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Environmental Compliance Roadmap for Advanced Reactor Prototype Deployments

April 24, 2024

Dave Goodman, PNNL

U.S. DEPARTMENT OF ENERGY
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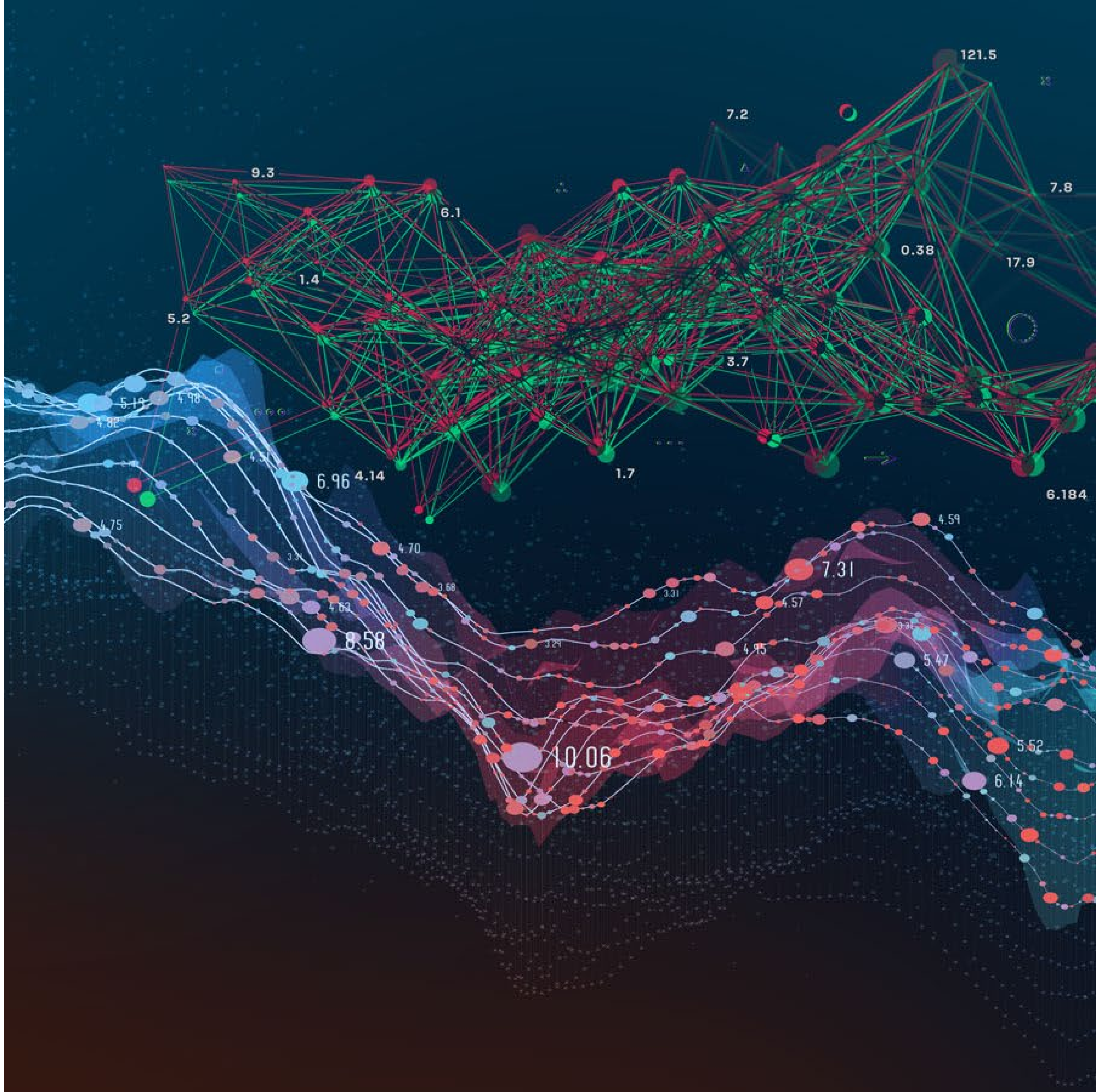


Presentation Goals

- Describe options for demonstrating reactor prototypes
- Introduce and describe NRC licensing and DOE authorization scenarios
- Outline anticipated NEPA review steps
- Provide general information required from project proponents

NOTE: While this report describes options for conducting environmental reviews for advanced reactor demonstrations both by the DOE and the NRC, the contents of the report have not been reviewed or approved by NRC staff. All statements herein are the interpretations and conclusions of the authors, which are solely responsible for their content.

Licensing/Authorization Scenarios

- Assumption: reactors will require either an NRC license or DOE authorization (not both)
  - DOE site use permit may be required
- NRC licensing is required if the proposed reactor will be:
  - Operated as part of the power generation facilities of an electric utility system, or
  - Operated in any other manner for the purpose of demonstrating the suitability for commercial application of such a reactor.
- DOE authorization is required for testing of reactor concepts

Application of the PPE/SPE Concept

- **Plant Parameter Envelope –** a set of reactor and owner engineered parameters associated with a suite of reactor designs
- **Site Parameter Envelope –** a set of parameters associated with the environmental resource requirements associated with one or more reactor designs
- The combination of the PPE with the SPE allows for environmental analysis of resource issues
- The PPE/SPE combination can support generic environmental analysis without a specific project proposal if the parameters are well-understood and consistent across projects (e.g., NRC ANR GEIS)

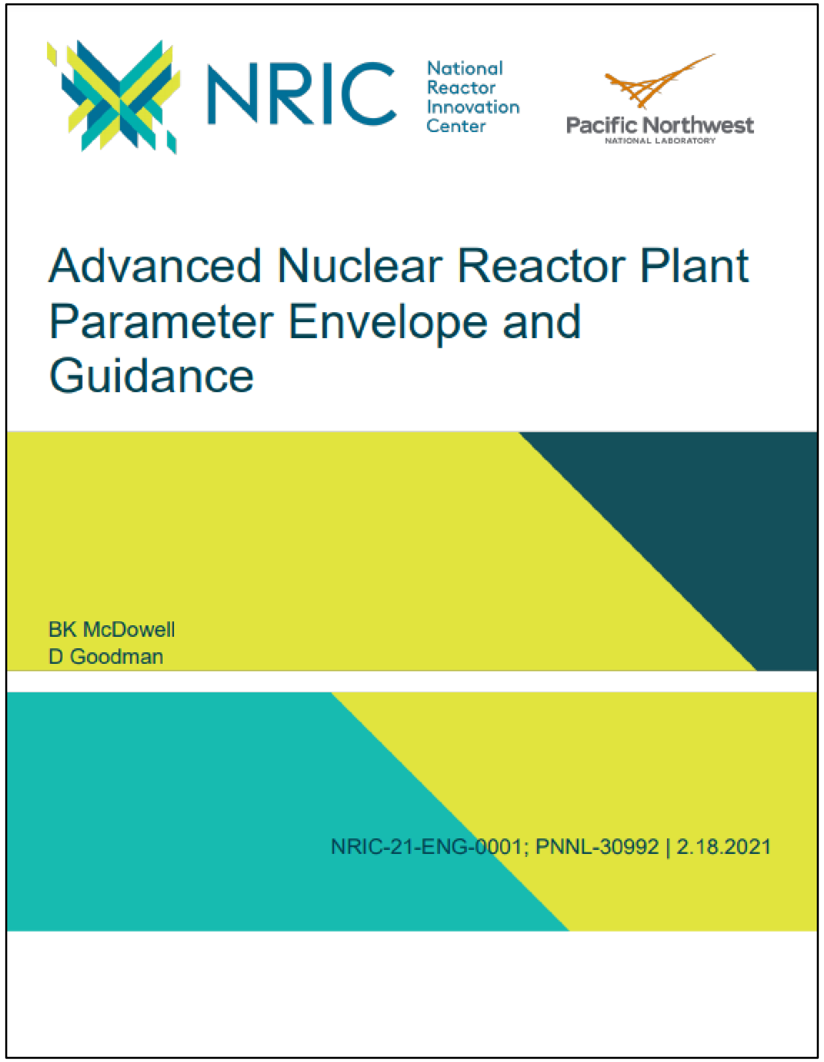
NRIC Adaptation of the PPE Framework

- PPEs are generally based on reasonable values for a wide range of anticipated designs as opposed to easily identifiable bounding values for generally similar designs.
- In some cases, e.g., the plant footprint, these parameters could be the largest parameter values of the potential reactors that could be deployed.
  - In other cases, there may not be a “bounding” value because of the wide range of potential designs, as would be the case for the nature of the fuel, coolant, or cooling technology. In those cases, the range of potential parameter values would be presented, and a reasonable value would be chosen.
- Two PPE/SPEs for two size ranges:
  - (1) microreactors, which are defined for this PPE as single units with outputs of 60 MWt or less, and
  - (2) small- to medium-sized advanced reactors with outputs above 60 MWt up to 1,000 MWt.

PPE and Guidance Report – Published February 2021

1. Background and Purpose
2. Methodology
3. Aggregated PPE Values
4. Guidance for Use
5. Documentation Supporting Development

[Link to the Report]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Advanced Nuclear Reactor Plant Parameter Envelope and Guidance

BK McDowell
D Goodman

NRIC-21-ENG-0001; PNNL-30992 | 2.18.2021

NRC Licensing at DOE Sites

- Involves the cooperation and input of both agencies
- Assumes that DOE must complete a NEPA review assessing site suitability before, concurrent with, or subsequent to the NRC NEPA review
  - A DOE site-use permit may be required
- Early Site Permit - may resolve site safety, environmental protection, and emergency preparedness issues independent of a specific nuclear plant design – includes multiple sequencing options:
  - DOE completes a NEPA review identifying suitable sites, subsequently applies to NRC for an ESP at these sites
  - DOE and NRC are co-lead agencies on an ESP EIS meeting both agency needs
  - DOE applies for an NRC ESP, subsequently uses the ESP to support DOE NEPA requirements
- Construction Permit or COL for a Known Project Design and Siting Location

