INL/MIS-23-75239-Revision-0

Arizona Public Service - NRIC Overview

October 2023

Samuel Matthew Reiss

Changing the World's Energy Future

Idaho National Laboratory

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

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Arizona Public Service - NRIC Overview

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October 2023

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National Reactor Innovation Center and Advanced Reactor Development Overview

Arizona Public Service BETA

October 30, 2023

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nric.inl.gov

NRIC is a Department of Energy (DOE) program, launched in Fiscal Year 2020

NRIC National Reactor Innovation Center

NRIC Enables Nuclear Reactor Tests & Demonstrations

- Authorized by the Nuclear Energy Innovation Capabilities Act (NEICA)
  - DOE-Office of Nuclear Energy (DOE-NE); Idaho National Laboratory (INL), Nuclear Science & Technology (NS&T)
- Partner with industry to bridge the gap between research and commercial deployment
- Leverage national lab expertise and infrastructure

Vision: Enable commercial nuclear by 2030

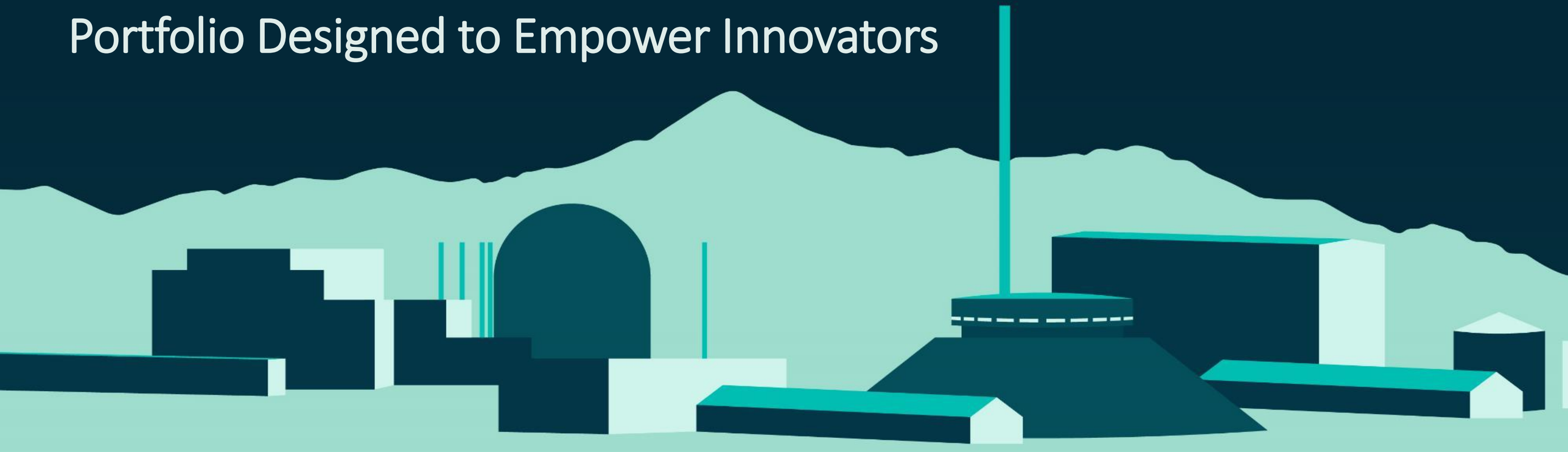
NRIC INL

Collaborative Approach

NRIC is partnering regionally and nationally to support demonstrations

NRIC INL

Portfolio Designed to Empower Innovators



- Building foundation for testing
  - Advanced Reactor Test Beds
  - Experimental Facilities
  - Virtual Test Bed
- Addressing Costs & Markets
  - Advanced Construction Technologies
  - Digital Engineering for Nuclear
  - Maritime Applications

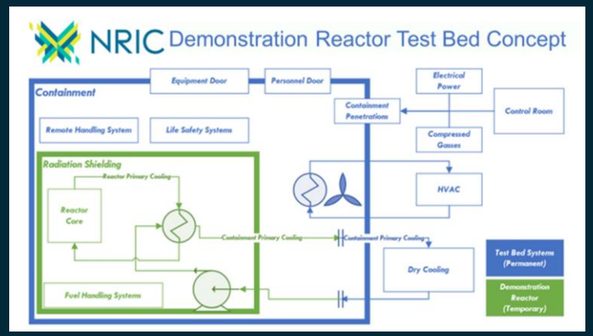
NRIC INL

NRIC Testbed Strategy

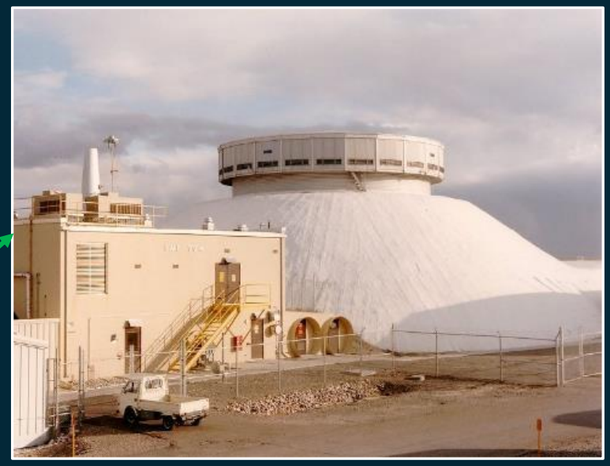
NRIC-DOME Testbed

Materials & Fuels Complex at INL

- EBR-II Operated from 1964 to 1994
  - 62.5 MW thermal
- Repurposing EBR-II as NRIC-DOME
  - <20MW$_{th}$ <20% enriched fuels
  - Final design complete
  - Construction begins 2023
  - First user expected 2026



