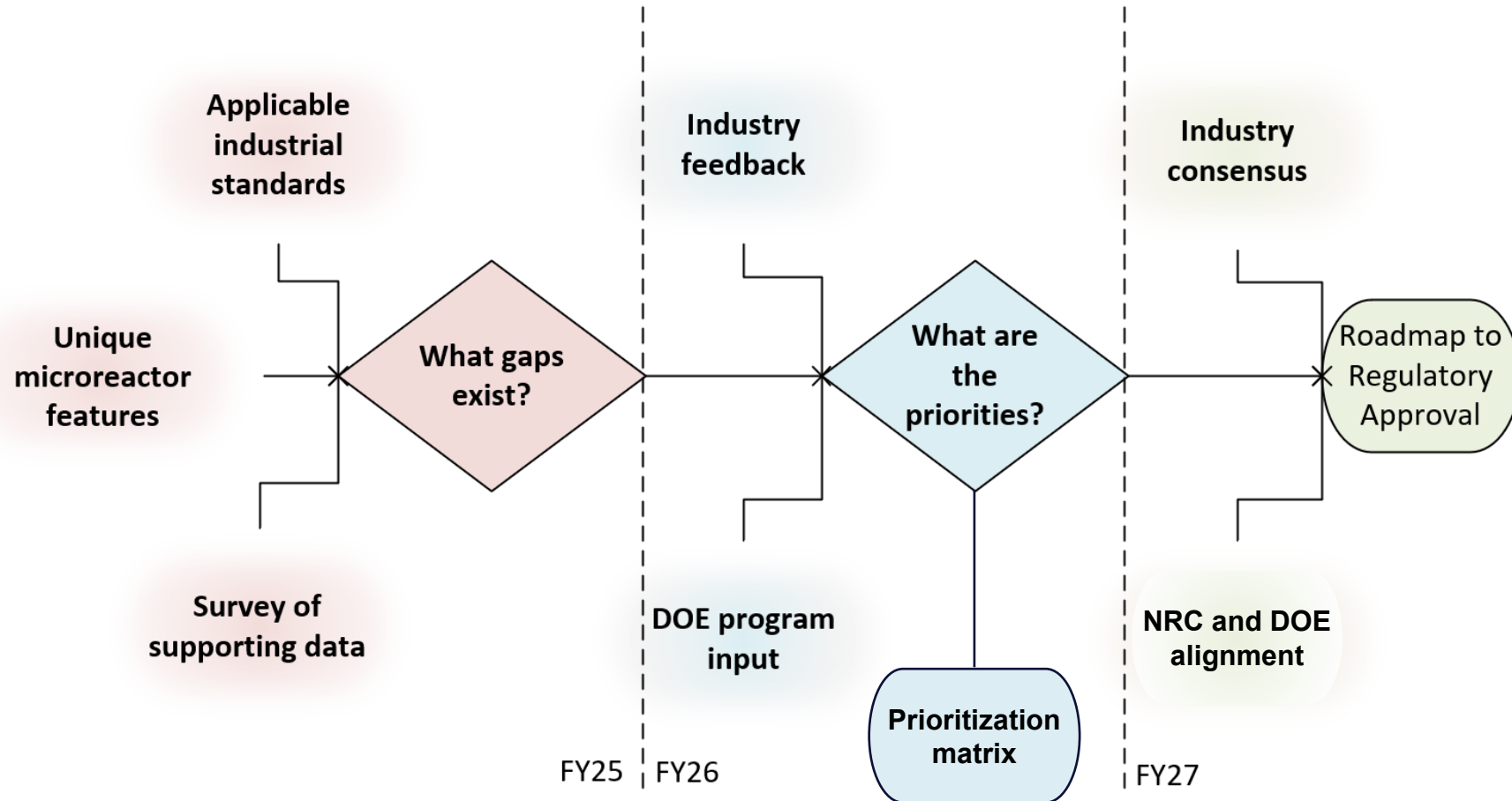
Compliance required for licensing
May affect interstate or international trade

Companies have to navigate standards gaps today



Each design decision impacts cost / timeline / efficiency / regulatory risk

This project is the first effort to identify gaps for microreactors and develop a pathway to address them



