U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Overview of Advanced Reactor Demonstration Program

National Academies Advanced Nuclear Fuel Cycles and Technologies Meeting

December 17, 2020

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Office of Nuclear Energy

Topics to be Covered

- Advanced Reactor Demonstration Program (ARDP) Overview
- Advanced Reactor Demonstration Funding Opportunity Announcement (FOA) Overview
- Announced ARD FOA Awards
- National Reactor Innovation Center Overview
- ARDP Regulatory Development
- ARDP Advanced Reactor Safeguards
- Summary/Questions

Advanced Reactors: U.S. Landscape

- Dozens of U.S. companies are working on advanced nuclear projects for a wide array of capabilities to meet the energy needs of the future
  - Light water-cooled advanced small modular reactors
  - Advanced sodium-, gas-, lead-, molten salt-cooled reactors
  - Significant levels of private sector investment
- Motivation for advanced reactor development
  - Potential for improved safety and operational capability
  - Various options for future commercial, limited-grid and remote applications
  - Potential for improved nuclear resource utilization and reduced nuclear waste
  - Flexible operation to support the national grid of the future containing many energy-source options

Use Cases and Market Drivers

Courtesy of Third Way #NuclearReimagined

4

Advanced Reactor Demonstration Program

- Established in FY2020 budget language
- Focuses DOE and non-federal resources on **actual construction** of real demonstration reactors
- Establishes ambitious timeframe for demonstration reactors – five to seven years from award, including design, licensing, construction and start of operations
- Program also addresses technical risks for less mature designs
- Desired outcomes:
  - Support diversity of advanced designs that offer significant improvements to current generation of operational reactors
  - Enable a market environment for commercial products that are safe and affordable to both construct and operate in the near- and mid-term
  - Stimulate commercial enterprises, including supply chains

ARDP Program Elements

- Advanced Reactor Demonstrations (Demos)
  - Cost-shared partnerships with industry (up to 50 percent (%) government, not less than 50% industry) to build two advanced demonstration reactors with significant improvements compared to current generation of operational reactors
  - Demos to be constructed and operational in a 5-7 year window after award
  - $160 million (M) appropriated for fiscal year (FY) 2020 ($80M per award)
- Risk Reduction (RR) for Future Demonstrations
  - Cost-shared research and development (R&D) activities with industry (up to 80% government, not less than 20% industry) to address technical risks in advanced reactor designs to support potential future advanced reactor demonstrations
  - $30M appropriated for FY 2020 (up to 5 awards)

ARDP Program Elements (cont.)

- National Reactor Innovation Center (NRIC)
  - Supports testing, demonstration, and performance assessment to accelerate deployment of advanced reactors through development of advanced nuclear energy technologies by utilizing unique DOE laboratory facilities and capabilities
  - $20M appropriated for FY 2020
- Advanced Reactor Regulatory Development
  - National laboratory led R&D to resolve technical challenges with licensing advanced reactors
  - Close coordination with NRC and industry
  - $15M appropriated for FY 2020
- Advanced Reactor Safeguards
  - Addresses safeguard and security issues unique to advanced designs
  - $5M appropriated for FY 2020

Advanced Reactor Demonstration FOA

- Advanced Reactor Demonstration FOA solicited applications for funding pathways aligned with different maturity levels:
  - Advanced Reactor Demonstration (Demos) awards
    - 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
    - Support for 2-5 additional, diverse advanced reactor designs that have potential to be operational in ten to twelve years following award finalization
  - Advanced Reactor Concepts-20 (ARC-20) awards
    - 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
    - Not formally part of ARDP; funded under separate budget line. Included in ARD FOA to allow developers to select best pathway.

Advanced Reactor Demonstrations Pathway Merit Review

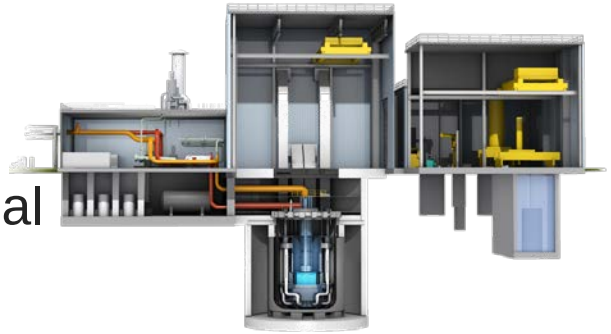
- Two sets of reviewers: non-federal subject matter experts (SMEs) and federal merit review panel (MRP).
- Congressional language that established the Advanced Reactor Demonstration Program directed the selection of projects be advised by subject matter experts:
  - Electric utility that operates a nuclear power plant
  - High-temperature process heat users (e.g., hydrogen production, industrial processing)
  - Design, manufacturing and operation of nuclear reactors
  - Finance industry with background in nuclear field
- Non-federal SMEs independently reviewed applications and provided individual feedback.
- Federal MRP members individually reviewed applications and then developed consensus recommendations, taking SME input into account.