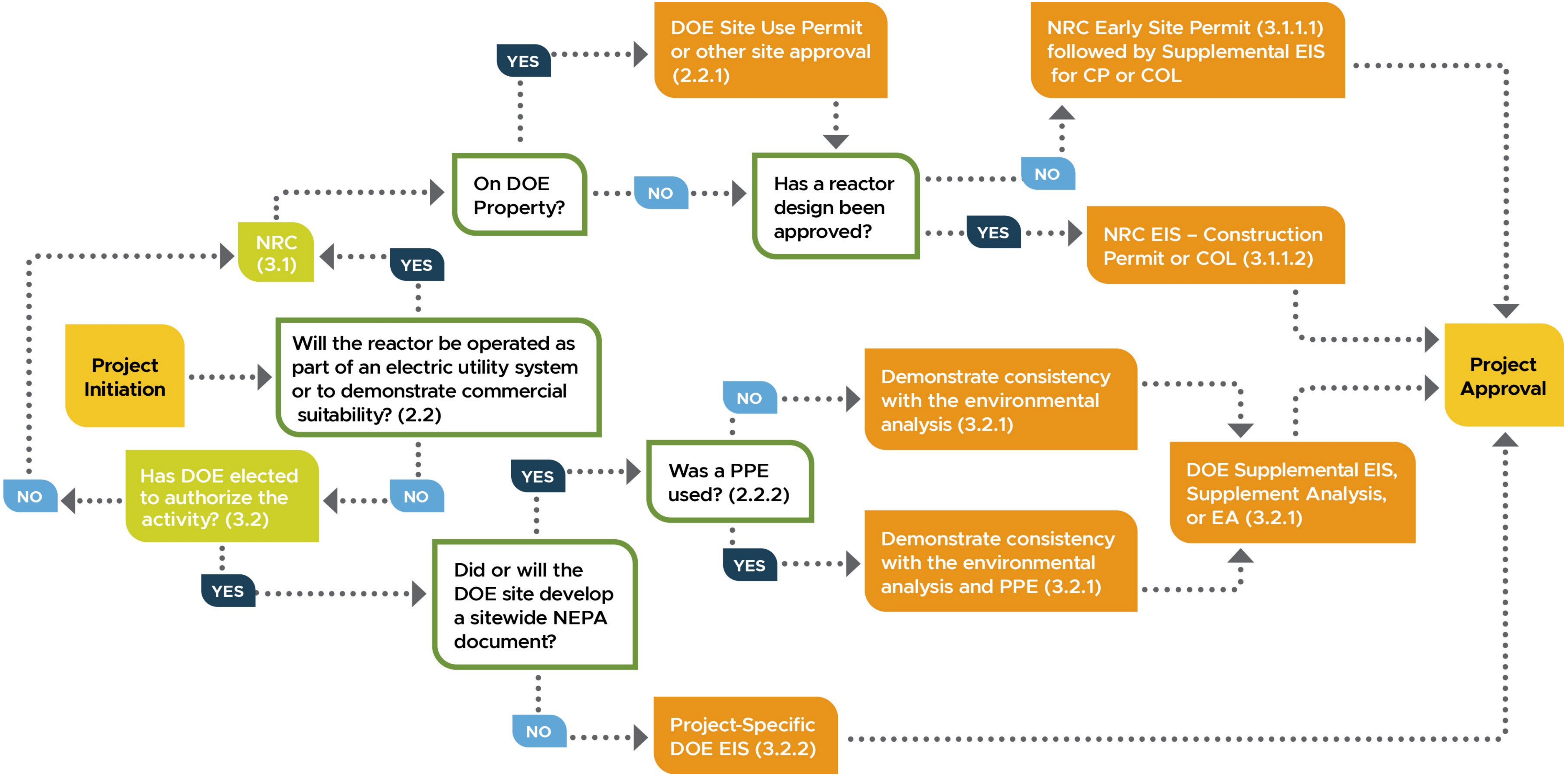
NRC Licensing at Non-DOE Sites

- Conducted through NRC licensing process under Part 50 or Part 52
  - Potential for future Part 53 licensing pathway
- DOE would not have a required role in the process unless providing project funding or
- The NRC Advanced Reactor GEIS, if/when completed, can be used to streamline the process

DOE Authorization

- For DOE authorization rather than NRC licensing, the reactor must not be:
  - Operated as part of the power generation facilities of an electric utility system, or
  - Operated in any other manner for the purpose of demonstrating the suitability for commercial application of such a reactor.
- The DOE authorization process can be streamlined if the desired DOE site has completed a siting or programmatic EIS analyzing advanced reactor deployment
  - The EIS would analyze the suitability of sites and the broad conditions regarding project approval
  - The NRIC PPE would have utility as a surrogate to support the generic environmental impact analysis
  - Similar to the NRC ESP approach
- If no siting or programmatic EIS exists, a single comprehensive project-specific EIS would be required

NRC Licensing/DOE Authorization NEPA Flowchart

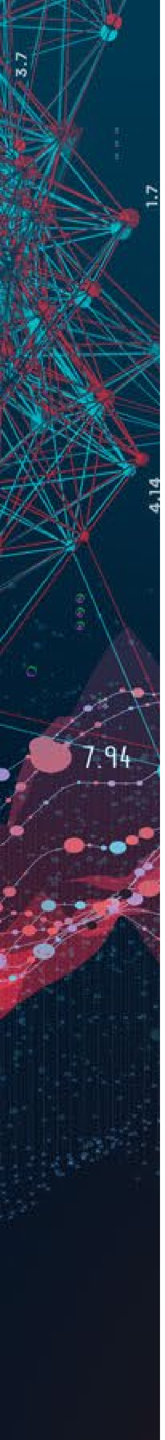


Information to be Included in an NRC Environmental Report or DOE Data Call

- NRC Regulatory Guide 4.2 provides guidance to the applicant on information to be included in the license application to support the development of an EIS
  - Currently being updated as part of the NRC Advanced Reactor GEIS Rulemaking – new appendix specific to advanced reactors
- Similar information to that required by NRC would be required for a DOE authorization.
- Categories of necessary information include:
  - Site location and footprint
  - Reactor and structure design
  - Offsite rights-of-way
  - Reactor construction
  - Air resources
  - Water resources
  - Terrestrial and aquatic resources
  - Noise
  - Environmental hazards
  - Waste management
  - Postulated accidents
  - Socioeconomics
  - Fuel cycle
  - Transportation of fuel and waste
  - Decommissioning

Conclusions

- Whether a project requires an NRC license or DOE authorization depends on the purposes and goals of the project
- Regardless of whether an NRC license or DOE authorization is required, information necessary to inform the environmental review process is similar
- The PPE/SPE combination can support generic environmental analysis without a specific project proposal if the parameters are well-understood and consistent across projects
- The appropriate permitting strategy depends on whether an NRC license or a DOE authorization is required, and can be informed by the existence of relevant programmatic NEPA guidance (e.g., NRC ANR GEIS or a DOE EIS using a PPE/SPE)



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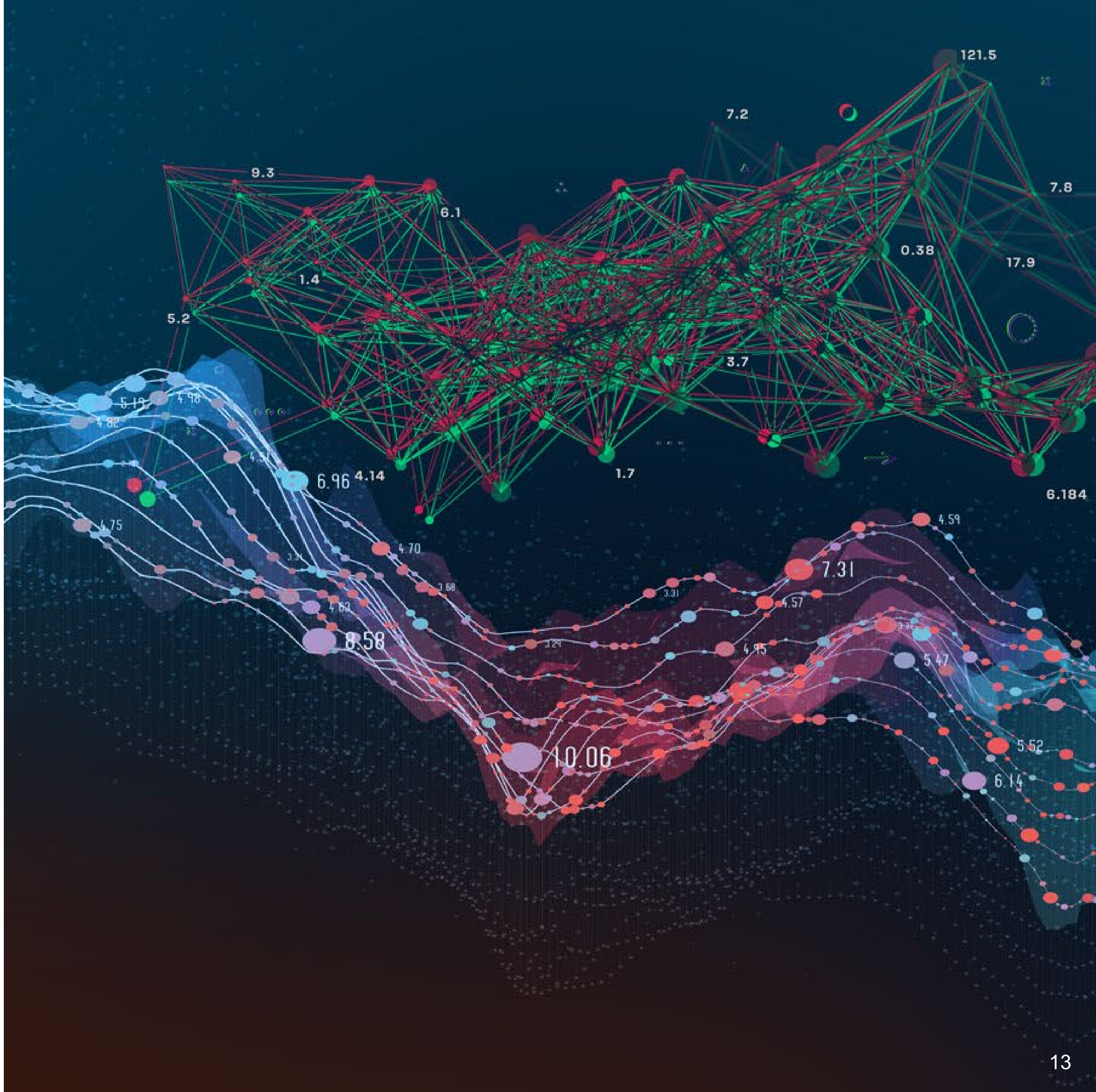
Thank you



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Overview of DOE Regulatory Development

Advanced Non-Water Technologies

Scott Ferrara, Idaho National Laboratory, Nuclear Science and Technology Regulatory Development