NRIC-LOTUS Testbed

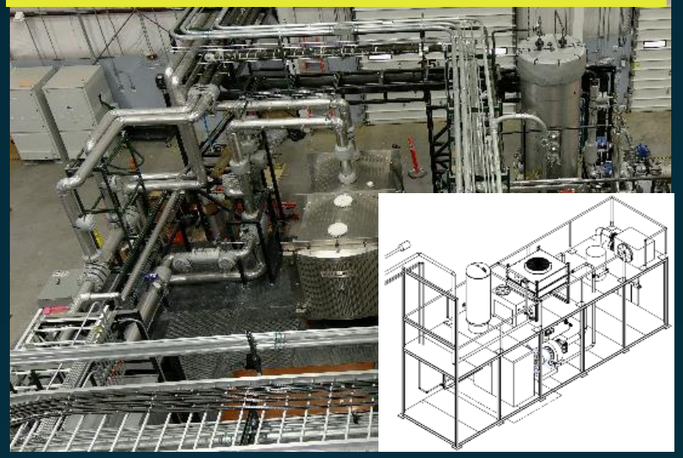


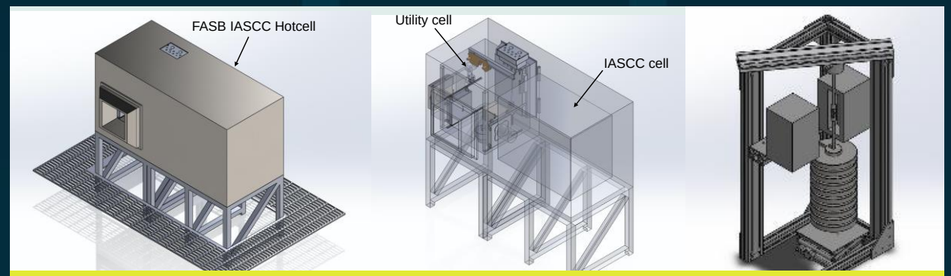
- ZPPR Operated from 1969 to 1990
  - Used for transuranic and enriched-uranium material inspection/repackaging and experiments
- Repurposing ZPPR Cell as NRIC-LOTUS Testbed
  - Small KWth reactors
  - >20% enriched fuels
  - Conceptual design phase complete
  - Preliminary/Final Design Initiated
  - First user expected 2027/2028

NRIC INL

NRIC Experimental Infrastructure

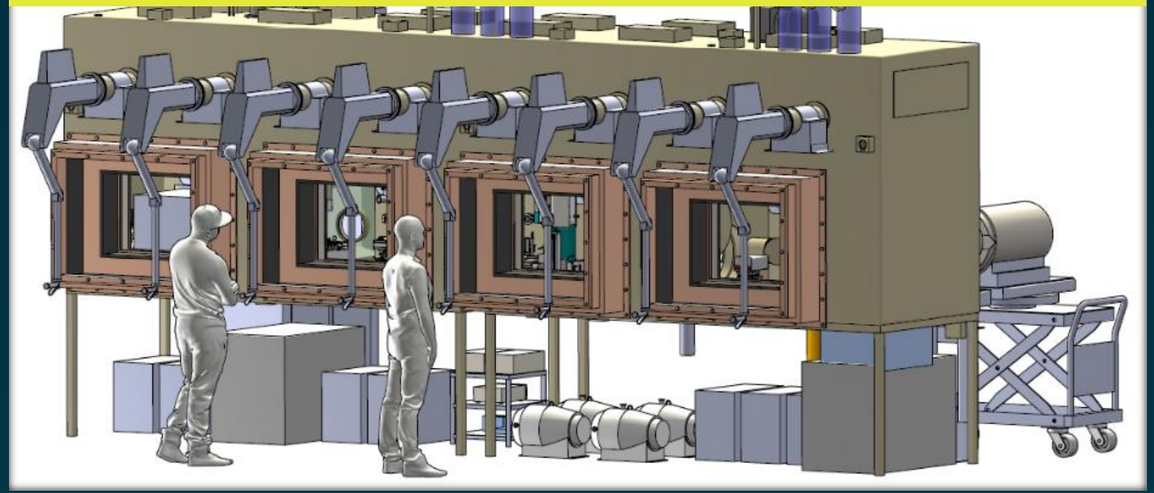
Helium Component Test Facility [*2022*]





In-Hot Cell Thermal Creep Frame [*2025*]

Molten Salt Thermophysical Examination Capabilities (MSTEC) [*2024*]