Project team



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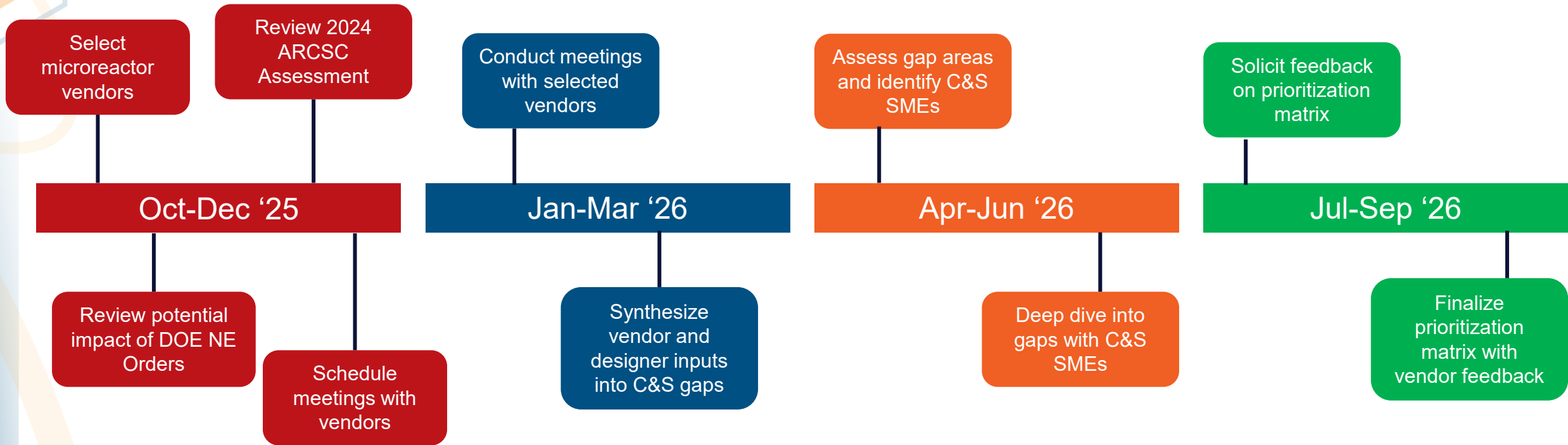
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Microreactors are unique and need special consideration

1. Small source term
2. Flexibly sited
3. Factory produced and tested
4. Mobile and transportable
5. Longer refueling cycles
5. Rapidly deployed
6. Autonomous/semi-autonomous
7. Short operational lifetimes
8. Minimal site preparation
9. Microgrid operation



Project timeline



Codes & Standards assessment: activities to date

- Internal review of codes and standards
 - **Reviewed gaps** identified by designers in publicly accessible documents
 - **Performed high-level assessment** of applicability of existing codes to microreactor technologies
 - **Consulted** with C&S experts to review the gaps identified
- External industry engagement
 - Conducted **45–60 minute structured interviews** with microreactor vendors
 - Vendors selected based on SME input, prioritizing DOE Pilot Program participants and DOE reactor teams
 - Discussions focused on specific C&S pain points, including applicability, interpretation, and **implementation challenges**
 - Ensured representation across diverse reactor technologies
 - **Captured recurring themes** to inform prioritization of future C&S modernization efforts

Internal review of codes and standards: key findings

- Existing C&S Framework Not Developed with Microreactors in Mind
 - Limited publicly available documentation that explicitly identifies C&S gaps
 - No precedent or clear non-nuclear code alternative for certain applications (e.g., transportation of a used reactor)
- Update Cycles May Not Align with Deployment Timelines
 - Update cycles can be long (e.g., ~2-3 years is most common)
 - Identified gaps may not be addressed by SDOs before first-of-a-kind deployments
- Implications
 - C&S update cycles will lag behind deployment needs
 - Greater reliance on case-by-case regulatory review
 - Diversity of microreactor designs will require a greater flexibility in C&S

External industry engagement: key themes identified

Pressure
Boundary Code
Applicability

Graded Design
Life &
Inspection

Materials
Qualification &
Benchmarking

Transportation
& Packaging
Analysis

Unique
Deployment
Configurations

Advanced
Modeling &
Validation

Pressure boundary and ASME code applicability

- Microreactor Design Context
 - Certain designs do not rely on pressure retention as the primary radiological containment function
 - Some configurations operate with equalized internal and external pressures
- Code Assumptions
 - ASME pressure boundary codes are structured around pressure-driven failure modes
 - Section III requirements assume pressure retention as a primary safety function
 - **No clearly recognized alternative pathway when pressure safety is not the primary design driver**
- Impacts
 - Unnecessary testing and analysis
 - Increased fabrication complexity
 - Potential structural overdesign
 - Added cost, schedule pressure, and licensing uncertainty

