



Support for Advanced Reactor Development and Deployment

National Academies Advanced Nuclear Fuel Cycles and
Technologies Meeting
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Nuclear Beyond Electricity – Advanced Reactors

NOW



Baseload Electricity Generation

FUTURE

Large Light Water Reactors



Small Modular Reactors



GEN IV Reactors



New Chemical Processes



Heat



e^-



Clean Water



Electricity



Industrial Applications



Hydrogen Production

Support for Advanced Reactor Development

- Research and development support at national laboratories.
- Competitive cost-shared industry funding opportunities
- Advanced Reactor Demonstration Program

Office of Nuclear Energy Research Areas

- Light water reactor sustainability
- Advanced Reactors
 - Advanced small modular reactors
 - Gas-cooled reactors
 - Fast reactors
 - Molten salt reactors
 - Microreactors
- Crosscutting Technology Development Areas
 - Advanced Sensors and Instrumentation
 - Advanced Methods for Manufacturing
 - Integrated Energy Systems
 - Nuclear Cybersecurity
 - Advanced Reactor Safeguards and Security
- Advanced Modeling and Simulation

Advanced Reactor Technologies - Mission & Objectives

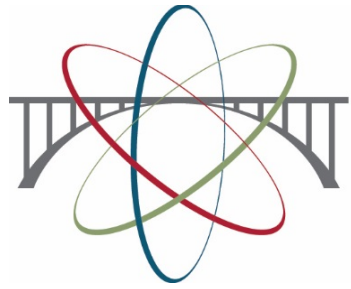
Mission: Support the development and commercialization of innovative concepts including microreactor, fast reactor, molten salt reactor (MSR), and high temperature gas-cooled reactor (HTGR) technologies through national laboratory-led R&D, university research programs, and cost-shared private-public industry partnerships.

Objectives:

- Conduct focused research and development to reduce technical barriers to deployment of advanced nuclear energy systems
- Develop technologies that can enable new concepts and designs to achieve enhanced affordability, safety, sustainability and flexibility of use
- Sustain technical expertise and capabilities within national laboratories and universities to perform needed research
- Engage with Standards Developing Organizations (SDO's) to address gaps in codes and standards to support advanced reactor designs
- Collaborate with industry to identify and conduct essential research to reduce technical risk associated with advanced reactor technologies

NE Advanced Reactor Technologies Campaigns

- **Fast Reactor Technologies**
 - Demonstrate feasibility of advanced systems and component technologies
 - Methods and code validation to support design and licensing
 - Qualification of legacy metallic fast reactor fuel performance data
- **Gas Reactor Technologies**
 - Advanced alloy and graphite materials qualification
 - Scaled integral experiments to support design and licensing
 - TRISO-coated particle fuel development and qualification
- **Molten Salt Reactor Technologies**
 - Investigate fundamental salt properties
 - Materials, models, fuels and technologies for salt-cooled and salt-fueled reactors
- **Microreactors**
 - Non-nuclear and nuclear integrated system testing supporting commercial demonstrations and end-user applications
 - Maturation of innovative components and semi-autonomous operating regimes
- **Advanced Reactor Regulatory**
 - Crosscutting non-LWR licensing framework activities
 - Close collaboration with campaigns, industry stakeholders, and Nuclear Regulatory Commission (NRC)



GAIN

Gateway for Accelerated
Innovation in Nuclear

Access to technical, regulatory, and financial support

- Funding opportunities to accelerate deployment
- Nuclear research expertise and capabilities
- Advanced computational tools
- Legacy U.S. research data

<http://gain.inl.gov>

DOE-NE Competitive Solicitations

- U.S. Industry Opportunities for Advanced Nuclear Technology Development
- GAIN Voucher Program
- Consolidated Innovative Nuclear Research (CINR)
 - Nuclear Energy University Program
 - Nuclear Science User Facilities
 - Nuclear Energy Enabling Technologies
- Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR)



<http://gain.inl.gov> – Funding Opportunities tab

U.S. Industry Opportunities for Advanced Nuclear Technology Development FOA

- Support innovative, industry-driven designs and technologies that have high potential to improve the overall economic outlook for nuclear power in the U.S.
- Key features:
 - Very broad scope
 - Open to U.S. companies with the expectation that resulting products will be manufactured in U.S.
 - Continuously open
 - Recently revised to two award cycles per year

