INL/MIS-25-84504-Revision-0

Nuclear Science & Technology Directorate: Creating a Secure & Resilient Energy Future

April 2025

Simon M Pimblott

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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Idaho Falls, Idaho 83415

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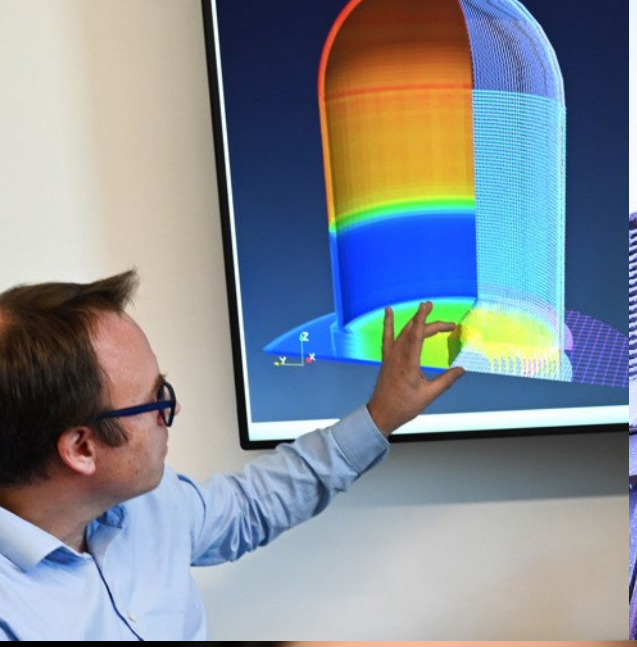
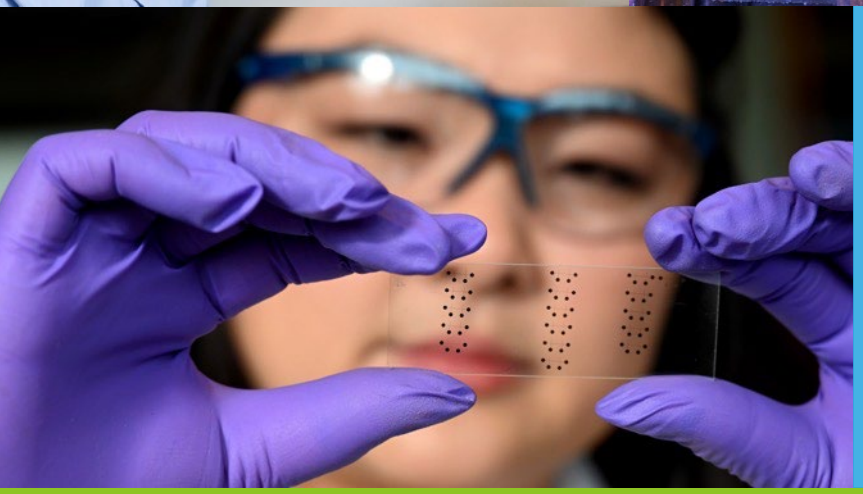


24 April 2025

Simon Pimblott, M.A., D. Phil., F.R.S.C.
Chief Scientist
Nuclear Science & Technology



Nuclear Science & Technology Directorate: Creating a Secure & Resilient Energy Future

Battelle Energy Alliance manages INL for the
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Idaho National Laboratory


INL
Idaho National Laboratory
Changing the World's Energy Future
www.inl.gov
ENTERING

Enabling energy dominance and security through research, development, and demonstration

VISION

To change the world's energy future and secure our nation's critical infrastructure.

MISSION

To discover, demonstrate and secure innovative nuclear energy solutions, other clean energy options and critical infrastructure.

Our Heritage: *The National Reactor Testing Station drove nuclear innovation in the U.S. and around the world*

1st Nuclear power plant

U.S. city to be powered by nuclear energy

Submarine reactor tested; training of nearly 40,000 reactor operators until mid-1990s

Mobile nuclear power plant for the army

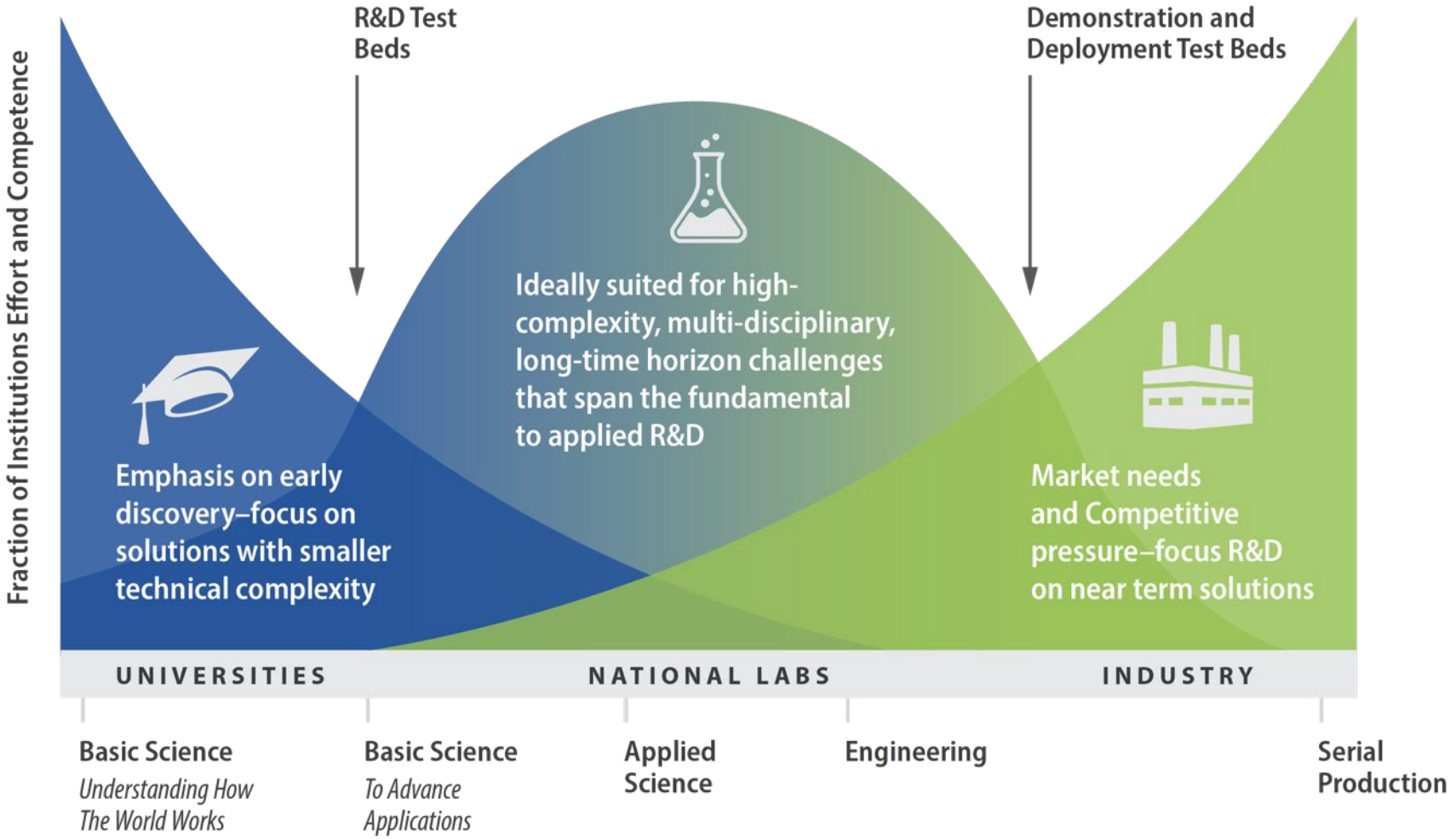
Demonstration of self-sustaining fuel cycle