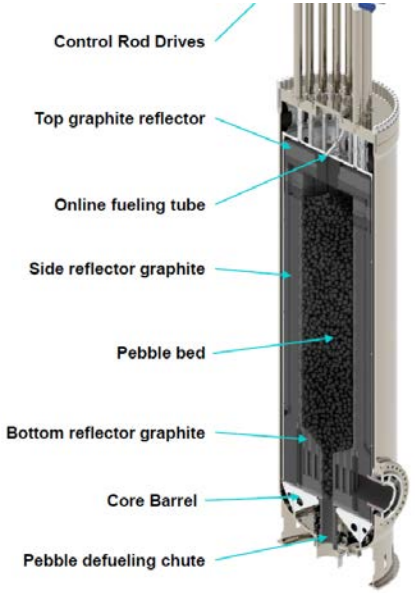
ARD FOA Status

- Applications due – August 19, 2020
- Strong industry interest, with proposals received under all three pathways.
- Demonstration awards announced October 13, 2020
  - Unsuccessful applicants had opportunity to be considered for Risk Reduction awards
- Risk Reduction awards announced December 16, 2020
- ARC-20 awards to be announced late December 2020

Demonstration Pathway Selected Technologies

- TerraPower LLC – Natrium Reactor
  - Sodium-cooled fast reactor that leverages of decades of development, including fuel
  - High temperature reactor coupled with thermal energy storage for flexible electricity output
  - New metal fuel fabrication facility
  - Visit: https://natriumpower.com/
- X-energy – Xe-100 reactor
  - High temperature gas-cooled reactor that leverages decades of development and robust fuel form
  - Provides flexible electricity output and process heat for a wide range of industrial heat applications
  - Commercial scale TRISO fuel fabrication facility
  - Visit: https://x-energy.com/



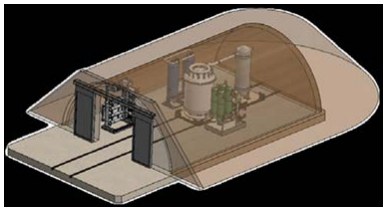


Risk Reduction Pathway Selected Technologies

Prime Applicant	Commercial Target Reactor Type and Fuel	Risk Reduction Project Key Deliverables
Kairos Power. LLC	KP-FHR - 140 Mwe thermal spectrum fluoride salt-cooled MSR, TRISO annular pebble fuel	Design, construction and operation of Hermes reduced-scale test reactor (precursor to commercial-scale KP-FHR)
Westing-house	eVinci - 4.5 MWe heat pipe-cooled microreactor, TRISO UCO compact HALEU fuel	Technical risk reduction for moderator design, wick manufacturing, refueling and licensing.
BWXT	BANR - 50 MWt transportable microreactor HTGR with UN TRISO	Maturation of technology, including the development of UN TRISO fuel, to improve the commercial viability of BANR
Holtec	SMR-160 - 160 MWe LW-cooled natural circulation PWR	Early stage design, engineering, and licensing activities for the SMR-160.
Southern Company	Molten Chloride Fast Reactor –180 MWt pool-type MSR fast reactor with liquid salt fuel	Design, construction and operation of Molten Chloride Reactor Experiment (MCRE)

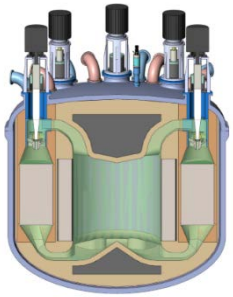
Kairos KP-FHR

WEC eVinci



BWXT BANR

Holtec SMR-160



TerraPower MCFR

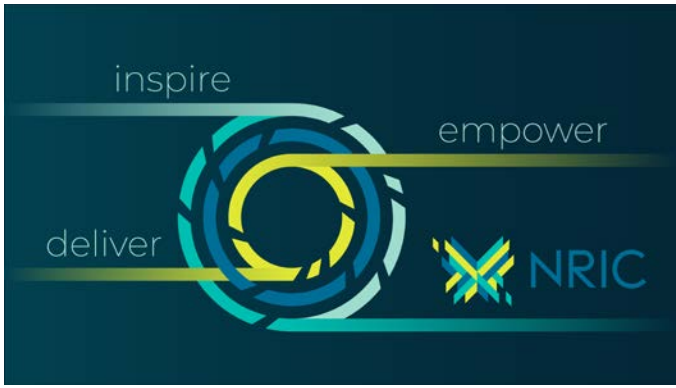
National Reactor Innovation Center (NRIC)

13

NRIC Overview

Objectives

- Empower innovators with access to facilities, sites, materials, and expertise to enable demonstration of at least two advanced reactor technologies
- Support advanced reactor regulatory readiness for demonstrations
- Execute best practices in stakeholder engagement
- Develop enduring demonstration support infrastructure
- Establish methods for efficient coordination among national laboratories