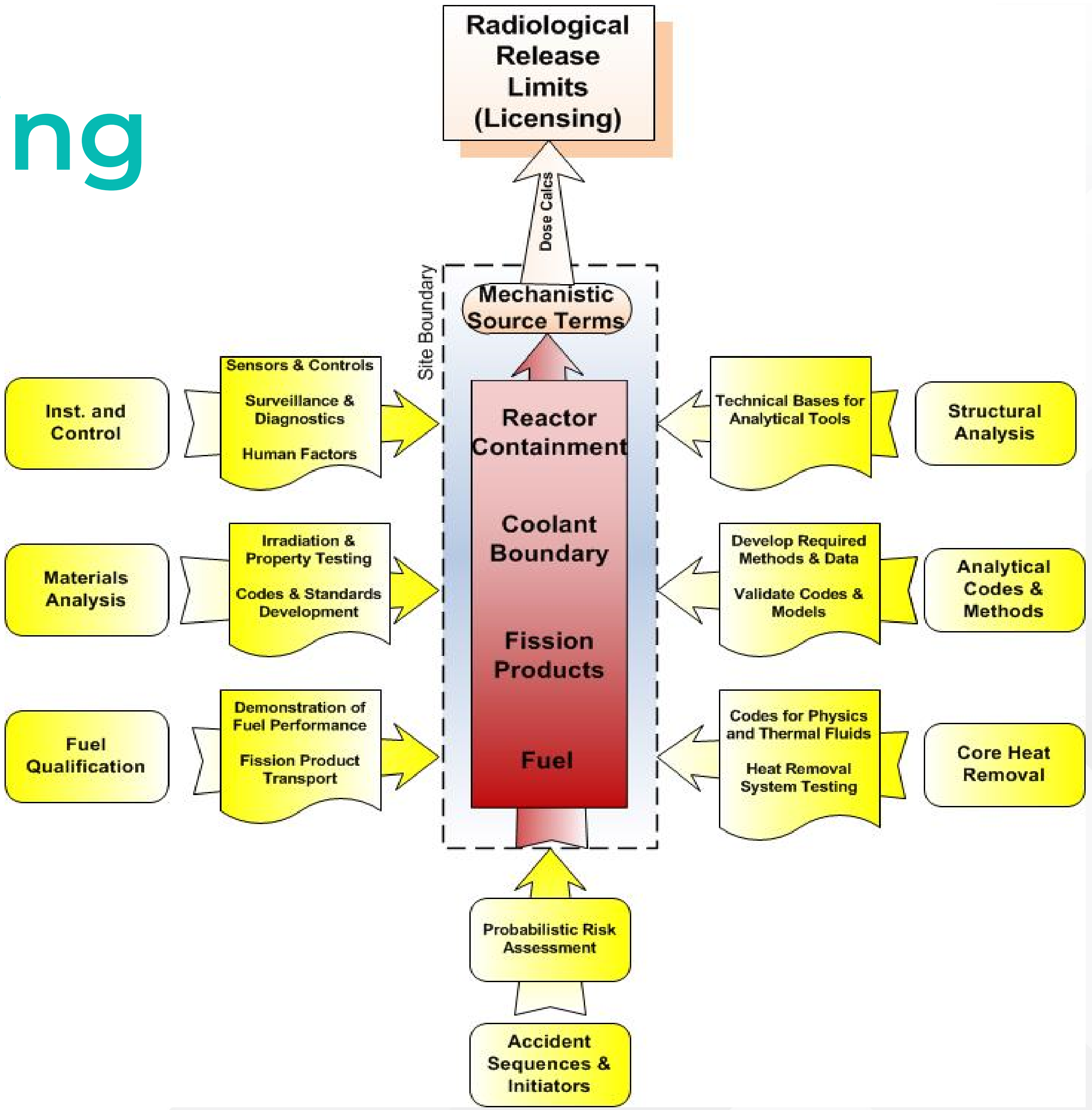
April 24, 2024

Overview of Licensing Inputs

All advanced reactor deployments will need to develop a design and associated safety case that satisfy regulatory requirements regarding protection of the public.

Multiple and integrated technical inputs are needed (advanced materials, cybersecurity, radionuclide transport analysis, etc.) and rely heavily on DOE programs.

Multiple DOE program efforts, including NRIC and the Advanced Reactor Regulatory Development Program, seek to help close technical and regulatory gaps that are inherent in the licensing tree depicted above for new advanced technologies.



Overview of Regulatory Development Structure

Advanced Reactor Regulatory Development is one part of the DOE's Advanced Reactor Demonstration Program (ARDP):

- Advanced Reactor Demonstration Projects (funded via DOE's OCED)
- Risk Reduction for Future Demonstrations
- National Reactor Innovation Center
- Advanced Reactor Regulatory Development
- Advanced Reactor Safeguards

Advanced Reactor Regulatory Development then has four major components:

- Regulatory Framework Modernization
- Fast Reactor Regulatory Development R&D
- Molten Salt Reactor Regulatory Development R&D
- Gas Reactor Regulatory Development R&D

Connections to DOE-NE Mission

DOE-NE Mission: Advance nuclear energy science and technology to meet U.S. energy, environmental, and economic needs.

Mission Goal # 2: Enable deployment of advanced nuclear reactors.

Objectives:

1. Reduce risk and time needed to deploy advanced nuclear technology.
2. Develop reactors that expand market opportunities for nuclear energy.
3. Support a diversity of designs that improve resource utilization.

It's noted that every commercial deployment of an advanced reactor will require regulatory engagement by the developer and the facility's owner/operator(s).

NRC's Implementation Action Plan (IAP)

The IAP is an U.S. Nuclear Regulatory Commission (NRC) initiative originated in 2015 to establish a strategy to assure NRC readiness to effectively and efficiently review non-water reactors, including the consideration of their fuel cycles and waste forms:

- NRC gathered industry inputs in 2015–2017 to identify and confirm readiness needs
- The IAP was issued in 2017 with 6 major focus areas identified.

Strategy 1	**Strategy 2**	**Strategy 3**	**Strategy 4**	**Strategy 5**	**Strategy 6**
Knowledge, Skills and Capability	Computer Codes & Review Tools	Flexible Review Processes	Consensus Codes and Standards	Policy and Key Technical Issues	Communication

DOE-funded programs are focused on strategy areas 2, 3, 4, & 5, and include for example:

- Strategy 2 NEAMS Program, ART Program, Microreactor Program
- Strategy 3 Non-LWR design criteria, Licensing Modernization Project, TICAP/ARCAP
- Strategy 4 ASME Section III Div. 5, Non-LWR PRA Standard, ANS 20.2
- Strategy 5 Functional containment, "right-sized" emergency planning, microreactor policy issues

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Regulatory Framework Modernization Program

Advanced Non-Water Technologies

Regulatory Framework Modernization Program

The Regulatory Framework Modernization part of the Regulatory Development subprogram coordinates with industry and the NRC to address and resolve key regulatory framework issues that directly impact the “critical path” to advanced reactor demonstration and deployment.

This area focuses on risk-informing and adapting (“modernizing”) the regulatory framework for commercial reactor facilities, including:

- Commission policy issue resolution
- Developing adaptations of light-water reactor (LWR)-based regulations for advanced non-LWRs
- Establishing risk-informed performance-based NRC license application content and review criteria guidance
- Establishing risk-informed regulatory approaches for key parts of the plant operations phase.

These program efforts are focused on achieving formal NRC endorsement or approval, where applicable, so that these areas of regulatory uncertainty are clearly resolved.

It’s noted that the identification and prioritization of scope considers topics that are specific regulatory challenges to ARDP awardees, and whose resolution would benefit both the awardees and the broader advanced reactor stakeholder community.

Examples & Outcomes of Completed Program Efforts

Regulatory Framework Modernization Program efforts have resulted in the elimination of regulatory uncertainties in key areas supporting advanced reactor deployments. This involved the development of regulatory proposals, coordinated with industry, that have been formally approved or endorsed by NRC for industry use, such as:

- Licensing Modernization Project (LMP) – NRC endorsed in Regulatory Guide 1.233
  - Established a risk-informed and performance-based approach to advanced reactor design and licensing
- Technology Inclusive Content of Application Project (TICAP) – NRC endorsed in Regulatory Guide 1.253
  - Provides guidance to both industry and NRC staff on LMP-based license application content expectations
  - Being utilized by the two DOE-ARDP awardees (TerraPower & X-energy) for commercial licensing
- Use of historical DOE experimental databases to support NRC licensing
  - NRC Safety Evaluation approving Argonne National Laboratory QA program to qualify certain EBR-II historical data
- Use of DOE R&D program results to support industry fuel qualification efforts
  - NRC Safety Evaluation of EPRI topical report that establishes an accepted foundation for TRISO particle fuel qualification.

Examples of Current Framework Modernization Work

Further Development of Risk-Informed and Performance-Based (RIPB) Approach

- Developed Technology Inclusive Risk Informed Change Evaluation (TIRICE) guidance for non-LWRs to evaluate changes to the facility that meets the intent of the 10 CFR 50.59 regulation for those licensees that have used the Licensing Modernization Project approach
- The Technology Inclusive Management of Safety Case (TIMaSC) project is looking at the full picture of the licensing basis for a plant with an LMP-based safety case provide for integration of the various activities associated with the risk-informed change management of a license

Risk-Informed and Performance-Based Emergency Planning

- Developing a consensus technology-inclusive RIPB approach to establishing the plume exposure EPZ and associated emergency plan

Hazards

- Developing an approach for assessing low-frequency external events as part of a RIPB licensing approach

Liquid Fuel Qualification

- Investigating the MSR-specific NUREG/CR-7299 approach to assess and identify any specific challenges with achieving liquid fuel qualification by addressing the key considerations reflected in NUREG-2246, "Fuel Qualification for Advanced Reactors"

Sodium-Fast Reactor Fire Protection – Industry Standard

- Assist with industry efforts to draft an updated version of ANSI/ANS Standard 54.8 - "Liquid Metal Fire Protection …"

International Collaborations

- Continued GIF-RSWG & IAEA participation, focused primarily on the development of advanced reactor safety design approaches and criteria

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Advanced Reactor Program R&D & Regulatory Connections

Advanced Non-Water Technologies

Fast Reactor Program

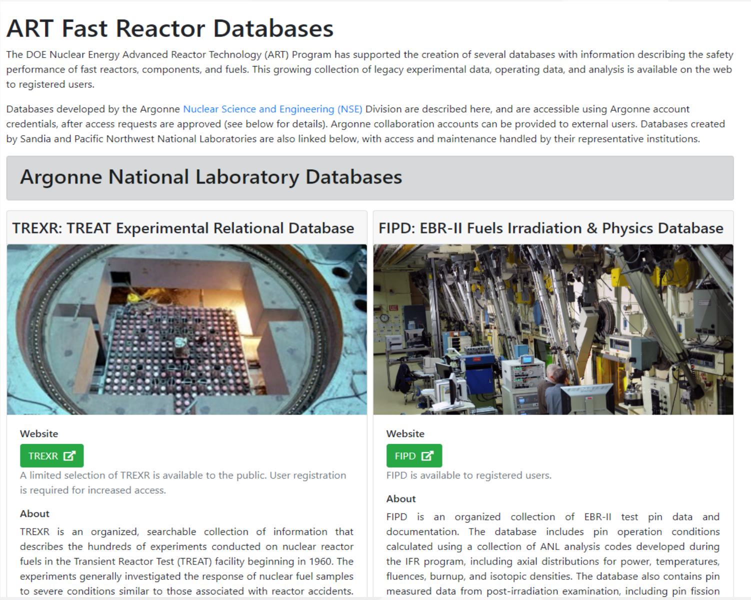
Ongoing research to support licensing:

- Archival of rich U.S. fast reactor operation and testing legacy and data from other test facilities in modern web-accessible databases:
- EBR-II, FFTF, TREAT, and ZPR test / EBR-II and FFTF fuels irradiation and physics databases
- Out-of-pile transient fuel testing & sodium component reliability database
- Maintenance, quality assurance, continued development, and validation of fast reactor physics and systems/safety analysis software to support their use in fast reactor license applications
- SAS4A/SASSYS-1, SRT (source term assessments), SPCA-ANL (sodium fire analysis)
- Generating mechanical properties and sodium compatibility data to support ASME code case for Alloy 709 for structural material use

Current priorities in program's regulatory R&D:

- Extension of NRC-approved FIPD quality assurance program plan (QAPP) to other fast reactor databases and their implementation to support their use in upcoming license applications
- Modern software quality assurance (SQA) practices to support commercial grade dedication of fast reactor software by the vendors

Experimental Breeder Reactor-II (EBR-II)



ART Fast Reactor Databases

The DOE Nuclear Energy Advanced Reactor Technology (ART) Program has supported the creation of several databases with information describing the safety performance of fast reactors, components, and fuels. This growing collection of legacy experimental data, operating data, and analysis is available on the web to registered users.

Databases developed by the Argonne Nuclear Science and Engineering (NSE) Division are described here, and are accessible using Argonne account credentials, after access requests are approved (see below for details). Argonne collaboration accounts can be provided to external users. Databases created by Sandia and Pacific Northwest National Laboratories are also linked below, with access and maintenance handled by their representative institutions.

Argonne National Laboratory Databases

TREXR: TREAT Experimental Relational Database

Website

TREXR

A limited selection of TREXR is available to the public. User registration is required for increased access.

About

TREXR is an organized, searchable collection of information that describes the hundreds of experiments conducted on nuclear reactor fuels in the Transient Reactor Test (TREAT) facility beginning in 1960. The experiments generally investigated the response of nuclear fuel samples to severe conditions similar to those associated with reactor accidents.

FIPD: EBR-II Fuels Irradiation & Physics Database

Website

FIPD

FIPD is available to registered users.