Basis for LWR reactor safety

Aircraft and aerospace reactor testing

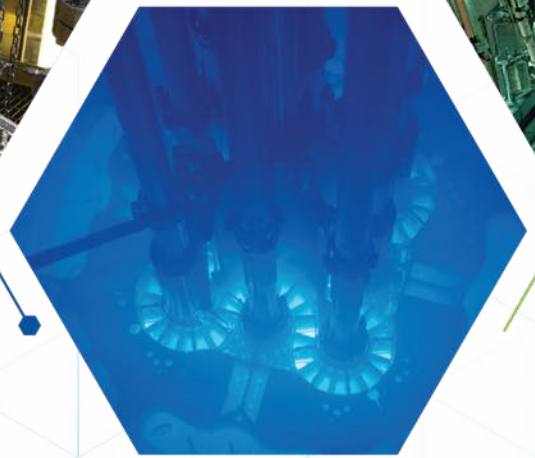
Materials testing reactors

DOE labs support the entire technology lifecycle



Creating an abundant, affordable, secure, resilient energy future

Nuclear Science & Technology



Advanced Test Reactor Complex

Materials and Fuels Complex

Energy & Environment Science & Technology

National & Homeland Security Science & Technology

WE ARE ATR

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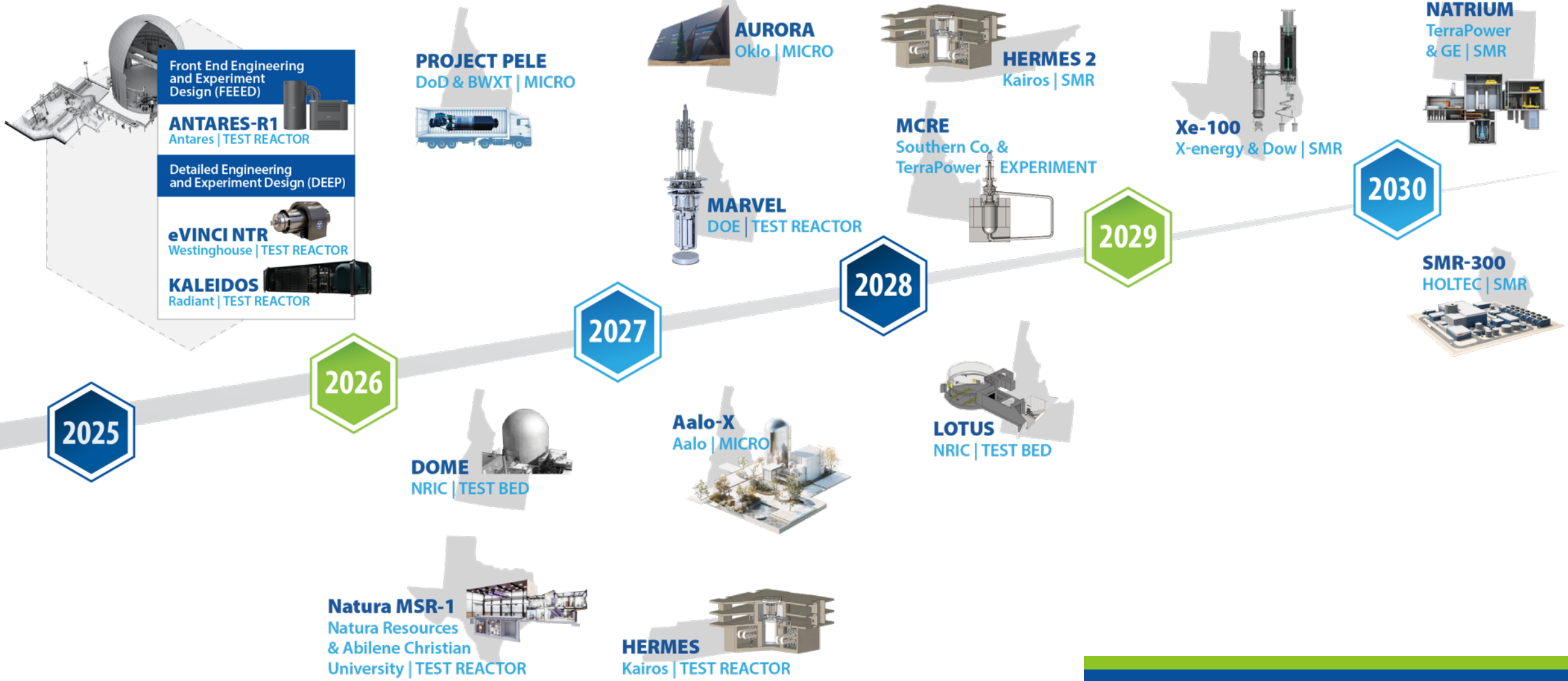
INL Idaho National Laboratory