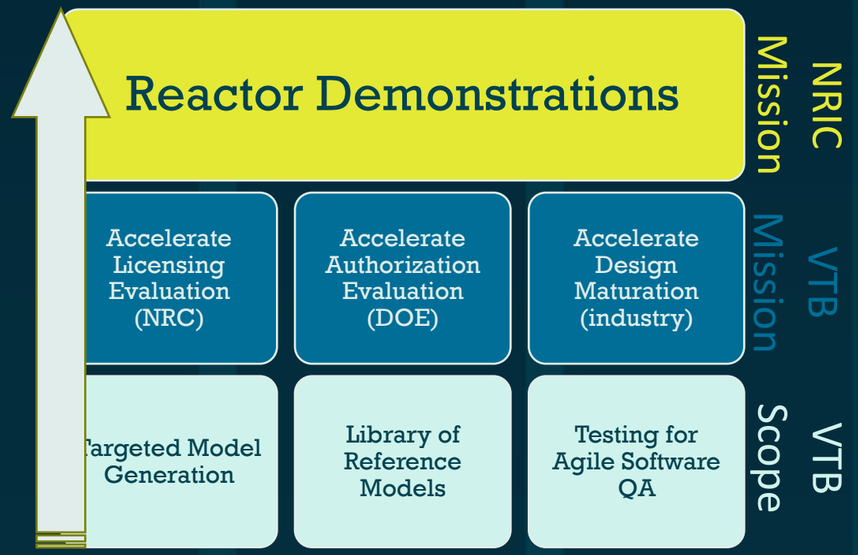


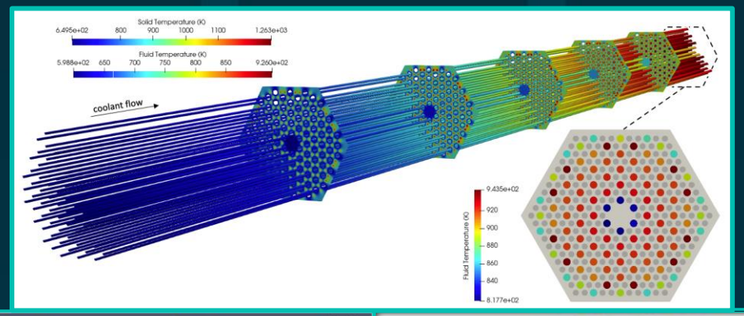
Mechanisms Engineering Test Lab (METL) [Operating]

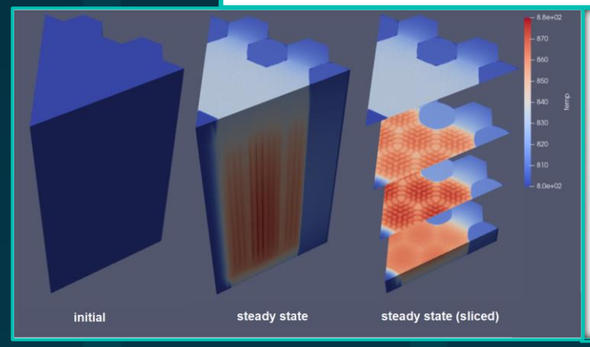
NRIC – Virtual Test Bed (VTB)

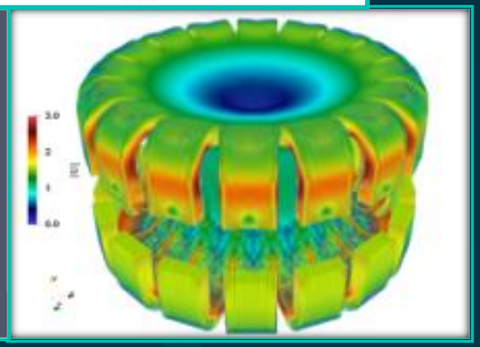
- Central location for reactor developers/stakeholders to access & leverage state-of-the-art ModSim models of advanced reactors to evaluate performance & safety
- Cross-laboratory and cross-program collaboration between NRIC and DOE Nuclear Energy Advanced Modeling and Simulation (NEAMS) program
- Repository/library of simulations for: sodium, gas, lead, micro, and molten salt reactors (continuously tested)
- Currently hosting 35+ distinct models with 12 NEAMS codes showcases… **More coming soon!**
- Averaging ~250 visits/month (period between July-Sep 2023) – representation from Industry/Regulators/Academia

Providing access to INL's mod/sim work and accelerating reactor development process



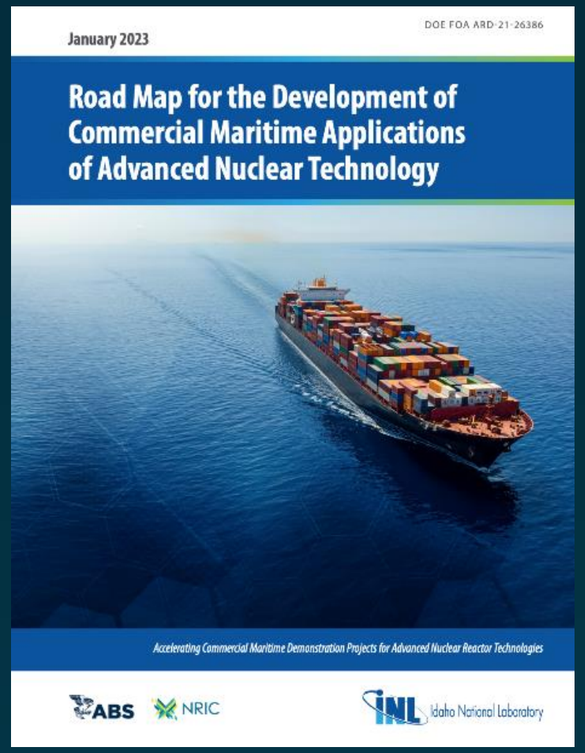


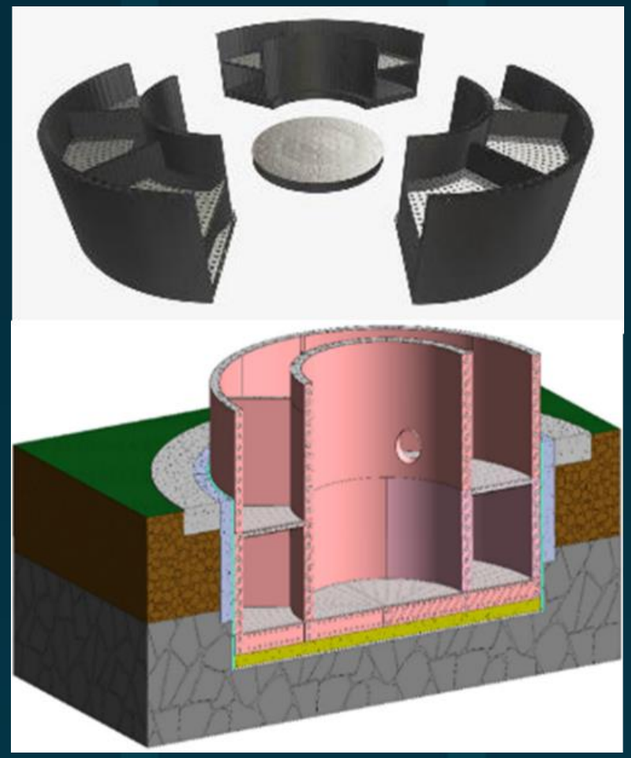




Addressing Cost and Markets

- Advanced Construction Technologies
- Digital Engineering & Knowledge Sharing/Lessons Learned
- Demonstration/Deployment Opportunities (Maritime)