About

FIPD is an organized collection of EBR-II test pin data and documentation. The database includes pin operation conditions calculated using a collection of ANL analysis codes developed during the IFR program, including axial distributions for power, temperatures, fluences, burnup, and isotopic densities. The database also contains pin measured data from post-irradiation examination, including pin fission

Molten Salt Reactor Program: Technical Areas of Strategic R&D

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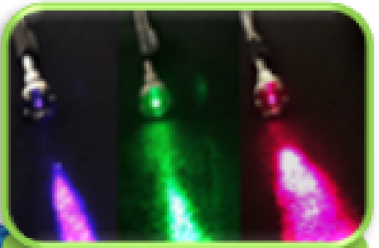
Determination of the Thermophysical and Thermochemical Properties of Molten Salts – Experimentally and Computationally

Salt Chemistry

Mission : Develop the technological foundations to enable MSRs for safe and economical operations while maintaining a high level of proliferation resistance.



Technology Development

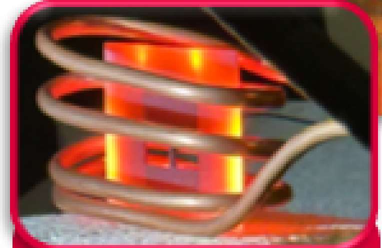
Los Alamos NATIONAL LABORATORY

Off Gas Management
Radionuclide Release Monitoring, Sensors & Instrumentation
LSTL & FASTR

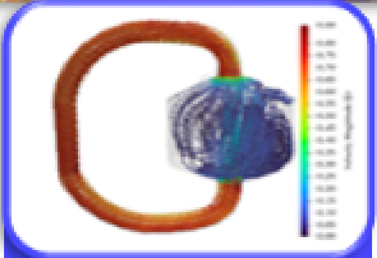
INL Idaho National Laboratory

Pacific Northwest NATIONAL LABORATORY

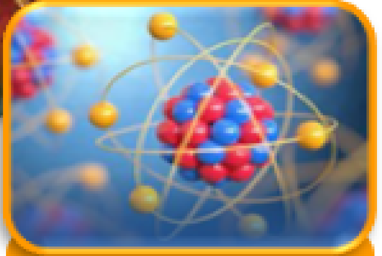
Development of materials surveillance technology
Graphite/Salt Interaction
Materials/Salt Interaction



Advanced Materials



Mod & Sim



MSR Radioisotopes

Developing new technologies to separate radioisotopes of interest to the MSR community

OAK RIDGE National Laboratory

Sandia National Laboratories

Resolve technical gaps related to mechanistic source term (MST) modeling and simulation tools.
Modeling radionuclide transport from a molten salt to different regions of an operating MSR plant

Molten Salt Reactor PROGRAM

Gas-Cooled Reactors Regulatory R&D Activities

Summary of current R&D activities that support industry regulatory engagements:

- TRISO: The June 2023 joint report by the Canadian Nuclear Safety Commission (CNSC) and the NRC establishes a common regulatory position on TRISO fuel qualification
- Metallics and Graphite
  - Qualify and incorporate Alloy 709 into the ASME Code
  - Complete high-dose graphite (HDG) experiments to provide baseline vs. irradiation performance data
  - Develop and implement high-temperature design methodology needed for advanced reactor designs into the ASME Code
- HTGR Core Simulation and Methods Development & Validation
  - New codes developed in the DOE-NE NEAMS
  - Domestic and international code validations (GIF/JAEA bi-lateral agreements through Generation 4 Forum)


U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

U.S. NRC—CNSC Memorandum of Cooperation

FINAL REPORT
concerning
Tristructural Isotropic (TRISO) Fuel Qualification

June 2023

Stakeholder Engagement & Coordination

Regulatory Engagement Considerations

DOE program outputs have a number of connections to industry regulatory engagements – close coordination is critical:

- Currently ongoing NRC licensing reviews (Kairos-Hermes 2, Abilene Christian-NEXT, Terra Power construction permit)
- Design and commercial license application development is underway (incl. DOE ARDP awardees)
- NRC pre-application interactions by various industry advanced reactor technology stakeholders are underway

General types of regulatory engagement directly supported by DOE NE-5 programs:

- Completion of R&D that provides experimental results, data, and validated methods that are reflected in DOE national laboratory reports (OSTI) that can be directly referenced by industry stakeholders in support of their license applications and associated regulatory interactions

- Completion of R&D and development of associated industry proposals that are submitted to NRC for formal endorsement and can then be utilized by multiple industry stakeholders without additional "up-front" regulatory approach evaluation

Regulatory Development Support for NRIC and Industry Needs

Regulatory Development obtains inputs from key stakeholders and reports (DOE, NEI/NEA, Developers, NRC, etc.) to prioritize and propose regulatory projects. Examples:

- Participation in NEI New Reactor Regulatory Working Group
- Regulatory topics within EPRI/NEI Advanced Reactor Roadmap – North America
- Participation in DOE advanced reactor technology program reviews

Regulatory development leadership desires additional information to meet the needs of NRIC and NRIC customers

Avenues for stakeholder engagement and input:

- Jim Kinsey, Technical Area Lead, Regulatory Framework Modernization Program
  jim.kinsey@inl.gov / (208) 569-6751
- Brad Tomer, National Technical Director, NRIC Programs
  bradley.tomer@inl.gov / (208) 526-2679

Questions?

NRIC National Reactor Innovation Center

X-energy ARDP

Luke Voss, Program Manager

04/24/2024

X-energy ARDP INL Support Team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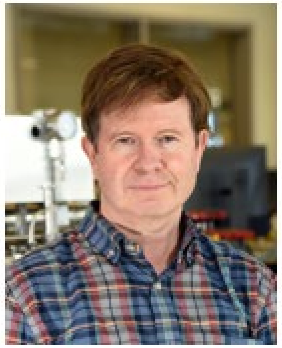
Principal Investigator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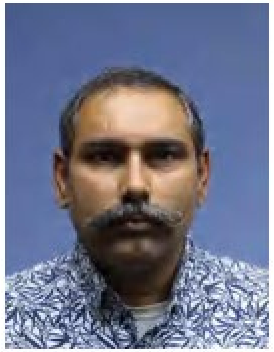
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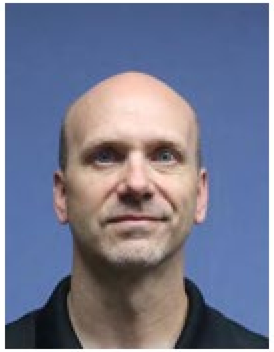
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Changhu Xing
Ryan Marlow
Mehmet Turkmen
Matilda Aberg Lindell
Giuseppe Palmiotti
Matthew Eklund
Lise Charlot
Gerhard Strydom

XPeRT-1: Xe-100 Test Fuel Irradiation Campaign

James B. Tompkins, ARDP Nuclear Fuel Lead

April 23, 2024

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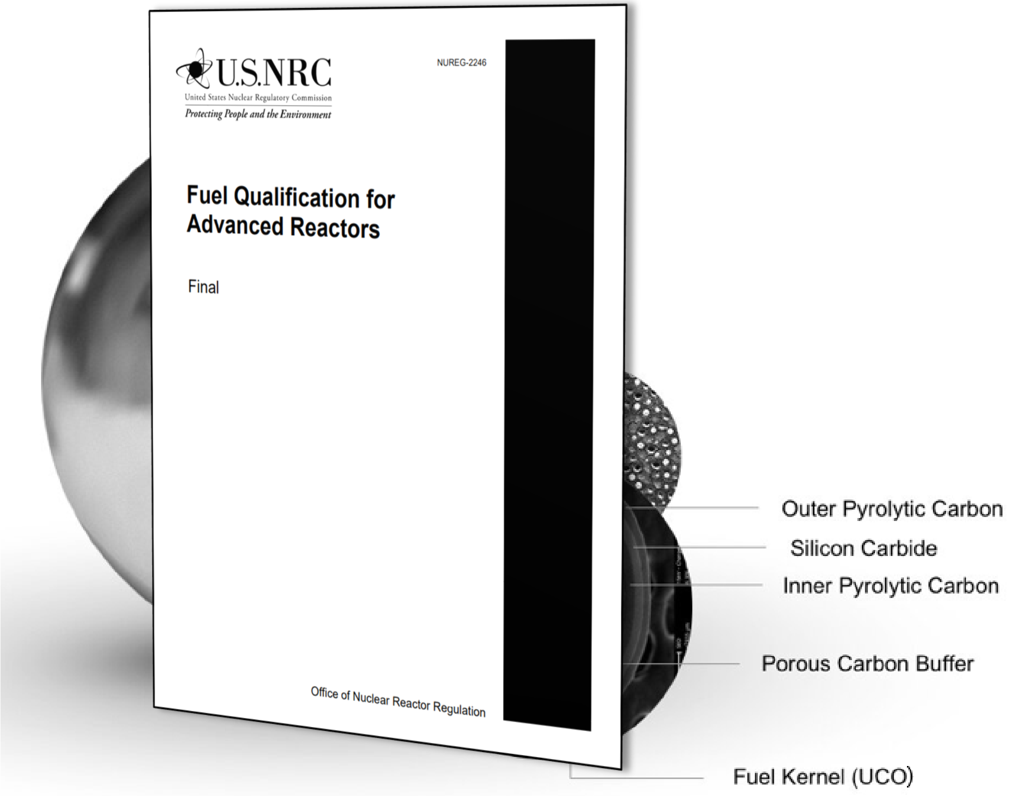
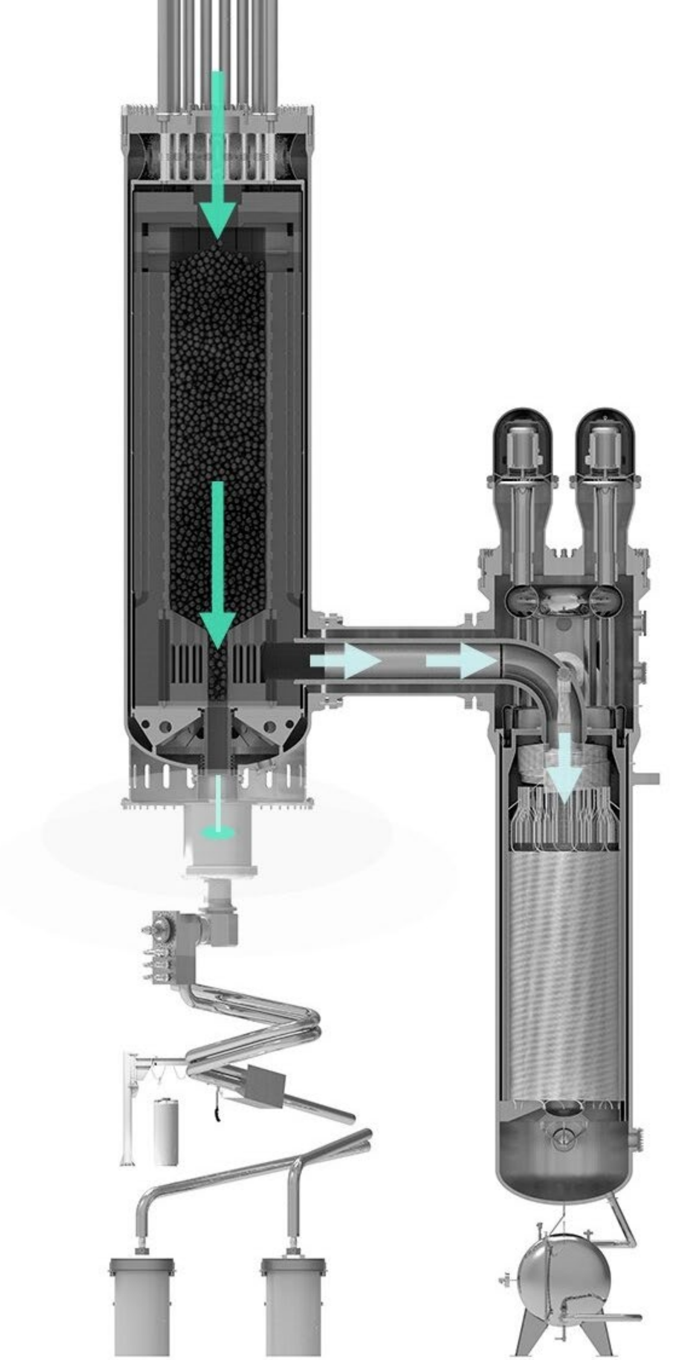
X-energy Gen IV SMR: Xe-100