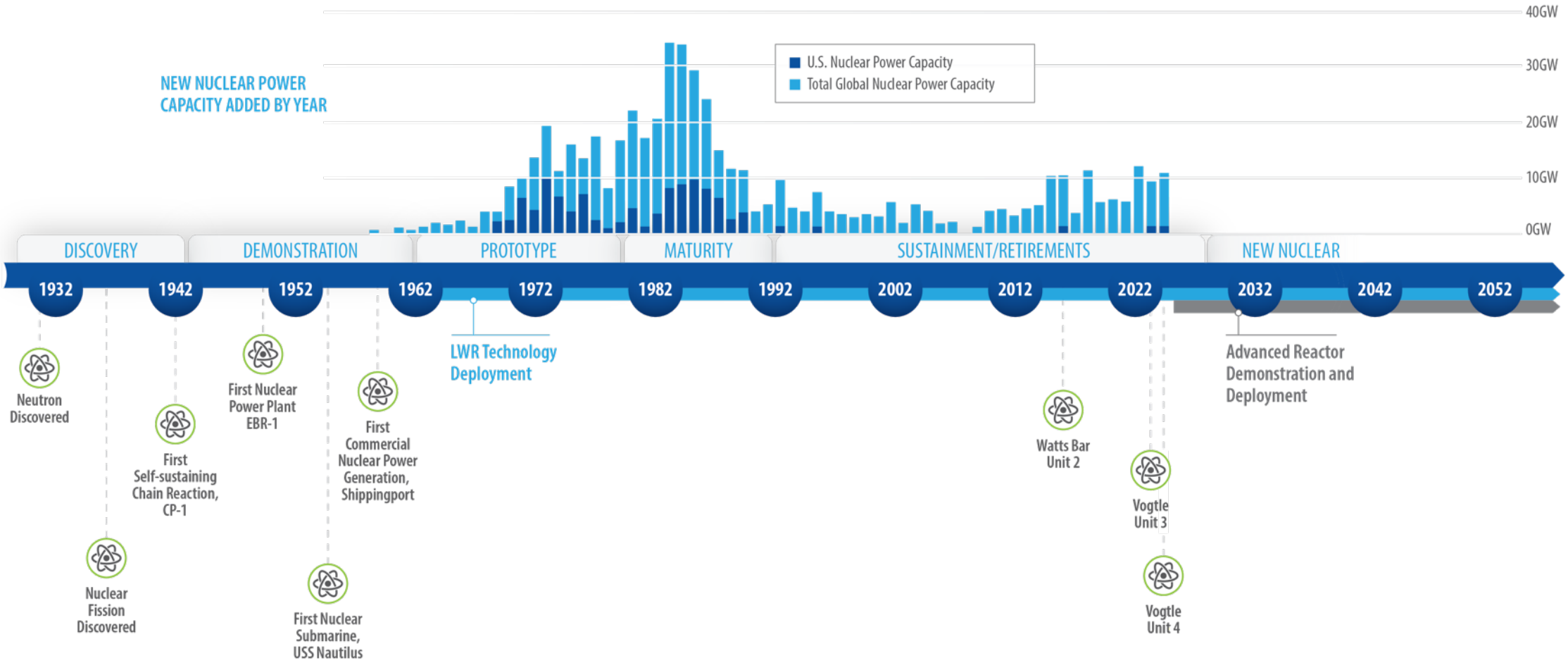
MFC

Idaho National Laboratory

Accelerating advanced reactor demonstration and deployment

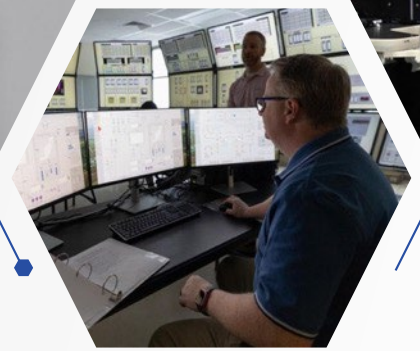


Economic prosperity and global competitiveness demand a dramatic, rapid expansion of nuclear



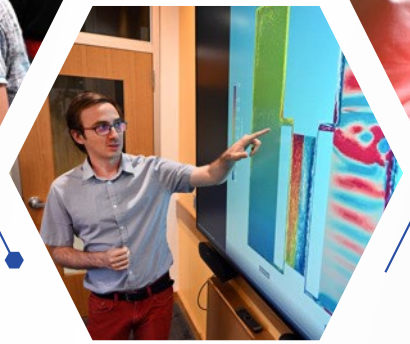
Sustaining the existing commercial reactor fleet and expanding deployment of nuclear energy

Advanced reactor technologies



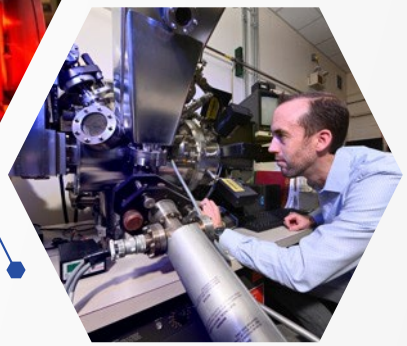
Regulatory and safety research

Fuel cycle and separations



Advanced modeling and simulation

Nuclear fuels and materials



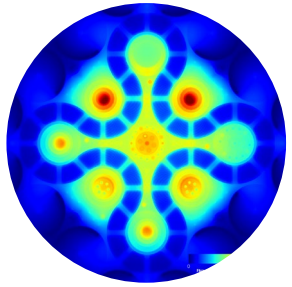
Fusion Energy

NSUF Nuclear Science User Facilities | GAIN Gateway for Accelerated Innovation in Nuclear | NRIC National Reactor Innovation Center

Reactor Systems Design & Analysis

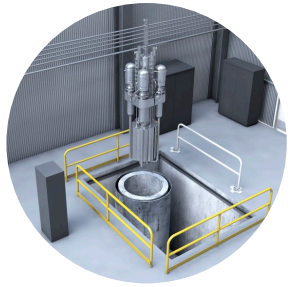
- Supporting analysis into reactor core design, physics, thermal hydraulics, irradiation experiment analysis, digital reactor technology development and integrated energy markets.

Capabilities



Reactor physics, core analysis, design & modeling

Irradiation experiment neutronics & thermal design & analysis



Design, development & testing of microreactors & integrated energy system experimental facilities

Systems analysis & economics

Nuclear Safety and Regulatory Research

Ensuring the nation's safe & sustainable use of complex systems by leveraging risk, reliability, & operational performance.

Capabilities

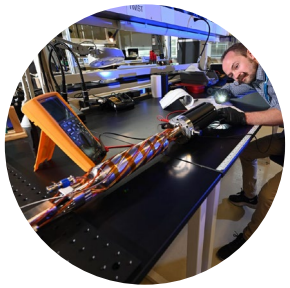
Advanced computer science, visualization & data

Risk & decision sciences

Nuclear engineering

Systems engineering & integration

Cyber & information sciences



User facilities & advanced instrumentation

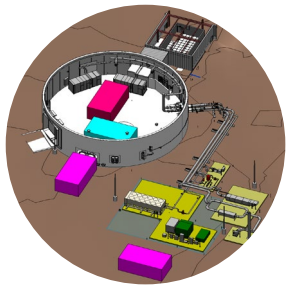
Power systems & electrical engineering

Licensing & regulations

National Reactor Innovation Center

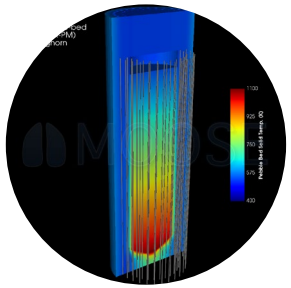
Partnering with industry and national labs to bridge the gap between research, development, and technology deployment; a national program located at INL

Capabilities



Advanced reactor testbeds

Experimental facilities



Virtual Test Bed

Engineering & experiment design expertise

Advanced construction technologies

Digital engineering for nuclear

Siting & regulatory support

Maritime demonstration

Fuel Cycle Science & Technology

Supporting solutions for the integrated nuclear fuel cycle, critical materials recovery, national security and space-related applications.

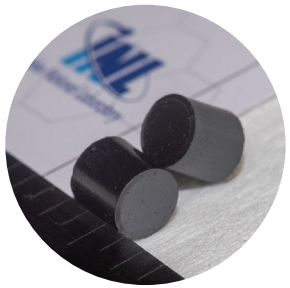
Capabilities

Radiation/actinide chemistry

Molten salt thermophysical properties & chemistry

Critical materials recovery/separation

Pyrochemical processing of oxide/metal fuel



HALEU conversion

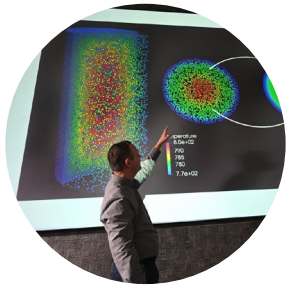
Used nuclear fuel transportation, packaging, & interim storage

Scientific Computing & AI

Supporting solutions for the integrated nuclear fuel cycle, critical materials recovery, national security and space-related applications.

Capabilities

Multiphysics frameworks and tools



Nuclear Computational Resource Center

AI/ML, data science, and visualization expertise

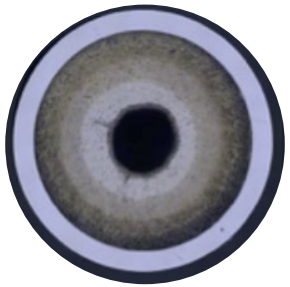
Supercomputers

Nuclear Research Data System

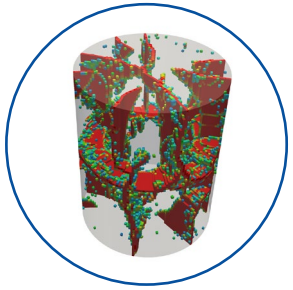
Nuclear Fuels and Materials

- Accelerating the development and qualification of nuclear fuels and materials.