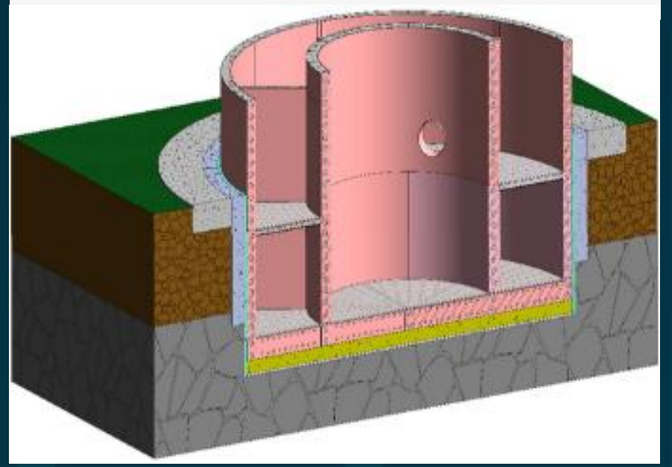




NRIC INL

Advanced Construction Technology

- Project Awarded – January 2022
- Team - General Electric Hitachi
  - Electric Power Research Institute (EPRI), Black & Veatch, Purdue, University of North Carolina at Charlotte (UNCC), Nuclear Advanced Manufacturing Research Centre (NAMRC), Caunton Engineering w/ Modular Walling Systems Ltd and Tennessee Valley Authority
- Purpose - demonstrate technologies to:
  - Reduce the cost of new nuclear builds by >10 percent
  - Speed the pace of advanced nuclear deployment
- Two phase project with demonstration in FY-2024/25
  - Vertical shaft excavation techniques
  - Steel Bricks™
  - Advanced monitoring & digital twin technology



NRIC INL

Steel Bricks is a trademark of Modular Walling Systems Holdings Limited

Steel Brick™ Concept

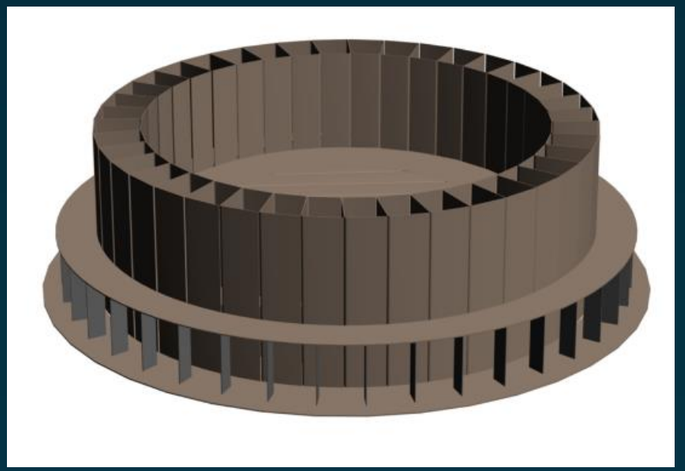
Next generation Steel Concrete Composite modules, for Seismic Category 1 structures installed in a radial configuration

Steel Brick™ Fabricated at Shop

Concurrent wall fab and excavation
Reduced schedule duration

Steel Brick™ Modules
Shipped to site

Reduced onsite work
Improved quality
Less rework



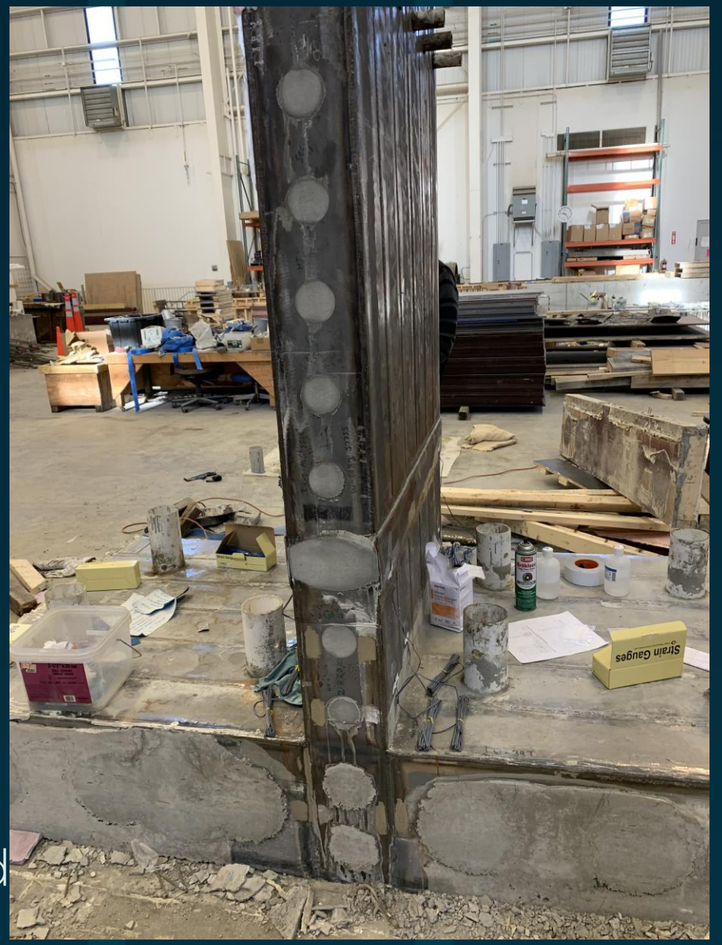
Assembled in field, outside of pit, lowered into pit