Industry FOA – Example Technical Topics

- Advanced nuclear reactor designs, including small modular reactors of various technology types;
- Engineering, analyses and experimentation that would address first-of-a-kind reactor design, certification, and licensing issues;
- Advanced manufacturing, fabrication and construction techniques for nuclear parts, components, and full-scale plants, or integrated efforts that could positively impact the domestic nuclear manufacturing enterprise;
- Sensors, instrumentation and control systems;
- Plant auxiliary and support systems;
- Operational inspection and monitoring capabilities;
- Modeling and simulation of various elements of plant life cycle;
- Procedures, processes, and methodologies that can impact operational efficiencies;
- Integration of nuclear energy into micro-grid, non-electric, and/or hybrid applications;
- Efforts to address regulatory and licensing issues with the NRC.

Advanced Reactor Demonstration Program (ARDP)

- A key pillar of the Office of Nuclear Energy mission is to establish an advanced reactor pipeline to improve the nation's economic and energy security posture
- In fiscal year (FY) 2020, Congress appropriated \$230 million for the Department to establish a program to demonstrate multiple advanced reactor designs
- Primary objective: construct and demonstrate several advanced reactors with beneficial capabilities, such as:
 - Inherent safety features
 - Superior reliability
 - Lower waste yields
 - Proliferation resistance
 - Greater fuel utilization
 - Improved thermal efficiency
 - Ability to integrate electric & non-electric applications
- ARDP will support multiple advanced reactor demonstrations representing a variety of technologies and designs
- ARDP demonstration projects to be implemented via funding opportunity announcement (FOA) resulting in cost-shared cooperative agreements with U.S. industry partners

ARD FOA Application Pathways

- The Advanced Reactor Demonstration (ARD) FOA includes the following funding pathways:
 - Advanced Reactor Demonstration (Demos) awards
 - \$160M initial funding for cost-shared demonstration of two reactor designs that have potential to be operational in five to seven years following award finalization
 - Risk Reduction for Future Demonstration (Risk Reduction) awards
 - \$30M initial funding to support 2-5 additional, diverse advanced reactor designs that have a commercialization horizon that is approximately 5 years longer than the Demos
 - Advanced Reactor Concepts-20 (ARC-20) awards
 - \$20M for a new solicitation (to be known as ARC-20) for at least 2 new public-private partnerships focused on advancing reactor designs moving toward demonstration phase

Summary

Advanced reactors employ innovative technologies and fuel cycles to improve economic competitiveness, safety, and resiliency of nuclear energy systems

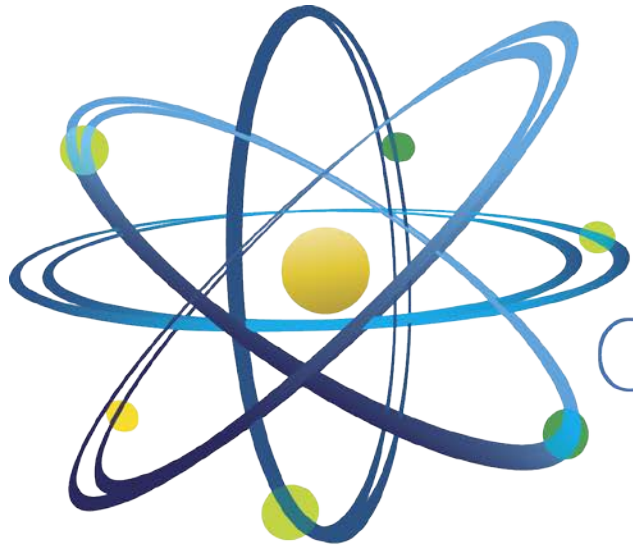
- Ensures nuclear energy continues to serve as a resource capable of meeting the Nation's energy, environmental and energy security goals

Through cross-cutting, national laboratory-led R&D, university research programs, and cost-shared private-public industry partnerships. NE supports the development and commercialization of innovative advanced reactor concepts including:

- Fast reactors
- High temperature gas-cooled reactors
- Molten salt reactors
- Microreactors

**Details on the Advanced Reactor Technology campaigns
provided as back-up**

Thank you! Questions?