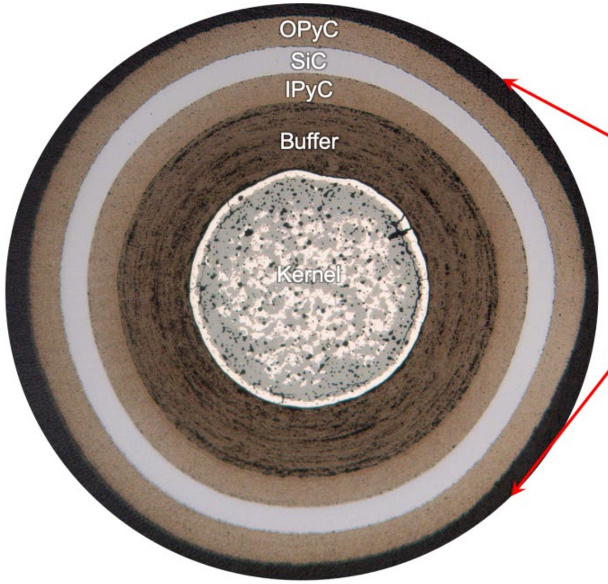
- Pebble Bed Modular High Temperature Gas-cooled Reactor (PB-HTGR)
- 200 MW thermal power for electricity generation (80 MWe) or high temperature process heating
- TRISO-coated UCO fuel in pebble form
- How to accomplish fuel qualification?



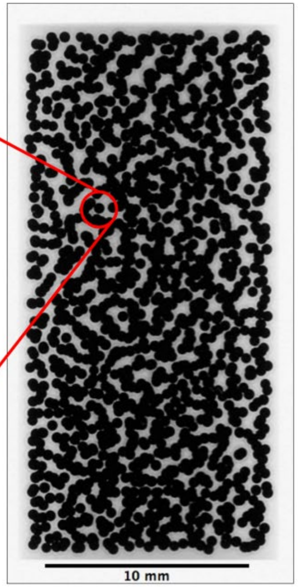


Mapping DOE AGR to Xe-100 Fuel Qualification

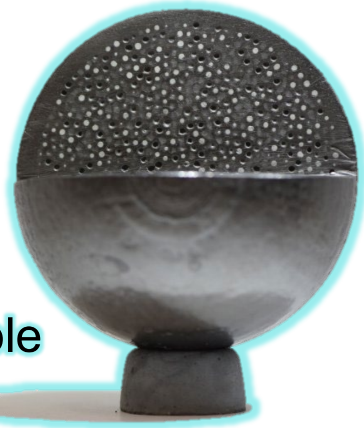
AGR TRISO Particle



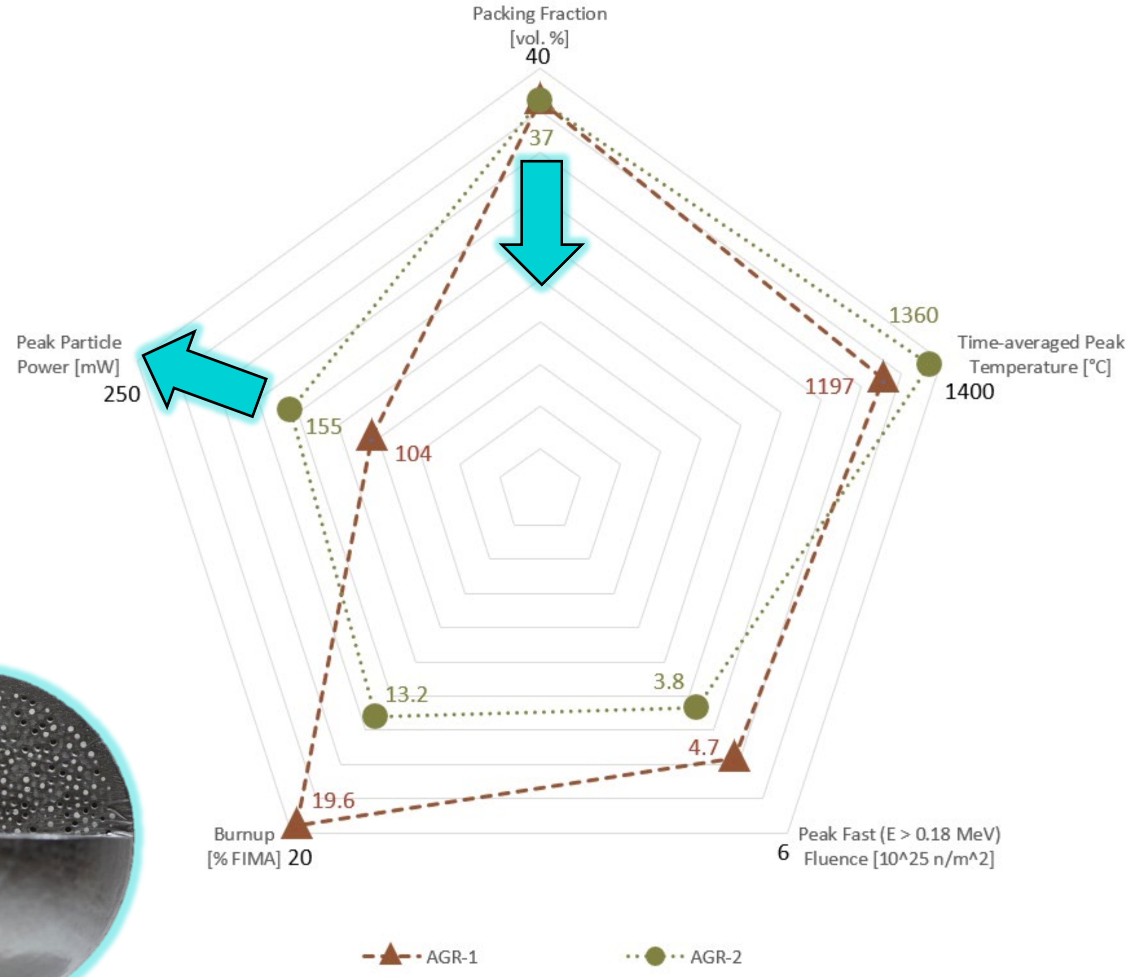
AGR Fuel Compact



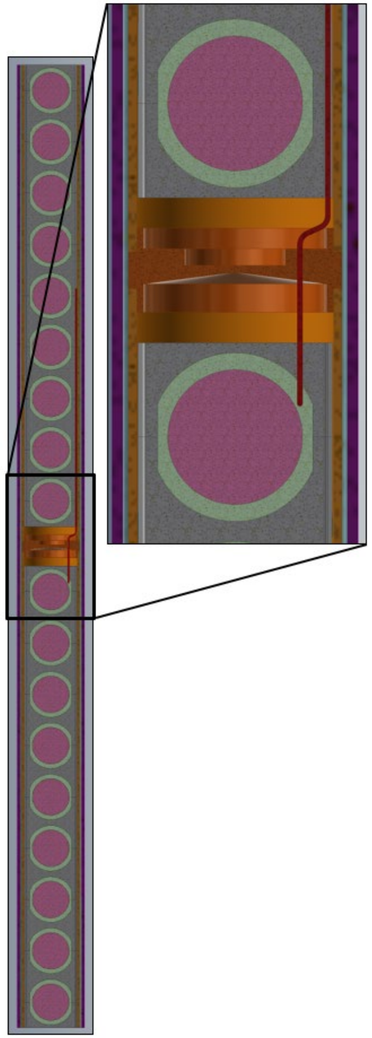
* T. J. Gerczak and J. D. Hunn, "AGR PROGRAM METHODOLOGY FOR EXAMINING TRISO FUEL PERFORMANCE AND PARTICLE FAILURE," presented at the 15th International Conference on CANDU Fuel, Aug. 2022. Accessed: Apr. 03, 2024. [Online]. Available: https://www.osti.gov/servlets/purl/1888923



TRISO-X Fuel Pebble

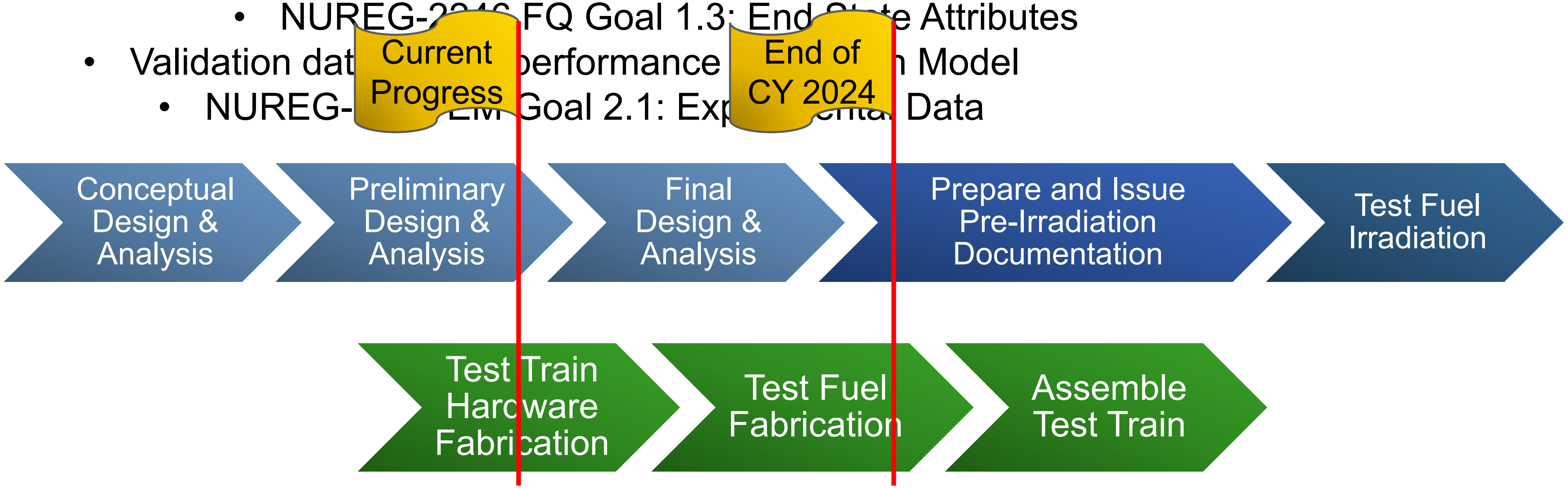


X-energy Pebble Reactor Test (XPeRT-1)