Graded design life and inspection

- Microreactor Design Context
 - Operational lifetimes of approximately 3–10 years
 - Intended replacement rather than refurbishment
- Code Assumptions
 - Existing nuclear standards assume multidecade service life
 - Inspection, in-service examination, and repair frameworks are built around long-duration operation
 - Limited support for graded approaches based on shorter operational duration
- Impact
 - Cost and licensing burdens that may be disproportionate to the risk profile of microreactor systems

Materials qualification and benchmarking

- Microreactor Design Context
 - Operation at elevated temperatures with advanced fuels and structural materials
 - Use of TRISO fuel, graphite, and novel high-temperature materials
- Current Code and Data Landscape
 - Limited code-qualified materials at microreactor-relevant temperatures
 - Insufficient benchmarking data for TRISO fuel, graphite, and advanced structural materials
 - Lack of validated cross section and thermomechanical datasets for particle fuels at higher enrichment levels
- Impact on Licensing Confidence
 - **Analysis uncertainty is a limiting factor (rather than material performance)**
 - Greater reliance on conservative assumptions
 - Extended review timelines and additional data needs

Transportation and packaging analysis

- Microreactor Design Context
 - Transportability is integral to many microreactor concepts, including use of HALEU and particle fuel
- Current Framework Limitations
 - Limited benchmark data for HALEU and particle fuel transportation
 - Transportation analysis is not well integrated with reactor safety and design decisions
 - Limited clarity on applying risk-informed approaches using existing certified packages
- Impacts
 - Increased analytical burden and regulatory uncertainty
 - Risk of late-stage redesign if transportation is not addressed early
 - Added cost and schedule exposure

Unique deployment configurations

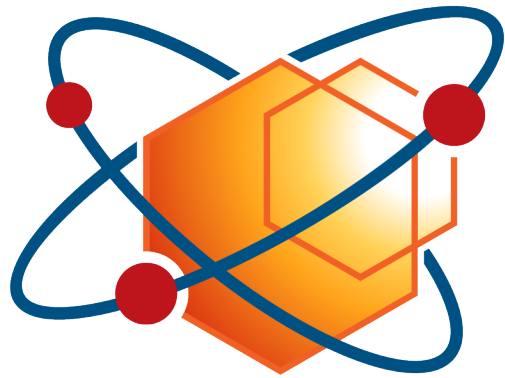
- Microreactor Design Context
 - Deployment below grade or in nontraditional structural configurations
 - Design features such as unsupported piping, limited inspection access, and single-cycle operation
- Current Code and Standards Landscape
 - Existing nuclear codes lack clear applicability for below-grade or unconventional installations
 - Non-nuclear industry standards provide partial analogs but lack nuclear-specific provisions (e.g., seismic)
 - Hybrid application of nuclear and non-nuclear codes creates compliance ambiguity
- Impacts
 - Uncertainty in regulatory treatment
 - Increased design iteration to reconcile code conflicts
 - Added cost and schedule risk due to unclear compliance pathways

Advanced modeling and validation

- Design and Regulatory Context
 - Increasing reliance on physics-based modeling and simulation to support design, safety analysis, and operational monitoring
 - Use of advanced multiphysics tools to inform licensing and performance assessments
- Current Validation and Acceptance Gaps
 - Limited validation benchmarks for coupled multiphysics codes applied to microreactor geometries
 - Lack of clearly defined acceptance criteria for digital monitoring and model-informed tools
 - Uncertainty in safety vs nonsafety classification of digital and analytical assets
- Impacts
 - Increased review scrutiny and requests for additional validation data
 - Licensing uncertainty associated with model credibility
 - Potential schedule impacts tied to tool qualification and regulatory acceptance

Next steps...

- **Align Findings with Ongoing Standards Activities (Q3 FY26)**
 - Evaluate how identified themes — pressure boundary applicability, graded design life, materials qualification, transportation, nontraditional configurations, and advanced modeling — intersect with current SDO efforts
 - Identify areas where existing codes may already provide adaptable pathways
 - Highlight gaps where coordination or targeted engagement may reduce deployment friction
- **Prioritize Critical Gaps and Outline Potential Pathways (Q4 FY26)**
 - Refine prioritization matrix across the identified technical themes
 - Distinguish near-term issues affecting first-of-a-kind deployments from longer-term modernization needs
 - Outline candidate actions for DOE and industry discussion, including data development, validation efforts, or standards engagement



MRP Microreactor
Program