Clean. **Reliable. Nuclear.**

Fast Reactor Technologies

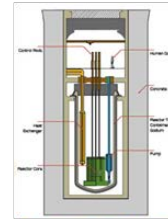
Fast Reactors



GE Hitachi
PRISM



TerraPower
TWR



Advanced Reactor
Concepts LLC
ARC-100

- Liquid metal (e.g., sodium, lead) or gas coolants
- Employs a fast (high energy) neutron spectrum
 - Greater fuel utilization
 - Actinide management
 - Used fuel reduction
- Advanced cladding and structural materials
- High temperatures allow for coupling to innovative and efficient power conversion systems (e.g., sCO₂)

NE Fast Reactor Campaign

For commercial deployment of fast reactors, stakeholders have identified two recurring challenges:

- Capital investment in fast reactors is a dominant cost (cost reduction is vital for competitiveness)
- A pathway must be established for non-LWR licensing

High-priority R&D areas:

- Preserving, streamlining access to, and qualifying legacy DOE fast reactor metallic fuel, R&D, and operational data for use in industry design and licensing cases
- Researching more effective fast reactor primary component, sensor, and reliability monitoring technology options identified by fast reactor designers
- Operating the Mechanisms Engineering Test Loop (METL) facility to demonstrate innovative fast reactor components and instrumentation in a prototypic in-sodium environment
- Improving, benchmarking, and validating existing fast reactor design and safety analysis code suites
- Providing the technical basis for ASME qualification of advanced structural materials for use in fast reactors



METL Facility, Argonne National Laboratory

High Temperature Gas-cooled Reactors

Gas Reactors



- Helium coolant
- Graphite moderator
- Robust ceramic Tri-structural isotropic fuel (TRISO) - UO_2 , UCO
- Prismatic or pebble fuel form
- Graphite structural components
- High-temperature reactor outlet (750°C - 950°C)

High Temperature Gas-cooled Reactors Benefits

- High temperature operation:
 - Improved efficiency
 - Potential source of process heat
 - Hydrogen production
 - Petrochemical and other industrial processes
- Chemically inert helium coolant
 - Helium does not corrode metals or react with graphite or water
- TRISO fuel forms
 - Robust ceramic fuel form with ability to withstand extreme accident scenarios
- Passive decay heat removal via conduction
 - Eliminates requirement for active emergency core-cooling systems

NE Gas Reactor Campaign

For the commercial deployment of high temperature gas reactors, stakeholders have identified two long term development challenges:

- TRISO Fuel development and qualification
- Material qualification especially for graphite

High priority R&D:

- ANL Natural Convection Shutdown Heat Removal Test Facility (NSTF) and operations for severe accident heat removal testing
- HTGR cross-section generation methods
- Developing HTGR benchmarks on bypass flows and natural convection
- Advanced materials qualification
 - Graphite qualification for use in high temperature reactors (HTRs) through a series of baseline characterizations, irradiation creep testing, irradiated properties testing, and model development
 - Obtained approval of ASME code case for Alloy 617 for (first new material added in decades)
 - Update high-temperature design methods in ASME Code

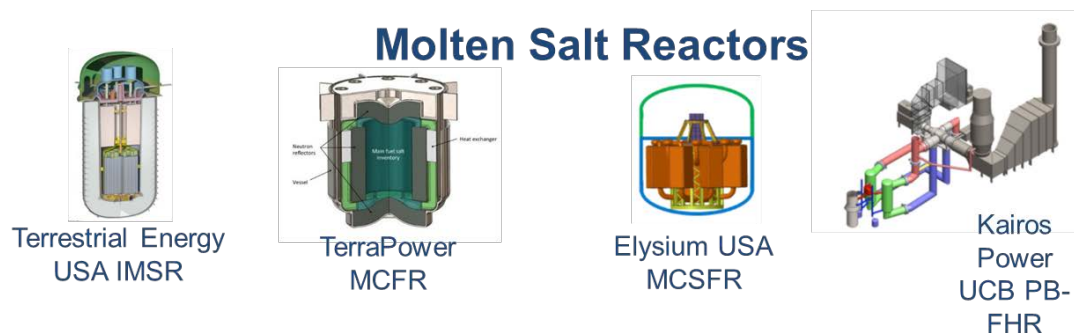


TRISO kernel and testing/production infrastructure



Prototypic HTGR graphite core block

Molten Salt Reactor Technologies



Two main MSR subclasses:

- Salt-cooled
 - Molten salt is the coolant in a graphite-moderated core fueled with either pebble or compact ceramic fuel form (e.g., TRISO)
- Salt-fueled
 - Fissile material is dissolved in the molten salt, which serves both as fuel carrier and coolant in the primary circuit (e.g., fluoride or chloride salts)

Molten Salt Reactor - Benefits

- As high temperature reactors,
 - Offer increased power conversion efficiency
 - High temperature process heat
- Increased fissile resource utilization
- Excellent heat transfer
- Passive decay heat removal feature of all proposed designs
- For salt-fueled concepts, fuel composition and chemistry can be continuously adjusted online
 - Minimizes outages

NE Molten Salt Reactor Campaign

For the commercial deployment of molten salt reactors, stakeholders have identified two recurring challenges:

- Investigate fundamental salt properties
- Develop infrastructure, materials, models, fuels, and fuel mass accountability technologies for salt-cooled and salt-fueled reactors

High-priority R&D areas:

- Provide baseline technology and access to salt purification, properties, and corrosion testing.
- Develop infrastructure for small and medium scale experiments to support flow loops and dynamic corrosion.
- Perform coupon, capsule, and in-pile loop irradiation studies and post-irradiation analysis to characterize the effects on materials over time
- Continue industry outreach and vendors engagement to shorten the critical path to deployment.

Microreactor Technologies

- Small, factory-built nuclear reactors that can be transported nearly fully assembled to an operating location via truck, ship, airplane, or railcar
- Anticipated to generate between 1 to 20 megawatts-electric (MWe)
- Provide customer choice in non-traditional energy markets
 - Off-grid communities
 - Remote industrial locations
 - Forward military bases
 - Disaster relief missions



Graphic courtesy of Westinghouse

Microreactor Benefits and Applications

Microreactors have the potential to provide the commercial and defense sectors with a clean, reliable, and resilient energy supply technology

Potential benefits include:

- Enhanced inherent safety characteristics
- Smaller footprints
- Semi-autonomous and remote control operations reducing staffing needs
- High temperature operation for both electricity and process heat production
- Highly integrated and transportable systems reducing on-site construction times

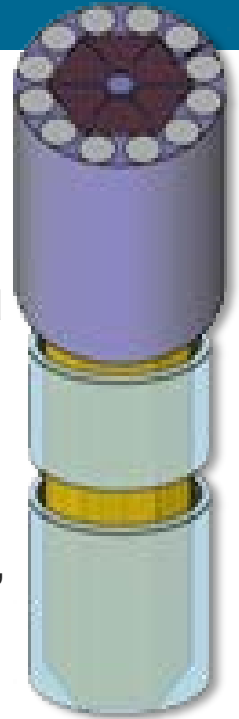
Potential applications include:

- Competitive electricity and process heat supplies for remote and off-grid communities and industrial locations
- Resilient and reliable energy supplies for remote and forward military bases
- Reliable and clean electricity supplies for disaster and emergency relief operations

NE Microreactor Campaign

Objectives

- Perform cross-cutting, national laboratory-led R&D activities to enable the demonstration and advancement of microreactor technologies.
- Develop experimental infrastructure supporting microreactor system testing and demonstration
- Provide cost-shared support for microreactor vendor concept development and licensing activities
- Remain closely engaged with the Nuclear Reactor Commission (NRC), industry, and Department of Defense (DoD) on related microreactor licensing and demonstration activities



Heat-Pipe Microreactor Concept

Priority R&D:

- Validation testing of integrated microreactor systems and end-user applications in both non-nuclear and nuclear prototypical environments
- Maturing cross-cutting microreactor technologies such as heat pipes, advanced moderators, advanced materials, and heat exchangers
- Testing and validating remote monitoring and semi-autonomous control systems
- Addressing technical licensing challenges for both near-term microreactor demonstrations and future “nth of a kind” commercial applications