NRIC INL

Digital Twin – Advanced Construction

- State of the art replica of the structure to integrate sensor data, artificial intelligence, machine learning, and data analytics. Cradle to grave monitoring
- EPRI, UNCC, Nuclear AMRC
- Organizes all project data by component and by life-stage
  - Each module with its own rich information, models and sensors
    - Flow of information through the modules - Back and Forth
    - Ability to query, investigate, assess conditions of individual Steel Bricks™ in the structure.
  - Semi-automated procedures to update Building Information Modeling & Finite Element Analysis models from field measurements
  - Long-term monitoring combining structural models with:
    - Earth pressure sensors (lateral stress)
    - LiDAR scans of base, shaft walls and ground surface
    - Procedures to stream data from the field for real-time decision-making via wireless transmission of sensor data

NRIC INL



- Steel Brick™ prototypes at Purdue from Caunton Engineering/Aecon.
- Filled with Concrete and imperfections for Stress Testing and Non-Destructive Examination
- Measure strength of splices/connections - generate data for digital twin and regulator acceptance as containment application

NRIC INL

Benefits of Testing & Demonstration

- Bridge the gap between development and commercialization
  - Mature technology readiness and reduce risks to participants for first of a kind build
  - Facilitate partnership between technology developers, end users, national labs, universities, regulators, industrial participants
- ‘Learn by doing’ reduces risks associated with first commercial build
  - Identify materials standardly available
  - Optimize design
  - Establish procedures
  - Sequencing of operations
- Builds confidence with regulators
- Develops supply chain
- Extends national footprint of INL

NRIC INL

NRC Collaboration

- Congress recognized the importance of agency coordination in the Nuclear Energy Innovation Capabilities Act
- DOE/NRC Memorandum of Understanding (MOU) to “coordinate DOE and NRC technical readiness and sharing of technical expertise and knowledge on advanced nuclear reactor technologies and nuclear energy innovation, including reactor concepts demonstrations, through the [NRIC].”
  - NRIC Rotations
- Monthly Coordination Calls – DOE/NRC/NRIC

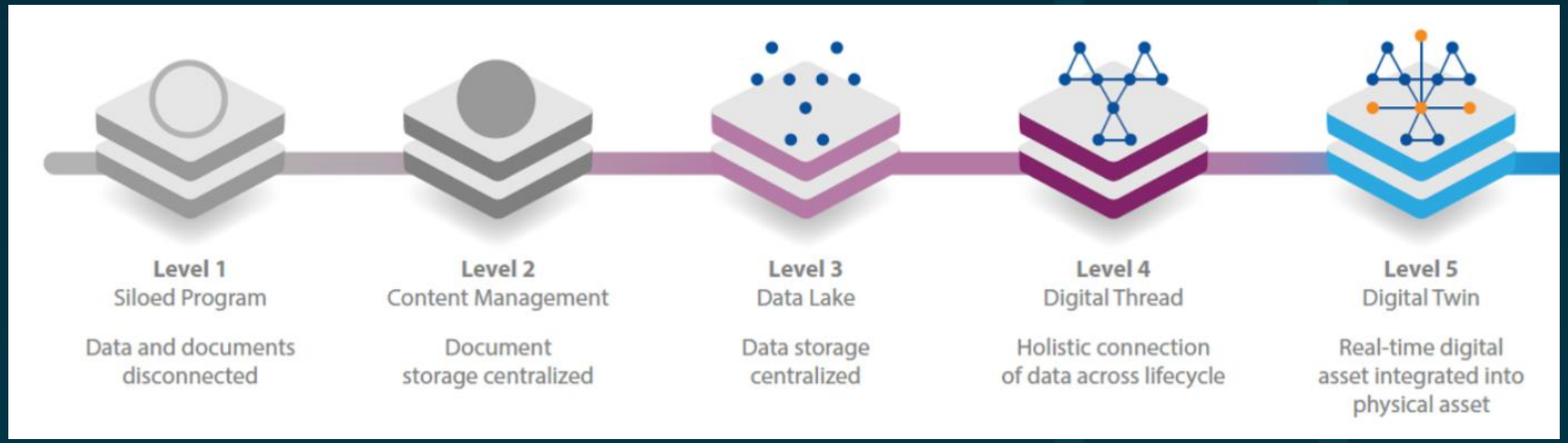
Fred Sock
Office of Nuclear Regulatory Research

Allen Fetter
Office of Nuclear Reactor Regulation

NRIC INL

NRIC Systems/Digital Engineering Overview

- Holistic approach to the design of a complex system:
  - Design using models/data instead of documents
  - Integration of data across models to realize significant risk reduction on project cost and schedule
  - Applying state-of-the art Model Based Systems Engineering Tools from requirements engineering through design, construction, and operations
  - NRIC-DEN (Digital Engineering for Nuclear) sharing this tool set architecture with industry partners and others to facilitate cost reductions and improve advanced reactor deployment