Capabilities

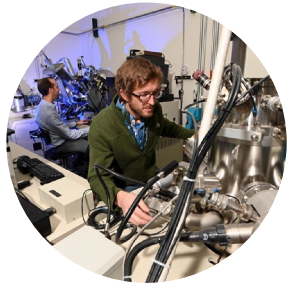


Nuclear fuels/materials development and qualification



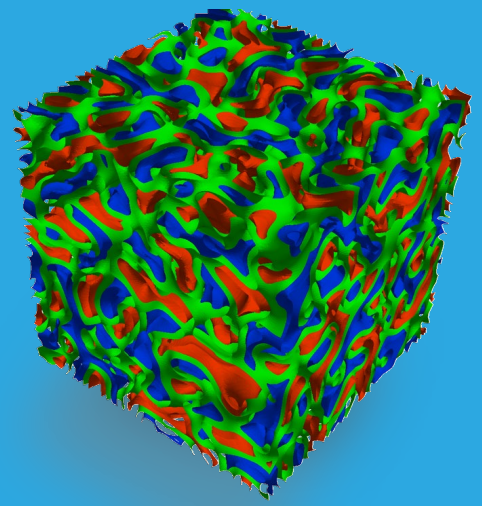
Mechanistic, multiscale modeling of fuels and materials under irradiation

Irradiation experiment design and testing in ATR and TREAT



Tritium transport/interaction with materials

Development of sodium-free metallic fuels



Modeling of microstructure evolution of nuclear fuels under irradiation using MARMOT

Lab Initiative: Enabling the Tripling of Nuclear Power by 2050

Goal:

- Triple U.S. commercial deployment of nuclear power by 2050 ensuring energy security.

Barriers:

- Finance - upfront costs, budget overruns.
- Generation – base-load vs load following, electrons and beyond
- Delivery - project delays, supply chain limitations and regulation.
- Sustainability – fuel supply, waste management, addressing proliferation concerns

US nuclear capacity has the potential to triple from ~100 GW in 2024 to ~300 GW by 2050

Pillar 1: Increase Nuclear Capacity to Ensure Energy Security.

Sustaining the Economics and Increasing the Life of the Current Fleet.

Technologies for Designing, Developing and Demonstrating Advanced Reactors.

Enabling Risk-informed Deployment of New Nuclear Plants.

Pillar 2: Realize Sustainable and Flexible Fuel Cycle Solutions

Developing and Demonstrating a Sustainable Front-end to Back-end Fuel Cycles.

Taking Fuel and Legacy Materials Management from Concept to At-scale Demonstration.

Developing Agile Instrumentation and Detection Technologies to Address Proliferation Risk Concerns

Pillar 3: Develop and Demonstrate Advanced Technology Fuels for Current and Advanced Concept Reactors

Moving Advanced Fuel Fabrication from Benchtop to Scale.

Designing Economic Recycled Fuel Fabrication.

Achieving the Promise of Advanced Fuels: Ceramic and Metallic Fuels and Fuel Salts.

Designing New Fuel Forms with Disposal in Mind.

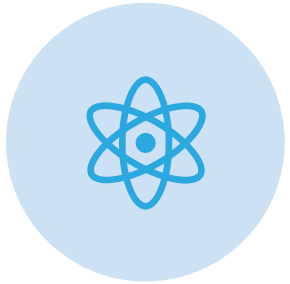
Pillar 4: Change the Build Paradigm for Nuclear Energy Systems

Deploying Advanced Manufacturing Technologies.

Implementing Factory-based Commercial Construction.

Implementing New Approaches to Instrumentation and Controls to Enable Remote and Autonomous Operation.

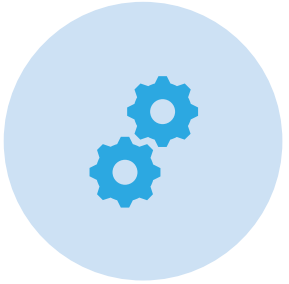
Advance the Mechanistic Prediction of the Performance of Nuclear Energy Systems.



Understanding Degradation Processes at the Level of the Electron, Atom and Molecule.

Improving Materials Performance in Harsh Environments

Developing High-fidelity Modeling and Simulation Methodologies.

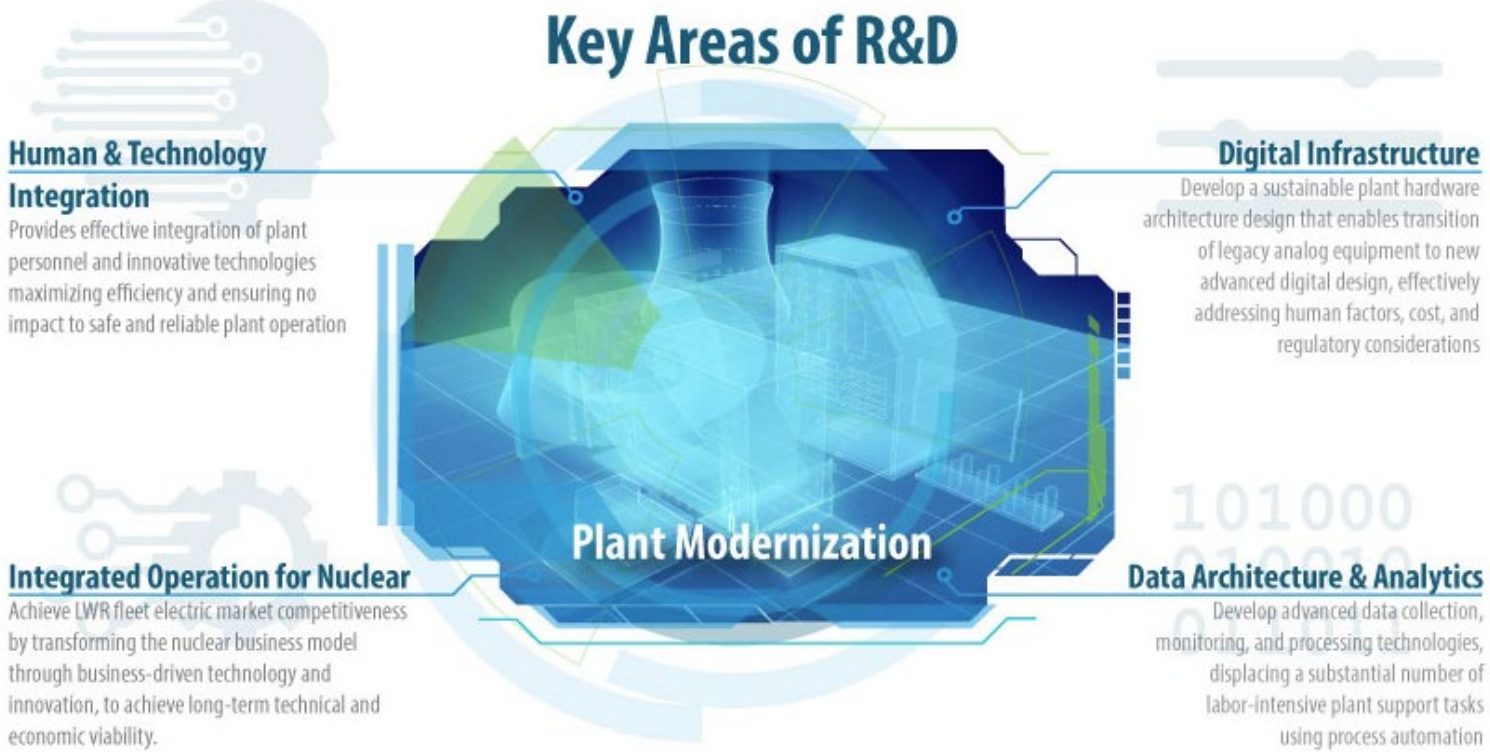


Enabling Challenge: Next-level Coupling of Test Design, Measurement, Data Analysis, and Modeling