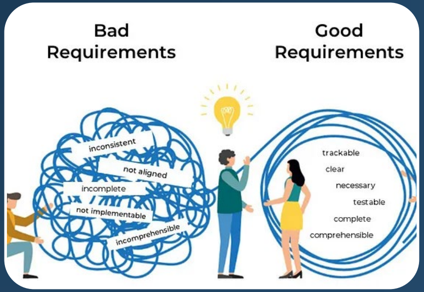


Testing Objectives

- Collect data to demonstrate performance of TRISO-X fuel pebbles in Xe-100
  - NUREG-2246 FQ Goal 2.1.1: Definition of Fuel Performance Envelope
  - NUREG-2246 ED Goal 4: Test Conditions
- Demonstrate performance consistent with AGR fuel
  - Radionuclide release
    - NUREG-2246 FQ Goal 2.2.3(b): Conservative Modeling of Radionuclide Retention and Release – Experiment Data
  - Microstructure
    - NUREG-2[illegible] FQ Goal 1.3: End [illegible]e Attributes
- Validation dat[illegible] performance [illegible]n Model
  - NUREG-[illegible] Goal 2.1: Exp[illegible] Data

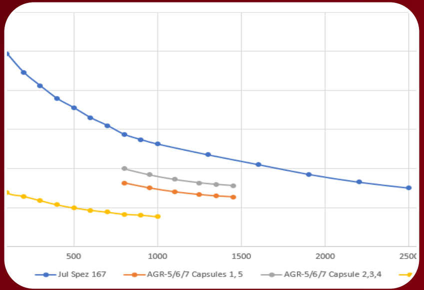


XPeRT-1 Collaborative Activities



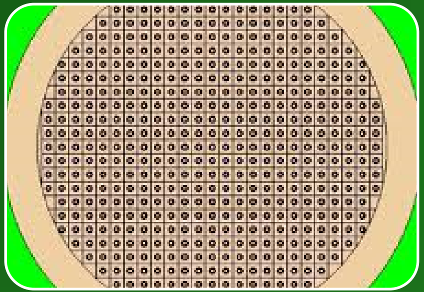
Functional & Operational Requirements

- Developed Requirements during Conceptual Design.
- Received feedback on risks to meeting Requirements from CDR.
- Revisited Requirements in Preliminary Design.
- Refined design to meet Requirements.



Thermal Modeling Alignment

- Reviewed thermal material property data.
- Alignment activities between XE and INL groups to discuss methods.
- Chose models and methods appropriate for test articles.



Neutronic Modeling Alignment

- Surveyed TRISO neutron transport methodologies.
- Held meetings to facilitate knowledge transfer between XE and INL SMEs.
- Determined error between homogeneous and explicit TRISO neutronics models for XPeRT-1.

Closing  Remarks

NRIC National Reactor Innovation Center

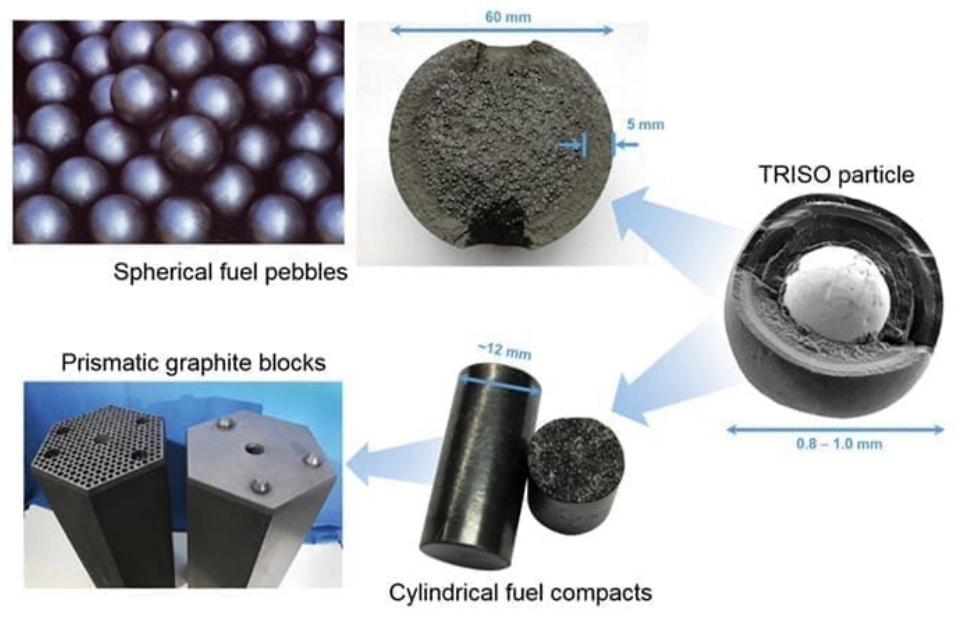
BANR-1 Program Update

Sam Reiss, Technical Program Manager (INL)
Mike Haggerty, Program Manager (BWXT)

April 24th, 2024

BANR-1: BWXT Advanced Reactor Demonstration Program (ARDP)

- 7-year DOE cost-shared ARDP with $24.3M of INL scope
  - Years 1-3: test train design
  - Years 4-5: irradiation
  - Years 5-7: post-irradiation examination (PIE)
- Irradiation of uranium nitride (UN) tri-structural isotropic (TRISO) prismatic fuel in ATR
- PIE will be conducted at MFC and ORNL
- NRIC overseeing program and ensuring continuity between disciplines/steps



BWXT ARDP Overview

Leverage INL learnings from Advanced Gas Reactor (AGR) programs and ORNL fuel expertise

- Uranium Nitride (UN) instead of Uranium Carbon Oxygen (UCO)
- Silicon Carbide (SiC) instead of graphitic matrix

Program leverages multiple functional areas

- Mechanical design, Neutronics, Thermal hydraulics, Modeling and simulation, structural analysis, TRISO expertise, Irradiation, Post-Irradiaton Examination (PIE)

Aligns with NRIC mission of strong private-public partnerships to expedite advanced reactor commercialization

- De-risking BWXTs gas cooled reactor, providing expertise, irradiation and PIE facilities

Seven-year program, $24.3M scope at INL

- Currently in year 3 of work

BWXT Perspective

BWXT ADVANCED TECHNOLOGIES

From Concept to Reality

Design, build and test new nuclear

Mike Haggerty

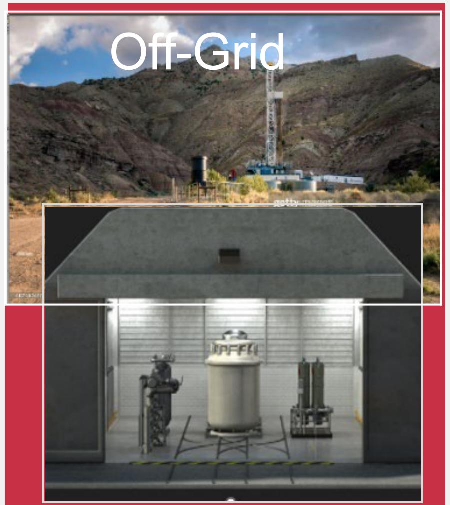
Program Manager
BWXT Advanced Nuclear Reactor (BANR)
BWXT Advanced Technologies LLC

BWX Technologies, Inc.

Land

Electric & Thermal Energy

- Military operations
- Reduced vulnerabilities and signature



- Data centers
- Small footprint
- Mining, Oil & gas sites

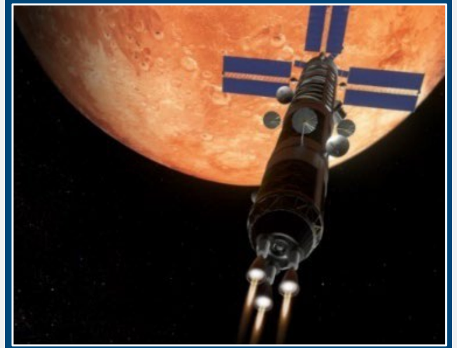
Sea

Naval Nuclear Propulsion

- Naval nuclear reactors and components
- Nuclear fuel & materials

Space

Propulsion & power



- Thermal propulsion for rapid transit in the cis-lunar volume
- Deeper space exploration

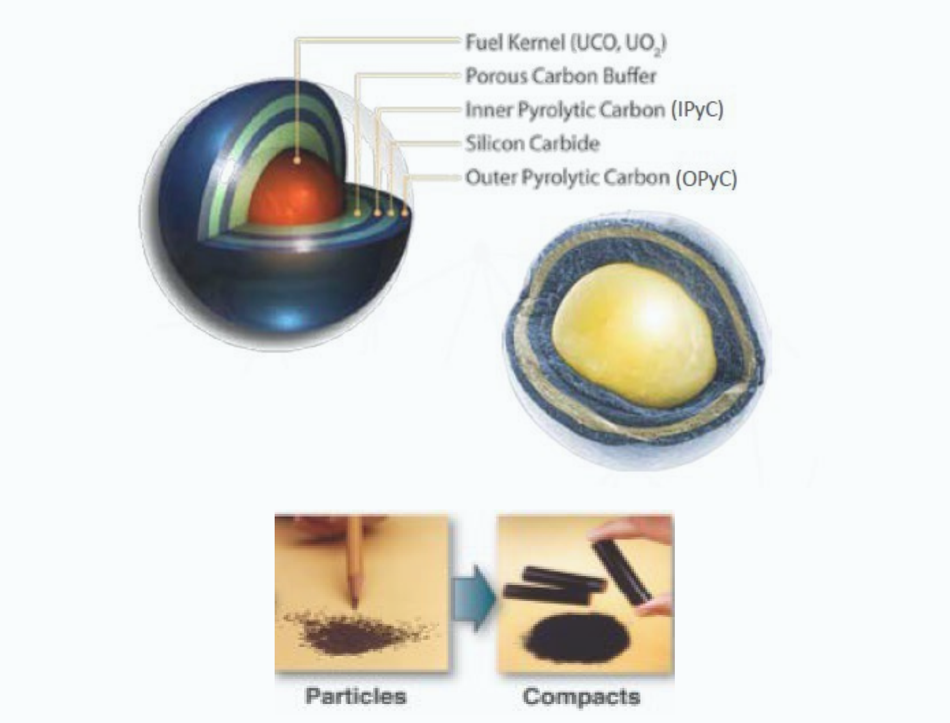
BWXT Advanced Nuclear Reactor (BANR)

50 MW_{th} per reactor, scalable to site needs

- Flexible power conversion: heat, electricity or co-generation
- High Temperature gas (HTGR) coolant technology
- High density, BWXT-fabricated fuel enables 5+ year refueling cycles
- Passive inherent safety
- Rapid modular installation & refueling

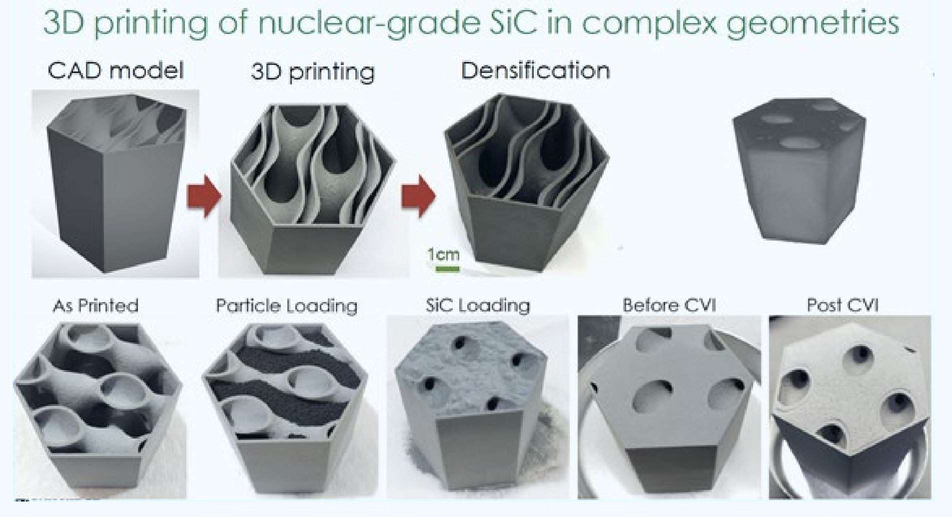
BANR ARDP Technology Development

Feasibility Study based on Advanced Gas Reactor (AGR) TRISO Fuel



- UCO fuel kernel coated with multiple layers of pyrocarbon (PyC) and Silicon Carbide (SiC)
- Can withstand extreme temperatures well beyond the threshold of current nuclear fuels
- Each particle acts as its own containment, retaining fission products under all conditions