NRIC INL

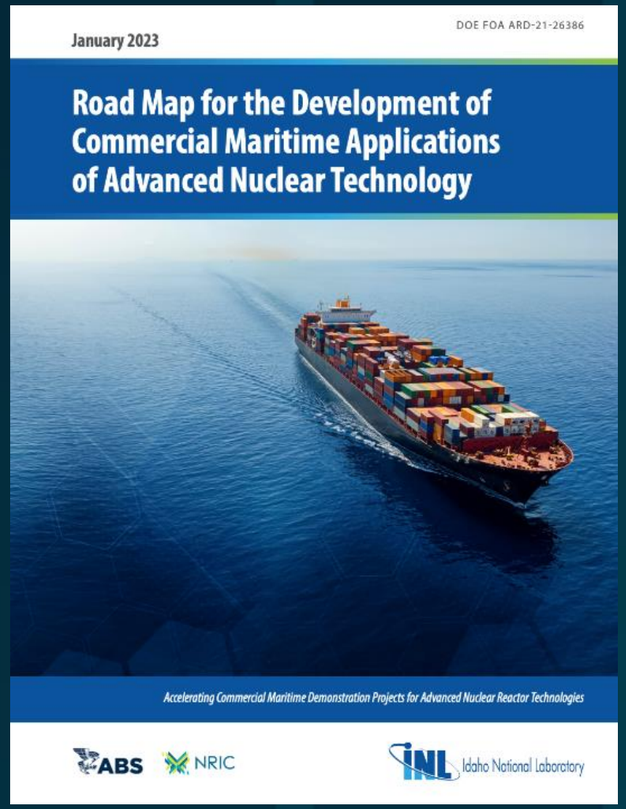
Evaluating Maritime Applications
NRIC & American Bureau of Shipping (ABS)

Maritime Nuclear Application Group

- Collaboration with ABS and Morgan & Lewis Law Firm to establish a forum for the maritime and nuclear energy sectors to demonstrate advanced nuclear technologies
- Identifies domestic and international legal and regulatory hurdles, catalogs and share relevant information resources, and collaborates with global stakeholders
- 100+ members representing 40+ domestic/international companies from nuclear, shipping, and oil/gas industries including:
  - Westinghouse, NuScale, BWXT, NEI, Shell, NRC, US Coast Guard, etc.
- Conducting assessment of experimental and testing gaps to fill

Industry FOA Award 2022 - ABS Accelerating Commercial Maritime Demonstration Projects for Advanced Nuclear Reactor Technologies System

- Develop roadmap for maritime application test/demonstration projects
- Reconcile maritime and nuclear licensing and conduct a regulatory gap analysis
- Develop business cases & 2050 market potential for nuclear-marine applications

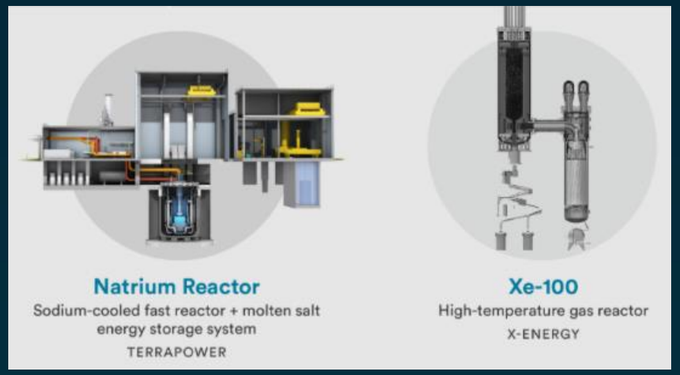


NRIC INL

INL Participation in ARDP Projects

- 9 projects supported
- Scope range
  - Modeling & Simulation
  - Irradiation & PIE
  - Fuel design & fabrication
- ~$175M – 7 years
  - $1M - $75M per project
- NRIC coordinates the ARDP work done at INL
- NRIC Deployed Digital Engineering and project management tools

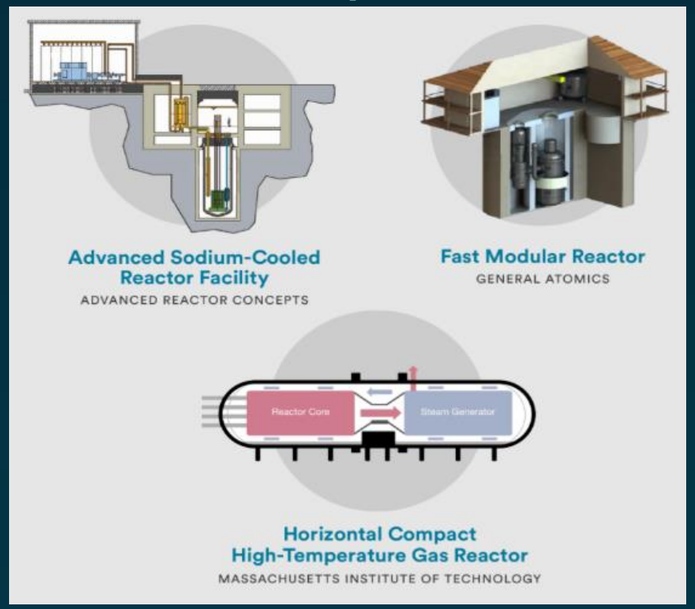
Demonstration



Natrium Reactor
Sodium-cooled fast reactor + molten salt energy storage system
TERRAPOWER