Recent Activities:

- Establishing NRIC through planning and engagement with industry, NRC, national laboratories, and other key stakeholders
- Performed gap assessment for demonstration capabilities
- Developing demonstration resource network
  - Experimental facilities
  - Test beds
  - Demonstration site identification and preparation

NRIC Webinar Series

- January 7, 2021 - “What Inspires Us”
- Focus on DOE awards to TerraPower and X-energy to build their advanced nuclear reactors by 2027.
- Feature conversations with Chris Levesque, president and chief executive officer of TerraPower and Clay Sell, chief executive officer of X-energy

- https://federallabs.org/events/nric-what-inspires-us-webinar

ARDP Regulatory Development

Major activities include:

- Supporting efforts with NRC and industry stakeholders to develop cross-cutting advanced reactor licensing frameworks
  - Licensing Modernization Project (LMP)
  - Technology-Inclusive Content of Application Project (TICAP)
- Focused R&D to address technology-specific regulatory challenges for NE advanced reactor campaigns
  - Fast reactors
  - High temperature gas-cooled reactors
  - Molten salt reactors
  - Microreactors
- Details on the Advanced Reactor Technology campaigns provided as back-up

ARDP Advanced Reactor Safeguards

- The Advanced Reactor Safeguards (ARS) program applies laboratory R&D to address near term challenges that advanced reactor vendors face in meeting domestic materials accountancy and physical protection requirements for U.S. builds.
- Reduce roadblocks in the deployment of new and advanced reactors by solving regulatory challenges, reducing safeguards and security costs, and utilizing the latest technologies and approaches for plant monitoring and protection.
- FY21 project focus areas
  - Materials Accountancy – MC&A for liquid-fueled and pebble bed reactors
  - Physical Protection - Identifying PPS design alternatives that can reduce cost or need for on-site responders
  - Gen-IV & IAEA Interface

Summary

The Advanced Reactor Demonstration Program:

- Supports a diversity of U.S. advanced reactor designs for near-term or mid-term commercial demonstration
- Employs 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

Thank you! Questions?

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NE Fast Reactor Campaign

For commercial deployment of fast reactors, stakeholders have identified <u>two recurring challenges:</u>

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

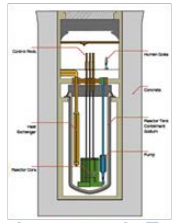
High-priority R&D areas:

- 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

Fast Reactors

GE Hitachi PRISM

TerraPower TWR



Advanced Reactor Concepts LLC ARC-100

METL Facility , Argonne National Laboratory

NE Gas Reactor Campaign

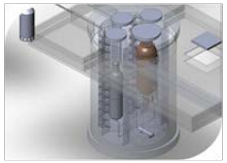
For the commercial deployment of high temperature gas reactors, stakeholders have identified <u>two long term development challenges:</u>

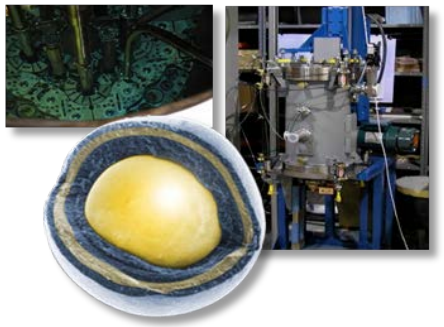
- TRISO Fuel development and qualification
- Material qualification especially for graphite

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

Gas Reactors


Framatome
SC-HTGR



TRISO kernel and testing/production infrastructure

NE Molten Salt Reactor Campaign

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

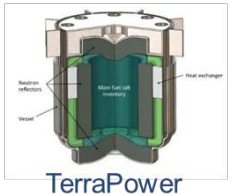
- Investigate fundamental salt properties
- Develop infrastructure, materials, models, fuels, and fuel mass accountability technologies for salt-cooled and salt-fueled reactors

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

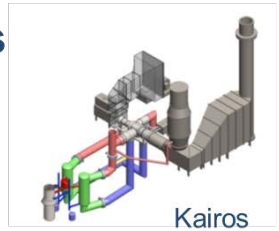
Molten Salt Reactors

Terrestrial Energy USA IMSR



TerraPower MCFR

Elysium USA MCSFR

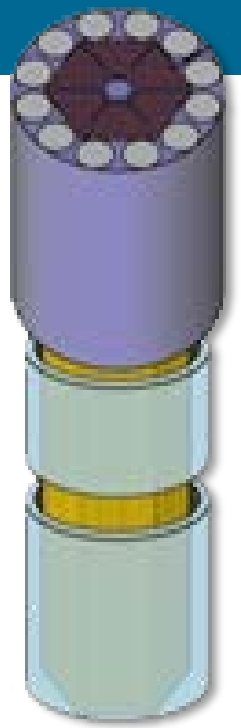


Kairos Power UCB PB-FHR

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 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