ARDP Application upgrades BANR to a higher density UN TRISO Fuel



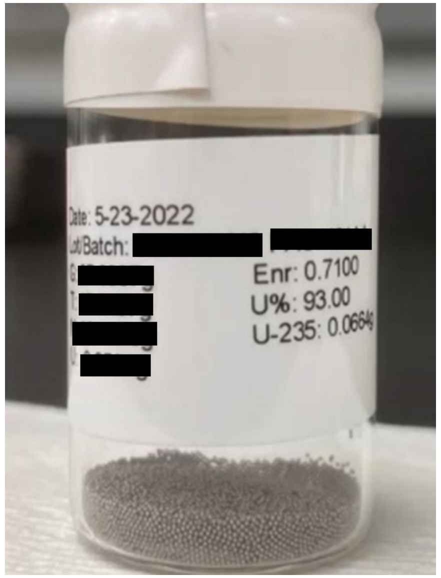
TCR Fuel Elements – Photo from ORNL

- UN fuel kernels packed in fuel shell
- UN fuel kernel provides ~ 2X fuel density compared to UCO or UO_2 … increasing power and extending core life
- Advanced manufacturing optimizes design, reduces cost & improves throughput
- Commercializes existing DOE development work

UN TRISO Fuel Development

- Particle Design Optimization 2021 – 2023
  - Significant modeling and simulation effort
    - BISON – fuel performance
    - MCNP – core analysis
    - MIXCOATL – core thermal hydraulics
  - Established particle architecture

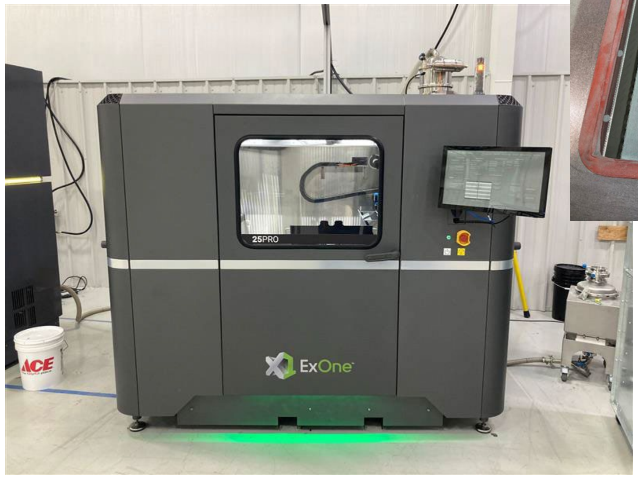
- TRISO Fabrication
  - Kernel fabrication development complete; HALEU kernel fabrication in progress
  - Coating development on surrogate material begins this Spring



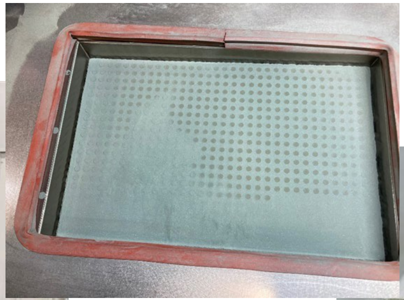
UN Kernel Development Complete

Fuel Element Development

- Fuel Element Shell
  - Binder Jet installed and operating
  - Fabrication process parameters developed
  - Packing studies performed



BWXT's Binder Jet



Fabrication

Packing Studies

- CVI Densification
  - BWXT furnace installation
  - ORNL furnace commissioning
  - UConn early development

BWXT CVI Furnace Installed

MTS Gas Cabinets

Supply Gas Installed

Wyoming - Microreactor Assessment

WEA Project Phase 1 (under contract)

- Microreactor Design & Site tailored to end-user requirements
- Supply Chain assessment
- Rough Order of Magnitude Estimate
- Licensing Roadmap

WEA Project Phase 2 (future option)

- Conceptual Design for lead unit
- Supply Chain demo & QA evaluation
- Regulatory Engagement Plan
- Fleet Economics Model

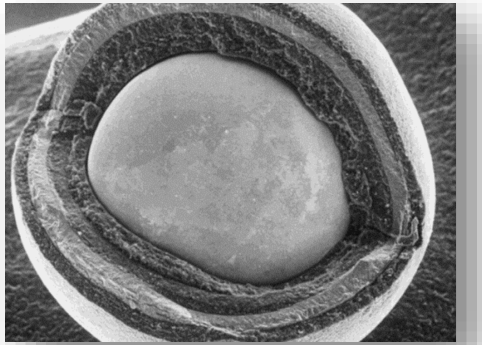
WEA Project Phase 3 (notional)

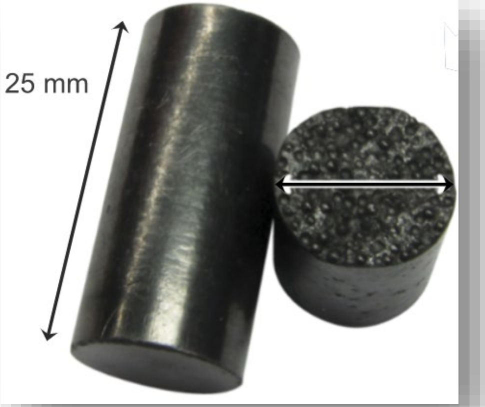
- Complete design
- Site preparation, licensing
- Manufacturing
- Wyoming deployment support
- Build & demonstration

BWXT AT Microreactor Program
U. S. DOE Advanced Reactor Demonstration Program

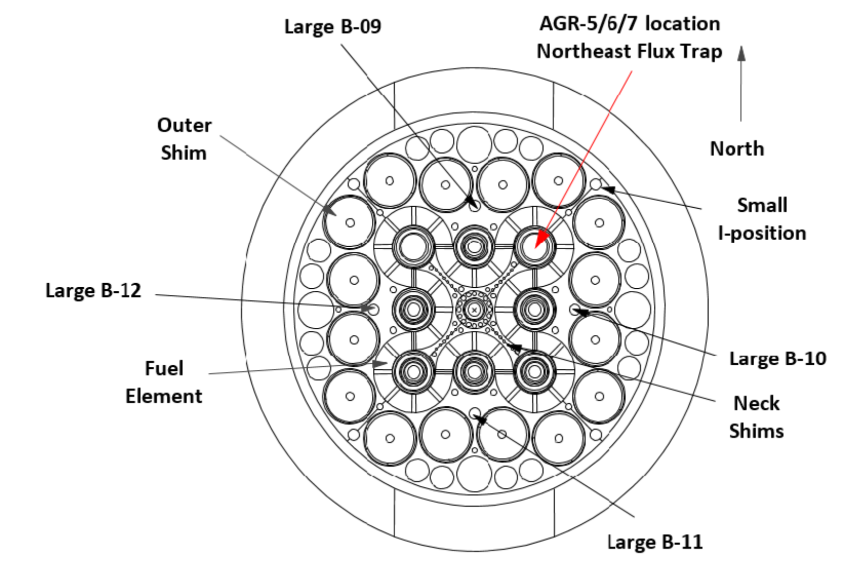
Wyoming – End User Requirements & Supplier Engagement

INL Perspective

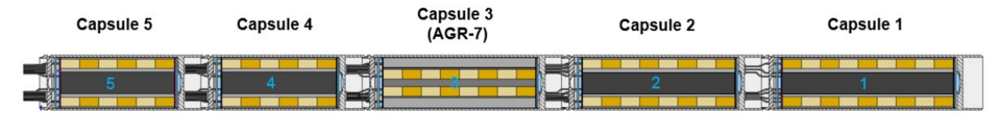




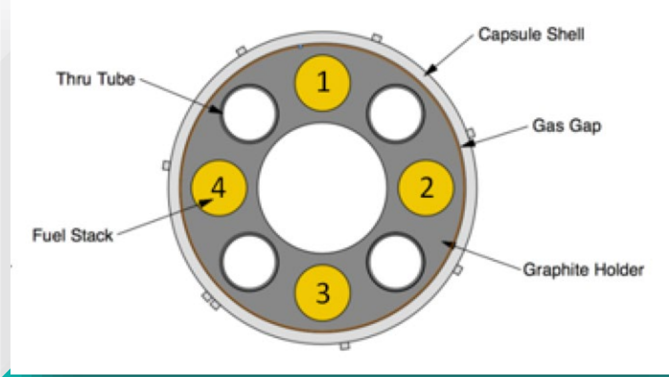
25 mm



Large B-09
AGR-5/6/7 location
Northeast Flux Trap
Outer
Shim
North
Small
I-position
Large B-12
Large B-10
Fuel
Element
Neck
Shims
Large B-11



Capsule 5
Capsule 4
Capsule 3
(AGR-7)
Capsule 2
Capsule 1



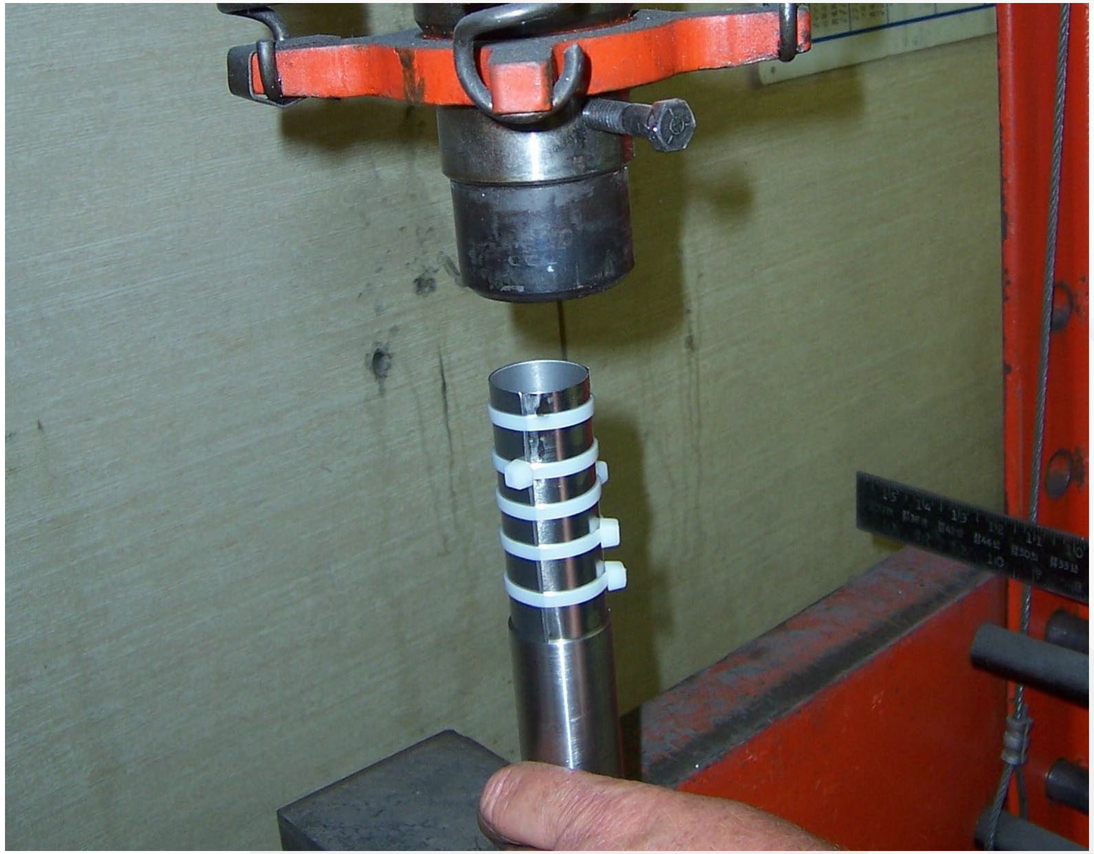
Capsule Shell
Thru Tube
Gas Gap
Fuel Stack
Graphite Holder
1
2
3
4