Light Water Reactor *Sustainment*

Modernize Fleet

INL Human Systems Simulation Laboratory
Task Analysis Workshop



Nuclear H_2 Demonstration Projects

2023

Constellation: Nine-Mile Point NPP (~1 MWe LTE)

2023–2024

Energy Harbor: Davis-Besse NPP (~1–2 MWe LTE)

~2024

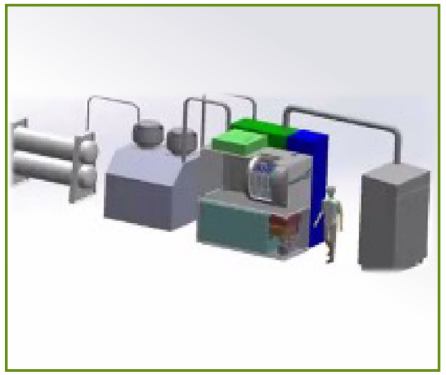
Xcel Energy: Prairie Island NPP ~150 kWe steam

*Thermal & Electrical Integration (*High-temperature steam electrolysis/ Solid oxide electrolysis (SOEC))

~2024

APS/Pinnacle West Hydrogen: Palo Verde Generating Station (~15–20 MWe LTE)

H_2 Production for Combustion and Synthetic Fuels



FuelCell Energy: Demonstration at INL (250 kW)

Nuclear energy and SOEC

Improving LWR Fuels

- Evaluations of accident-tolerant fuel with High Burnup
  - Objectives
    - Economic gains via extended refueling cycle, lower volume of new and spent fuel
- Plant Reload Optimization
  - Objectives
    - All-inclusive integrated framework for fuel reload analyses
    - Optimization of core configuration to minimize new fuel volume
  - Benefits of Risk-Informed Approach
    - Allows enhanced optimization of core configuration and further reduction of new fuel volume

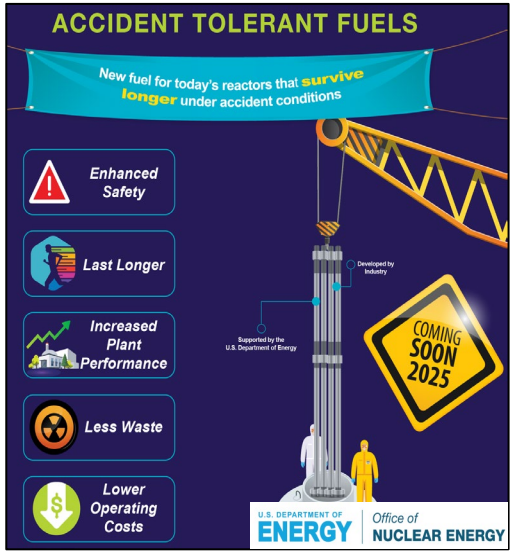
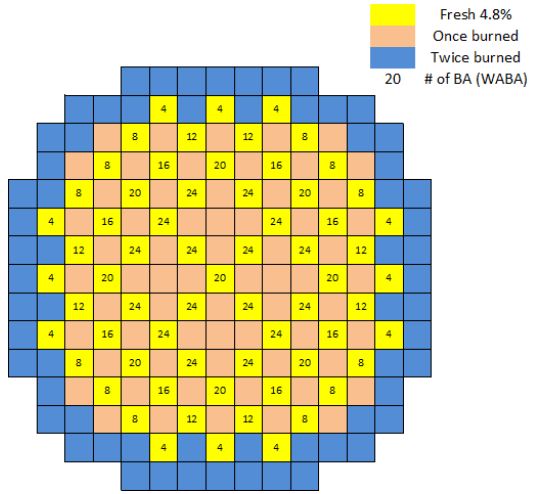


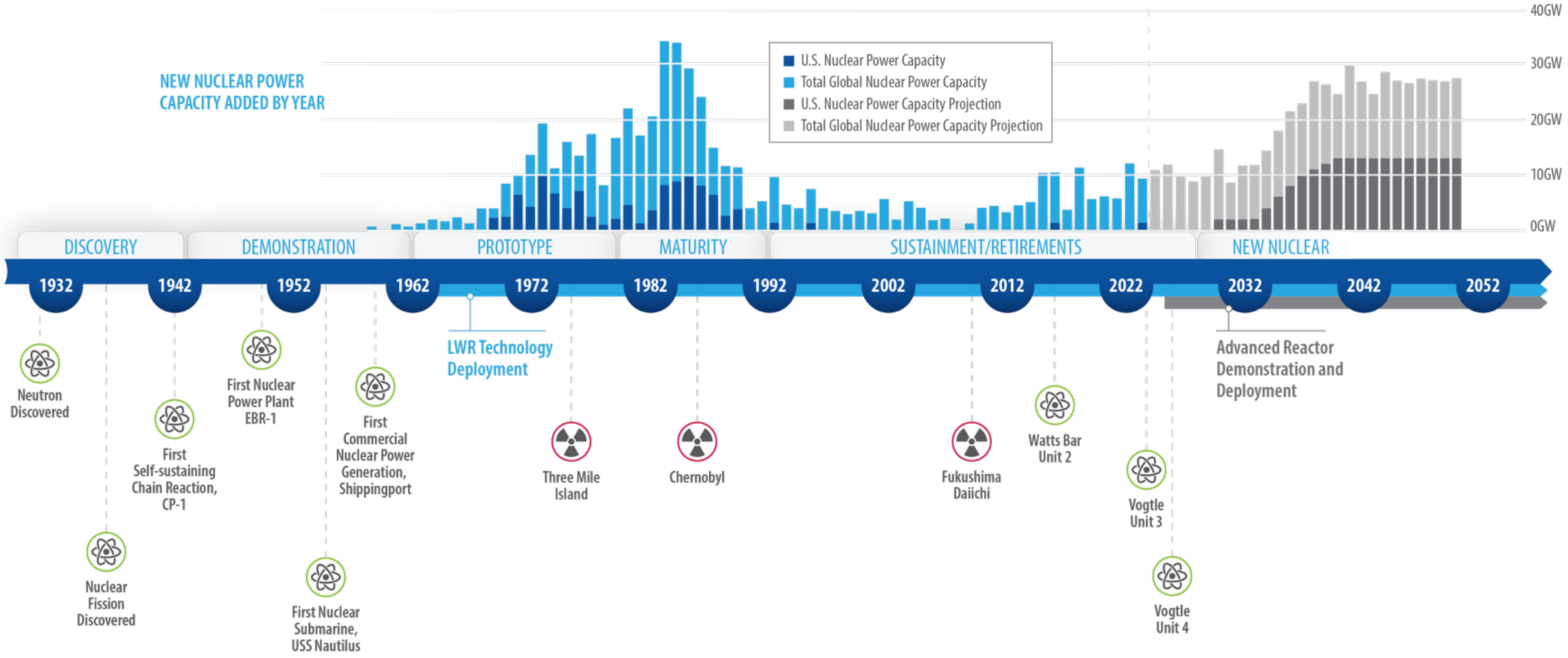
Image Credit: U.S. Department of Energy (link)