Xe-100
High-temperature gas reactor
X-ENERGY

Concept Development

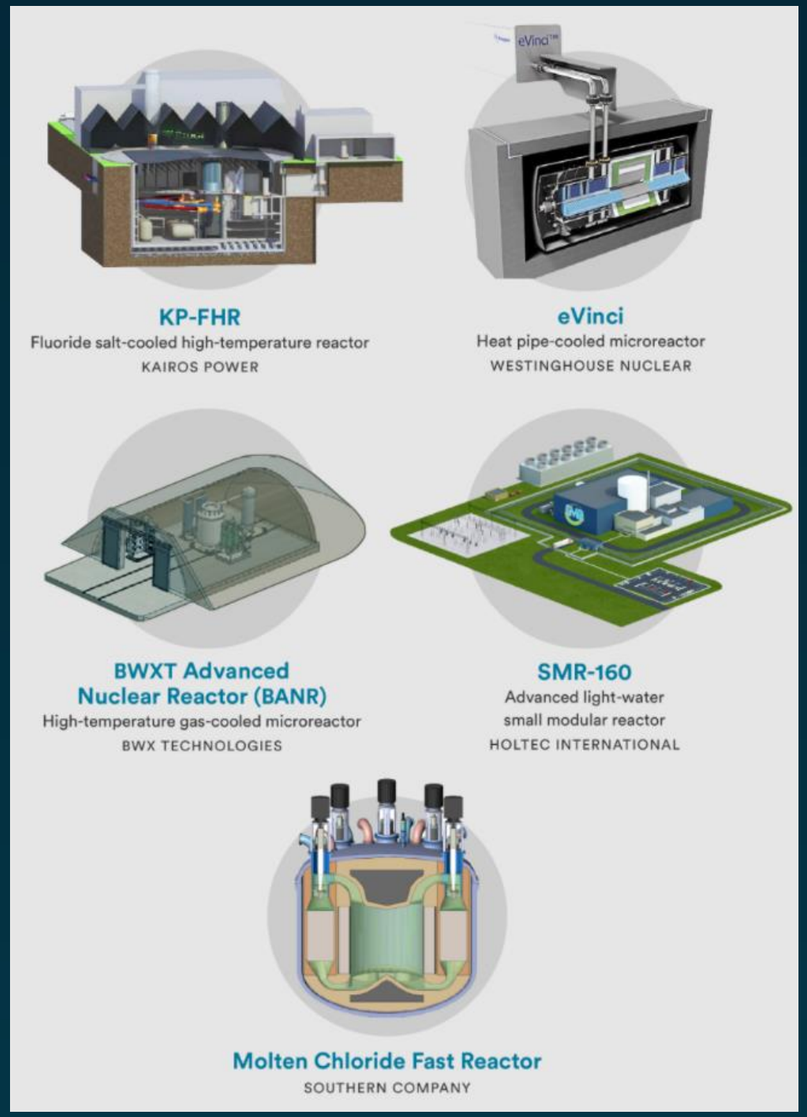


Advanced Sodium-Cooled Reactor Facility
ADVANCED REACTOR CONCEPTS

Fast Modular Reactor
GENERAL ATOMICS

Horizontal Compact High-Temperature Gas Reactor
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Risk Reduction



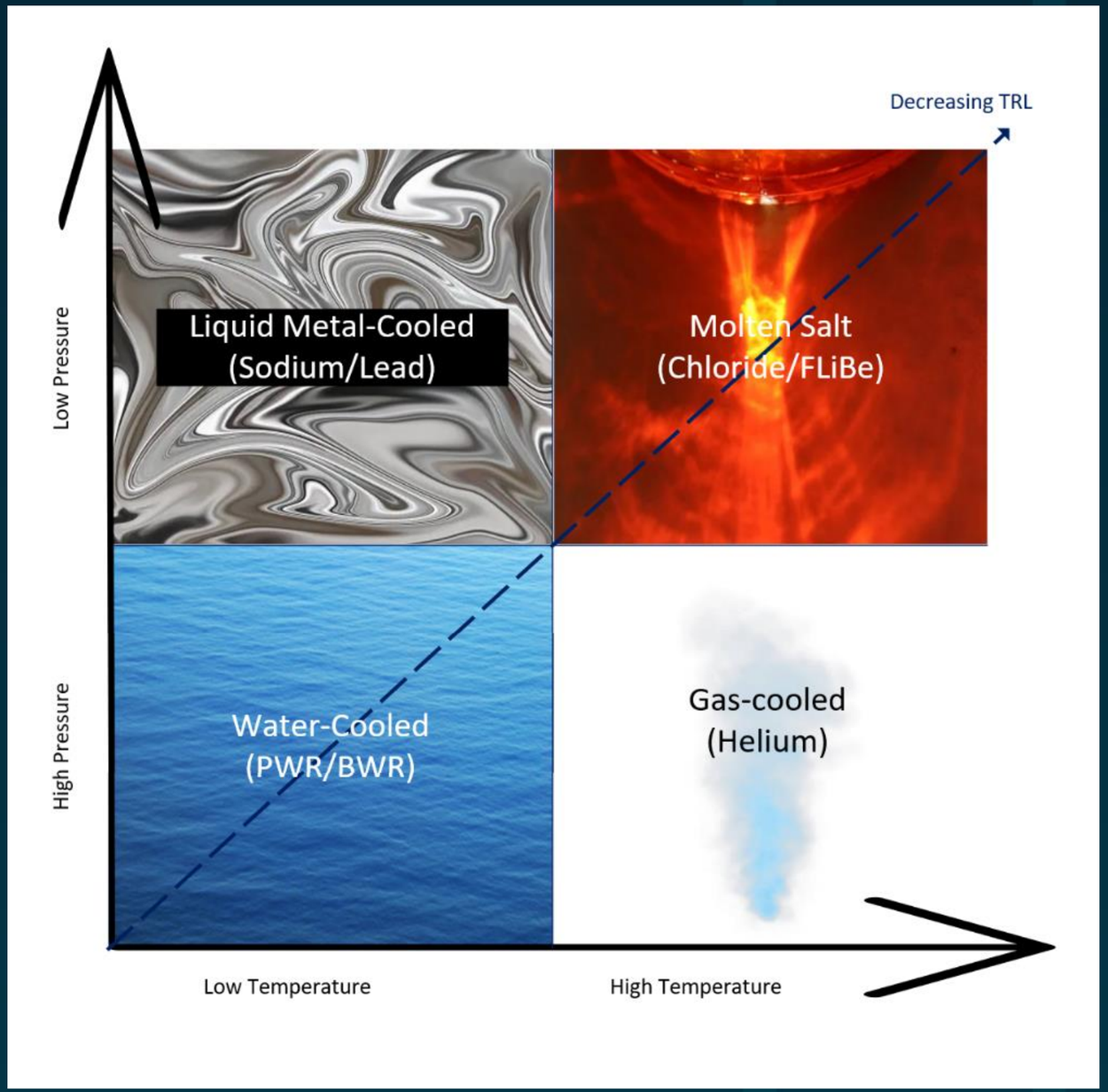
KP-FHR
Fluoride salt-cooled high-temperature reactor
KAIROS POWER