Current Progress

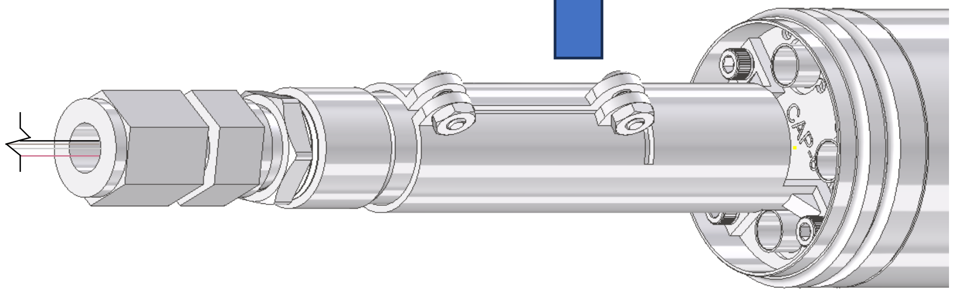
Hafnium Foil for Neutronics Control

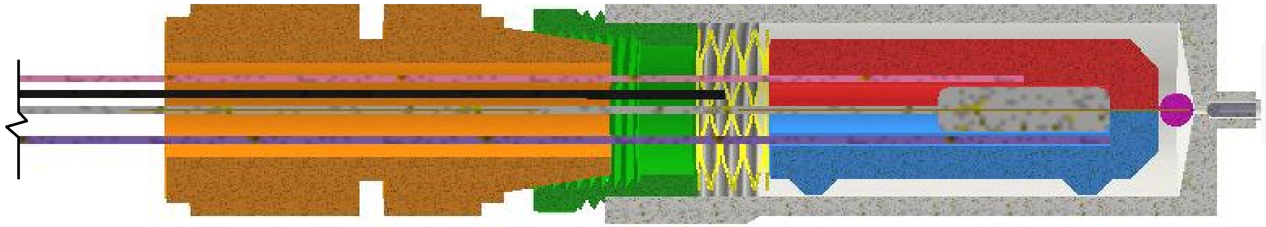
- Hafnium foil loading in capsule body
- Use of the foil is required to reach ideal fast/thermal neutron flux

Key Contributors: Joe Palmer, Tiger Xing, Dong Choe



Additive Manufactured Test Piece





- 3D printed prototype
- Will secure optical fiber pressure sensor
- Non-QA version to ensure supplier can meet requirements

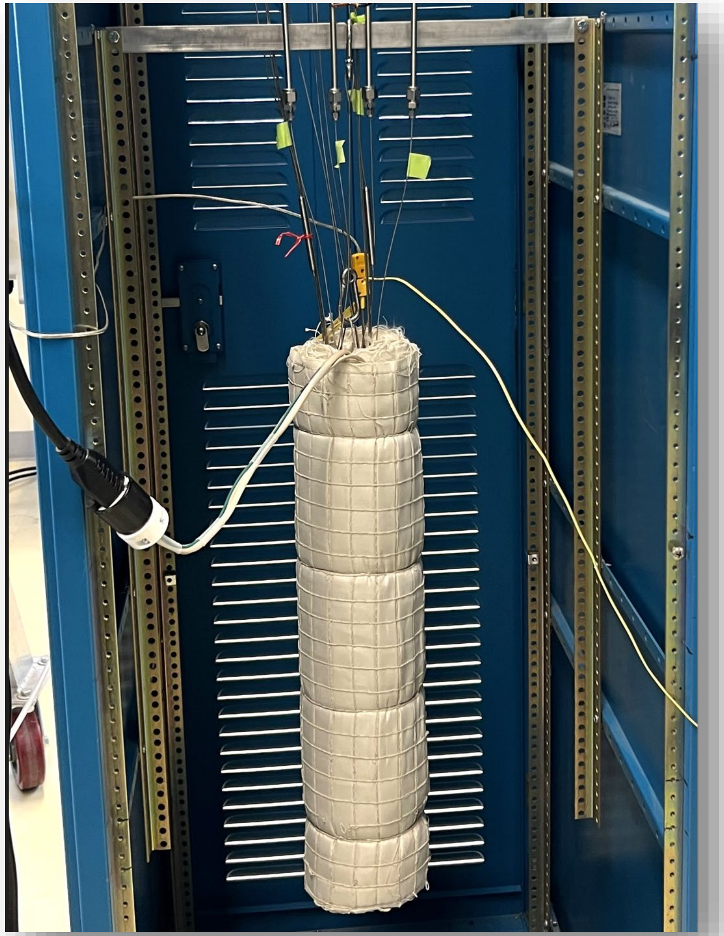
Key Contributors: Joe Palmer, Dakota Neary

Capsules Manufactured for Core-Section Mockup

- Summer 2024 will test assembly of capsules before summer 2025 actual assembly
- 3 of 6 test capsules pictured
- Horizontal stripes are laser etched markers for hot cell cutting of test post-irradiation

Key Contributors: Joe Palmer, Dakota Neary, Bill Schultz

Two-Capsule Heated Mockup Undergoing Testing



- Mockup to test whether brazing ultrasonic temperature transducer and bending it will suppress signal
- 600C heated test
- Test successful, sensor will be used in this configuration

Key Contributors: Richard Skifton, Joe Palmer, Jonathan Littlejohn

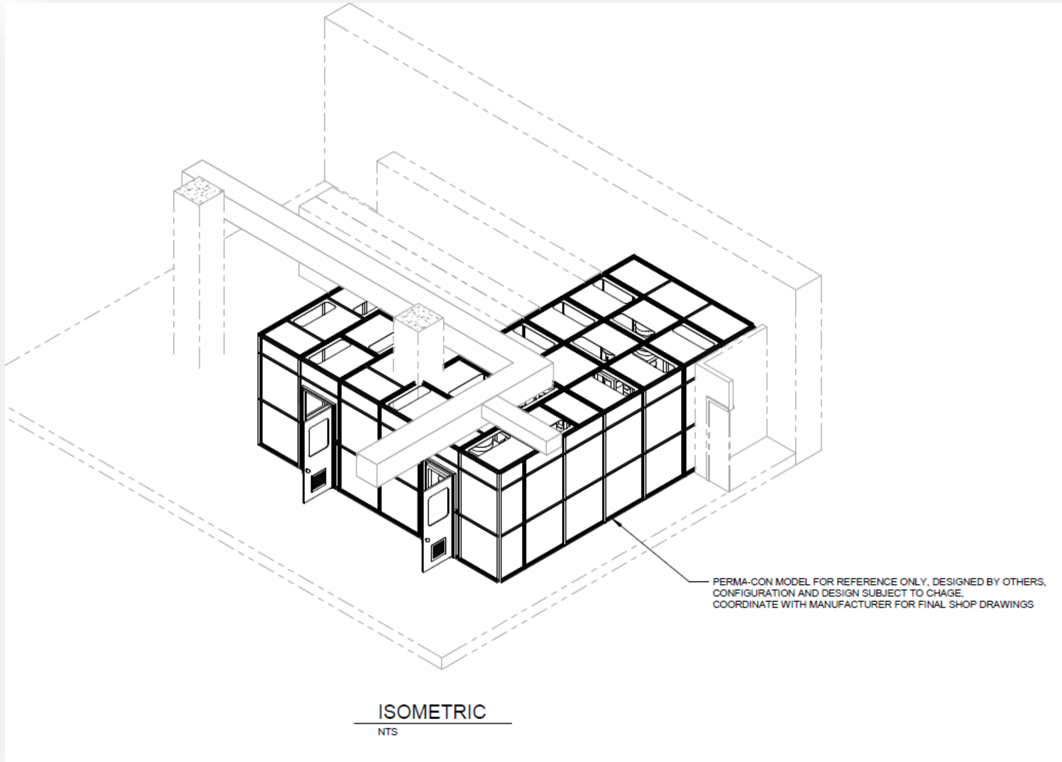
Thermocouples and Gas Lines for BANR-1 Received

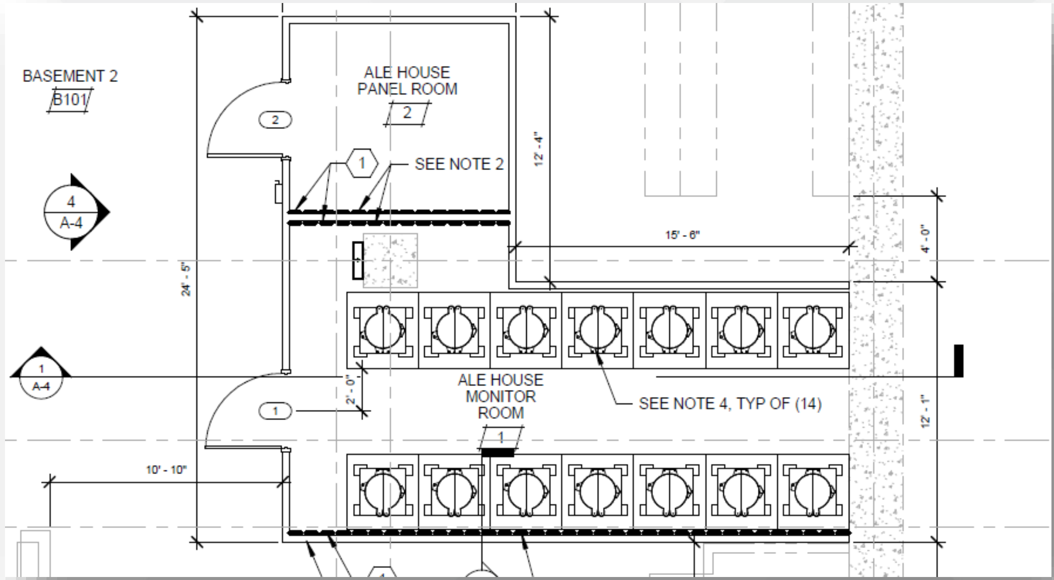
All the single point Type N TCs needed for BANR-1 have been received. [A few multi-point TCs are still on order.] The green tags visible in the photo show that the TCs have passed quality inspection.

BANR-1 uses larger diameter gas lines with thicker walls than AGR-5/6/7 to reduce chances of failure. These are 2 mm custom drawn lines.

- Joe Palmer, Pattrick Calderoni

Auxiliary Leadout Experiment (ALE) House Progress





ATR funded work that will support the BANR-1 program.

Key Contributors: Marvin Guzman, Wes Smith, Dakota Neary

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Questions?

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