Configuration of Reactor Core

Advanced Reactor *Expansion*

The past and future of nuclear power

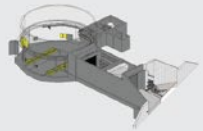


Advanced reactor experiments, demonstrations, and test beds at INL

1 Materials and Fuels Complex

DOME
NRIC | TEST BED

LOTUS
NRIC | TEST BED



MCRE
Southern Co. & TerraPower | EXPERIMENT

2 Transient Reactor Test Facility

MARVEL
DOE | TEST REACTOR

3 INL Site

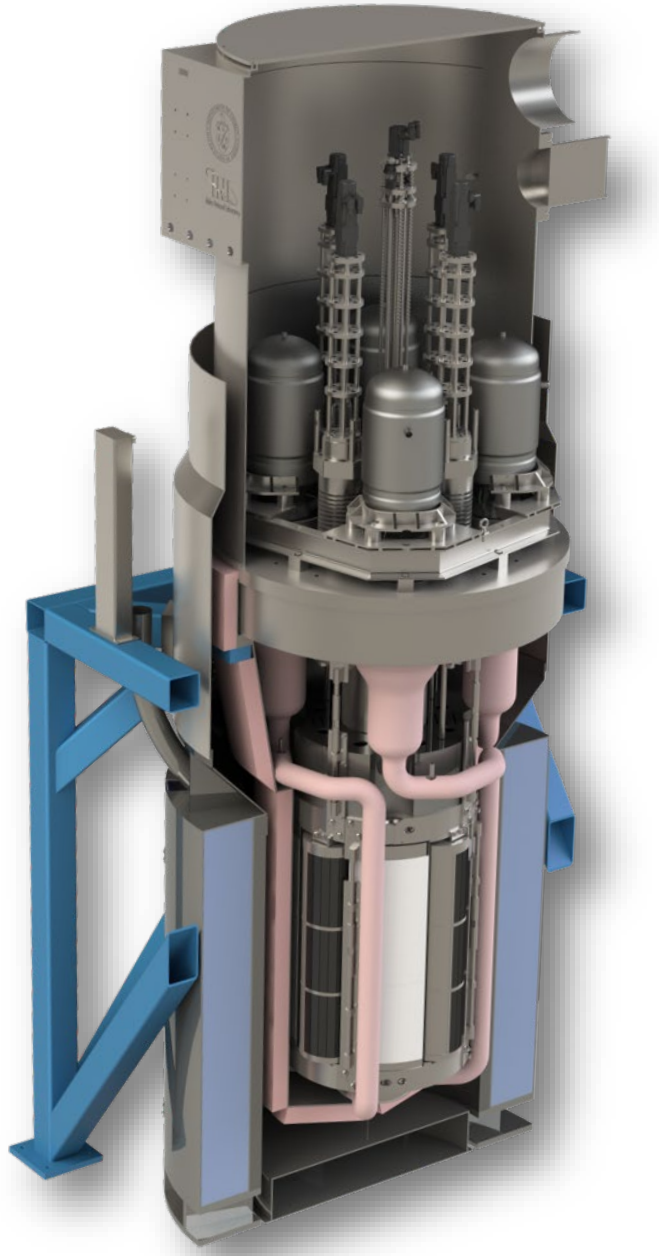
AURORA
Oklo | MICRO

4 Critical Infrastructure Test Range Complex

PROJECT PELE
DoD & BWXT | MICRO

MARVEL - Test Microreactor

Key Design Features	
Thermal Power	100 kW (85 kW nominal)
Electrical Power	20 kWe (QB80 Stirling Engines)
Weight	< 12 US ton
Primary Coolant	Sodium-Potassium eutectic
Intermediate Coolant	Lead
Coolant Driver	Natural Convection, single phase
Fuel	HALE(UZrH), 304SS clad, end caps
Moderator	Hydrogen
Neutron Reflector	Graphite, Beryllium (S200), Beryllium oxide
Reactivity Control	Radial Control Drums, Central Absorber
Primary Coolant Boundary	SS316H



Project Goals:

Rapid development of a small-scale microreactor that provides a platform to test unique operational aspects and applications of microreactors

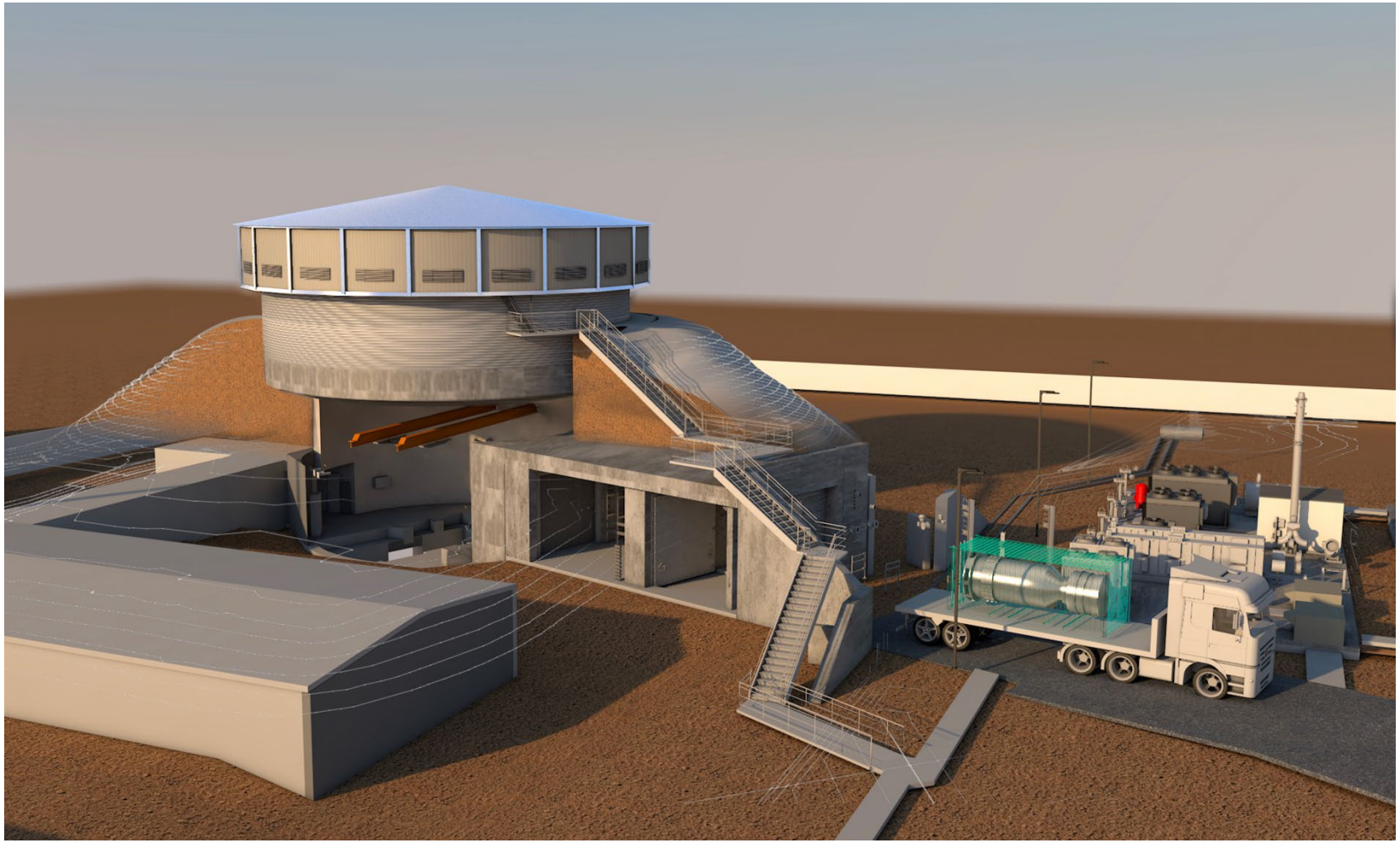
MRP Microreactor Program

Demonstration of Operational Microreactor Experiments (DOME)