eVinci
Heat pipe-cooled microreactor
WESTINGHOUSE NUCLEAR

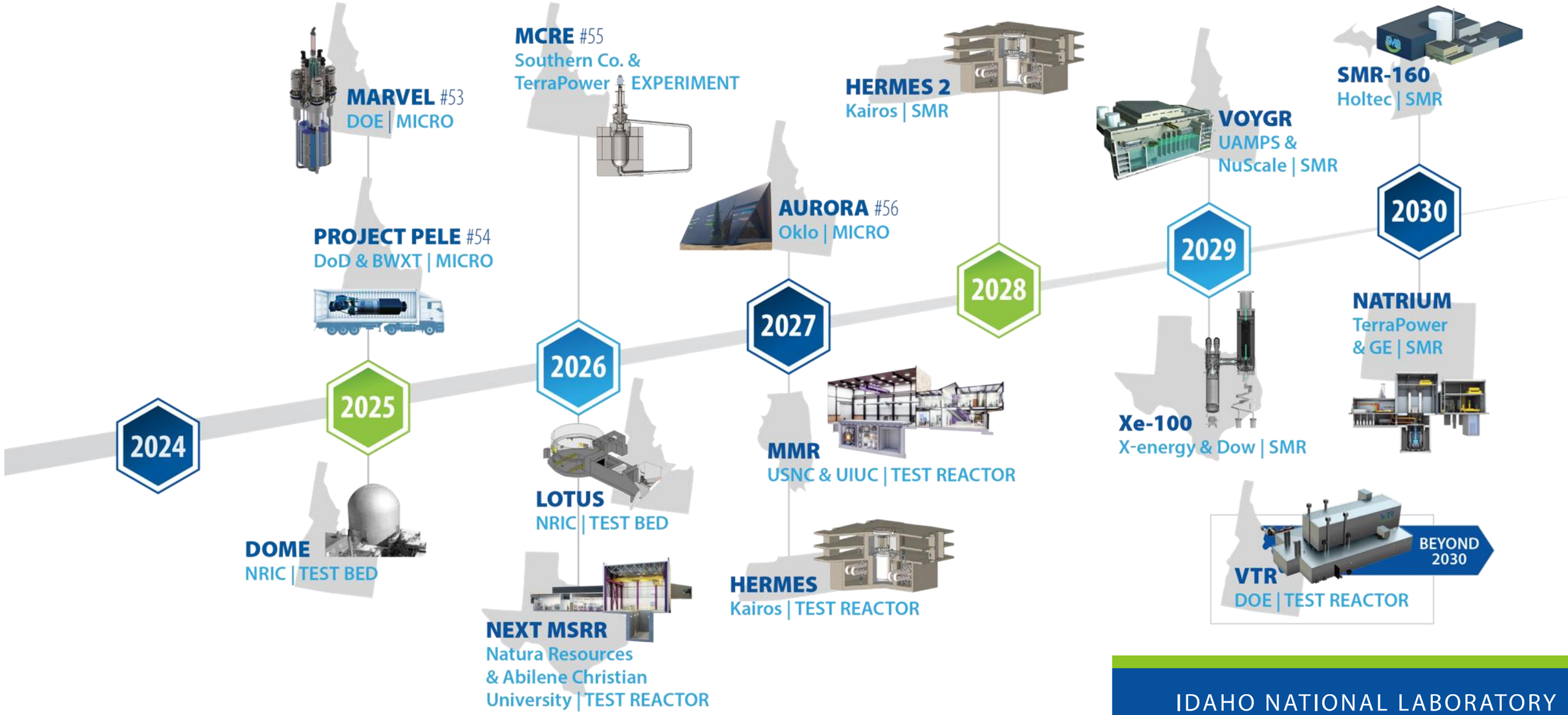
BWXT Advanced Nuclear Reactor (BANR)
High-temperature gas-cooled microreactor
BWX TECHNOLOGIES

SMR-160
Advanced light-water small modular reactor
HOLTEC INTERNATIONAL

Molten Chloride Fast Reactor
SOUTHERN COMPANY


Decreasing TRL
Low Pressure
High Pressure
Liquid Metal-Cooled
(Sodium/Lead)
Molten Salt
(Chloride/FLiBe)
Water-Cooled
(PWR/BWR)
Gas-cooled
(Helium)
Low Temperature
High Temperature

Accelerating advanced reactor demonstration & deployment



Companies NRIC works to support include:

- Terrapower
- X-energy
- Kairos
- BWXT
- Oklo
- Holtec
- ARC Clean Energy
- General Atomics
- Micronuclear
- Radiant
- GE-Hitachi
- CorePower
- Westinghouse
- USNC
- GERA
- Aalo

NRIC INL

NRIC's National Footprint

NRIC National Reactor Innovation Center