- Repurposing EBR-II dome
- Test bed for microreactors less than 20 MWt
- Construction underway
- DOE authorization
- FEEED Studies Underway With Westinghouse, Radiant Nuclear, Ultra Safe Nuclear Corp
- Operational as soon as 2026

NRIC National Reactor Innovation Center

Laboratory for Operations and Testing in the U.S. (LOTUS)

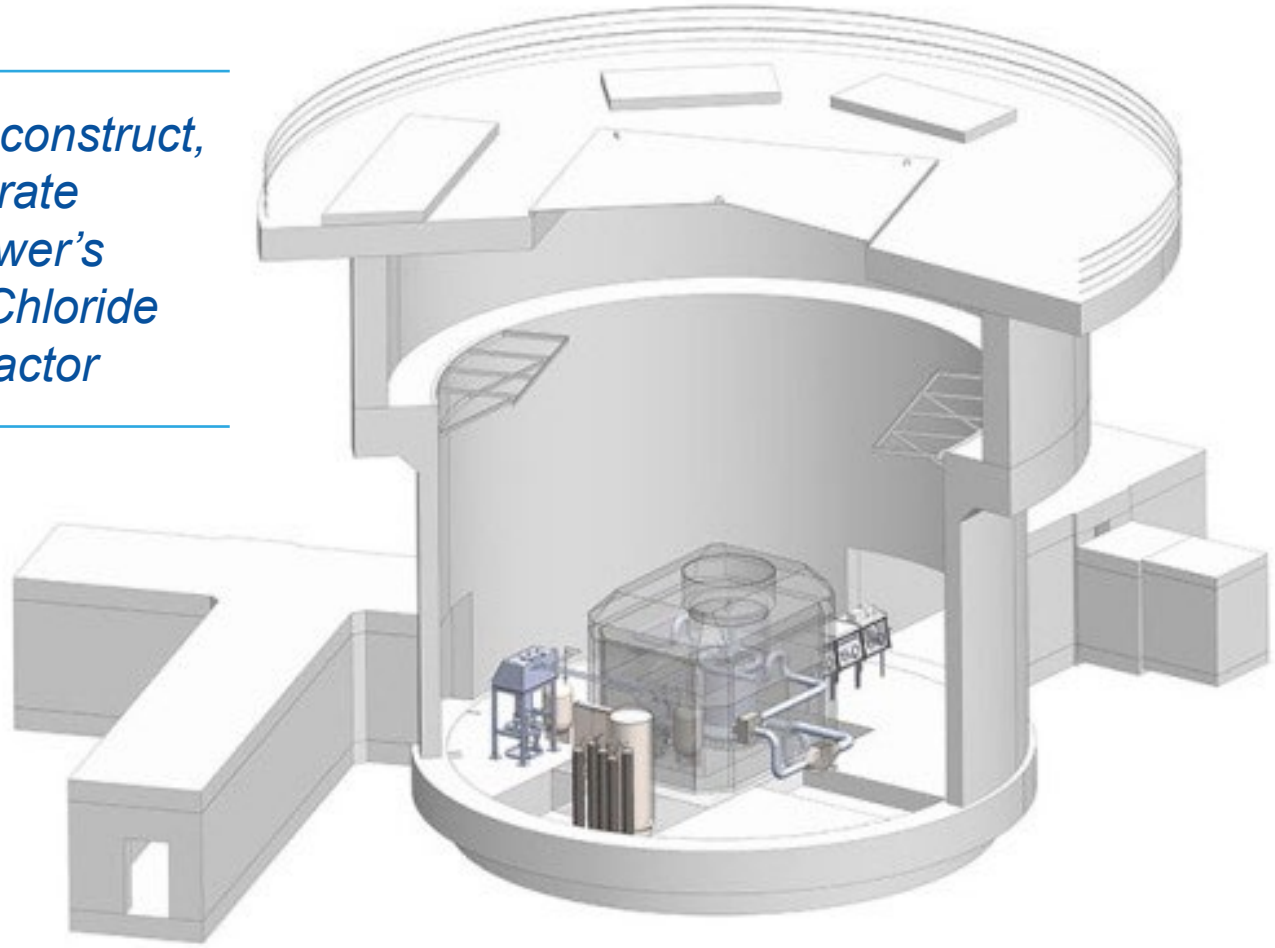


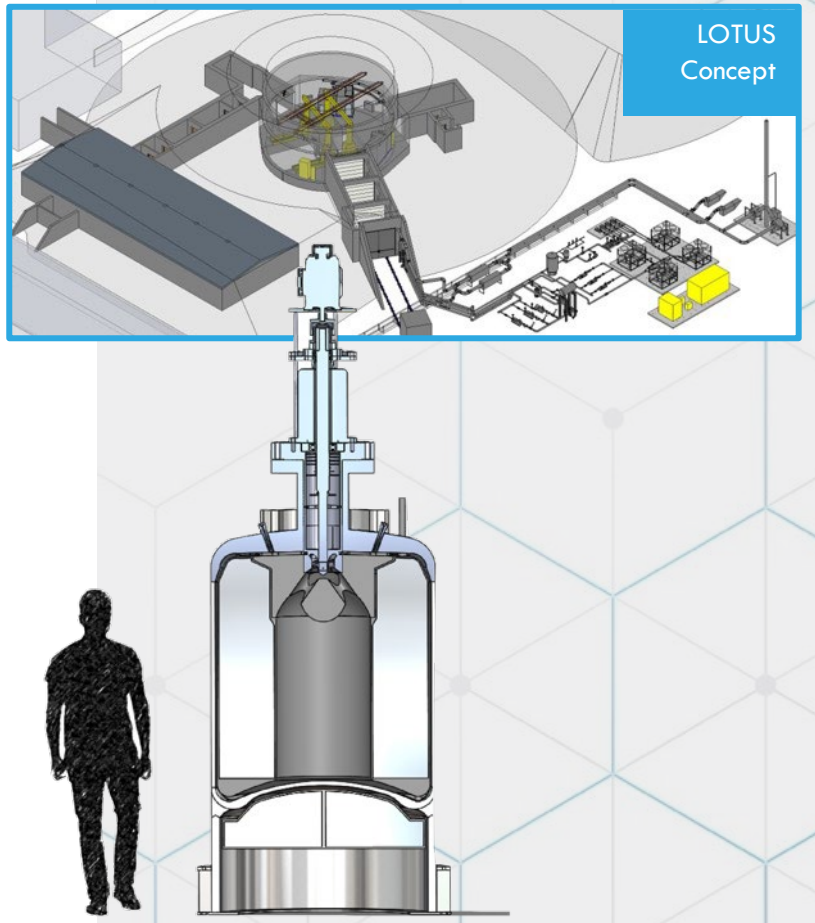
- Repurposing Zero Power Physics Reactor cell
- Supports high security materials
- First experiment will be the Molten Chloride Reactor Experiment, a partnership between TerraPower and Southern Company
- Completed preliminary design reviews January 2024
- Operational as soon as 2027

NRIC National Reactor Innovation Center

Molten Chloride Fast Reactor Experiment (MCRE)

Design, construct, and operate TerraPower's Molten Chloride Fast Reactor

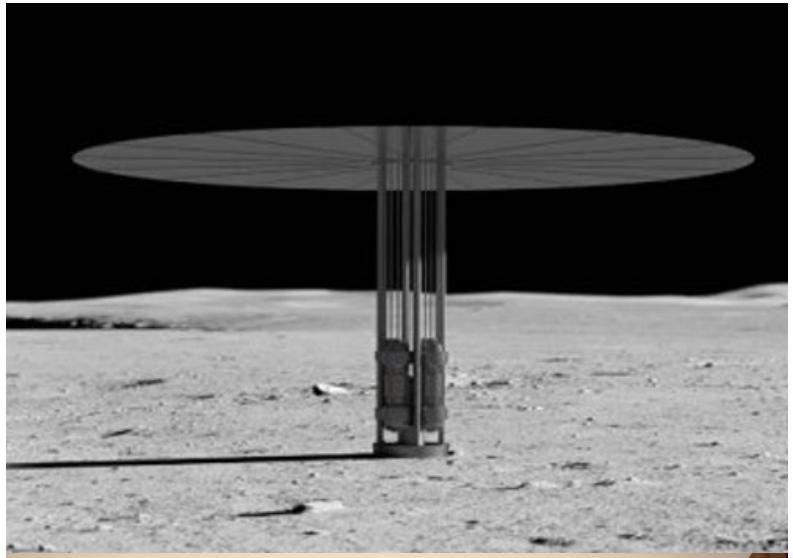




Space Nuclear Power

Fission Surface Power

Supporting NASA for Lunar and Martian nuclear surface energy
And space exploration.



Nuclear Thermal Propulsion

Develop an NTP reactor and engine technologies capable of sending humans to Mars in the 2030's

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Enabling future fusion energy systems

Modeling and simulation

- MELCOR fusion for plant safety assessment
- Modern probabilistic risk assessment to support design and regulatory approaches
- MOOSE high-fidelity multi-physics tools

Experimental capabilities

- Tritium production, transport and inventories (STAR facility)
- Modified neutron spectrum testing (ATR)
- Irradiated/tritium materials characterization (SPL/IMCL)

Collaborations

- National Labs: ORNL, SRNL, PPPL and LLNL
- General Atomics for blanket design
- Private-public industry partnership initiatives

Commonwealth Fusion Systems | XCIMER ENERGY CORPORATION

Transforming our energy system provides an opportunity for a secure and resilient energy future

Advancing R&D across our S&T initiatives with AI and ML

Nuclear reactor sustainment and expanded deployment
- Autonomous operation
- Semi-autonomous design
- Licensing automation

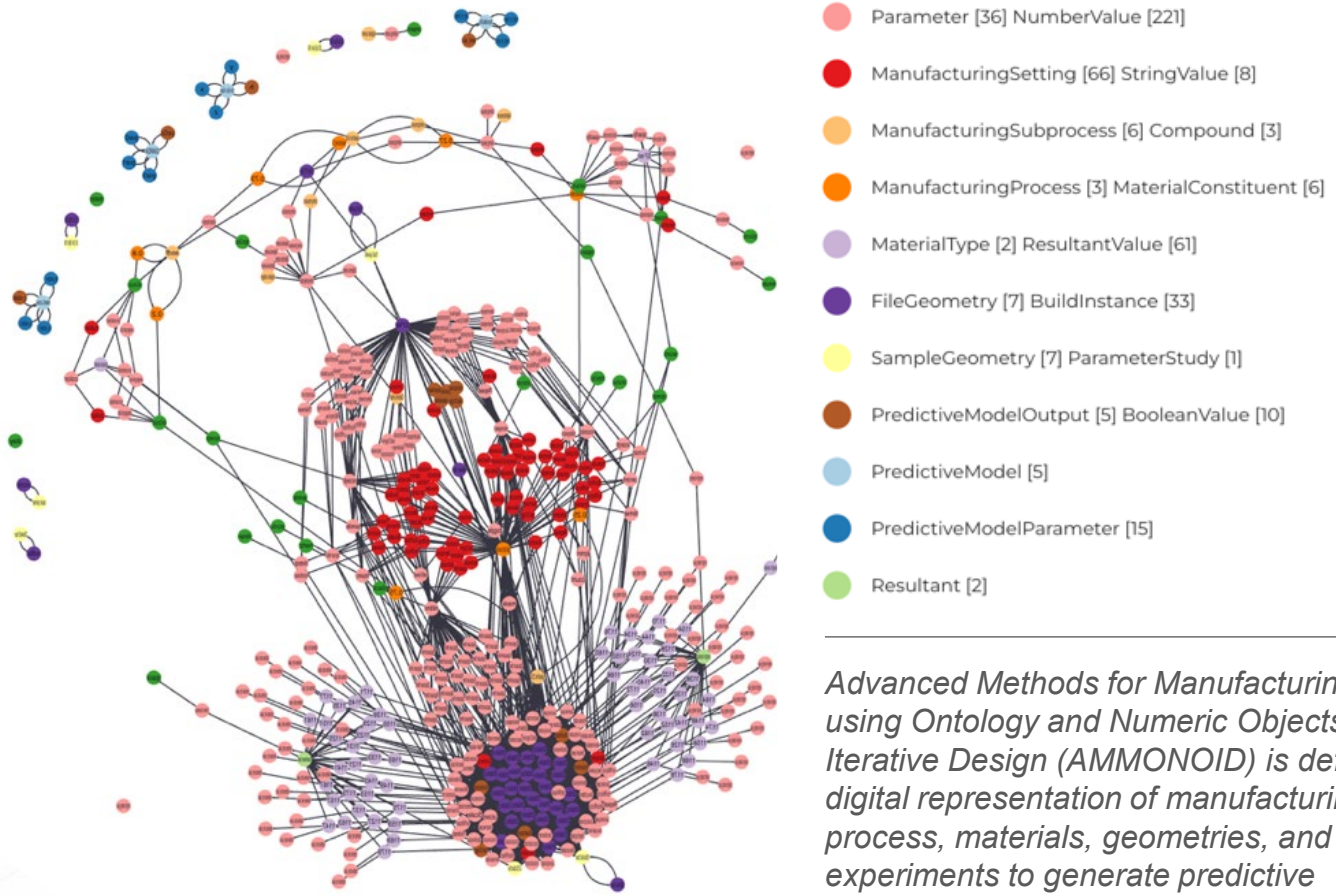
Integrated fuel cycle solutions
- Nonproliferation autonomous detection

Integrated energy systems
- Integrated energy and grid twins
- Autonomous siting tool

Advanced materials and manufacturing for extreme environments
- Material prediction for harsh environments

Secure and resilient cyber physical systems
- All hazards analysis

Crosscutting frameworks
- Big data
- AI frameworks
- Surrogate physics tools



Advanced Methods for Manufacturing using Ontology and Numeric Objects for Iterative Design (AMMONOID) is defining digital representation of manufacturing process, materials, geometries, and experiments to generate predictive models and digital twins.

Idaho National Laboratory