# BWXT Advanced Nuclear Reactor (BANR)
# Regulatory Update
# BANR-LTR-23-0489
# Public Meeting

BWX Technologies, Inc.

October 24, 2023

# Agenda

1. Goals and Objectives
2. Fuel Qualification Plan White Paper
3. TRISO Fuel and Core Analysis
4. Fuel Manufacturing Development
5. Irradiation Testing
6. Fuel PIRT
7. Review, Questions, Actions

# 1 – Goals and Objectives

- BWXT to provide NRC Staff with technical updates
  - Progress on white paper
  - Fuel Manufacturing
  - Core Design / Neutronics
  - Irradiation Testing
  - Post Irradiation Examination
  - PIRT
- BWXT/NRC Open Discussion
  - Technology Development
  - Fuel Qualification approach
- BWXT listen to comments, feedback, areas of concern from NRC Staff

# 2 – Fuel Qualification Plan White Paper

- Provide the framework and methodology for Fuel Qualification Topical Report
  - Focus on our ***approach*** to fuel qualification methodology
  - Contents adjusted after June BWXT/NRC meeting
  - Possible follow-on Topical Reports:
    - » Fuel Qualification Methodology
    - » Fuel Qualification for BWXT ARDP BANR

- BWXT Fuel Qualification White Paper to be submitted in December 2023

# 2 – Fuel Qualification Plan White Paper

- Contents and Format Informed by
  - Fuel Qualification Assessment framework (AQFK)
  - Evaluation Model Development and Assessment Process and Graded Approach (RG1.203)
  - Accelerated Fuel Qualification (AFQ)
  - BWXT Design Verification and Validation Process
  - Past fuel qualification submittals
  - Methodology supports Requirements
    - 10 CFR 50 43(e)(1)(i), 43(e)(1)(iii), and 34(a)(1)((ii)(D)
    - 10 CFR 52 47(a)(2)(iv) and 79(a)(1)(vi)
    - General Design Criteria (GDC) contained in Appendix A to 10 CFR Part 50: 2, 10, 27, 35

# 2 – Fuel Qualification Plan White Paper

- Introduction
  - Objectives (*specific feedback desired from NRC*)
  - Discussion of our high-level approach and basis for fuel qualification
- Regulatory Drivers
  - Summary of relevant Regulations and Guidance
  - Summary of US precedence with TRISO (fuel qualification, reactors)
- TRISO particle discussion
  - Details of critical characteristics
- PIRT for Fuel Qualification
  - Comparison to historical fuels, e.g. AGR
  - Comparing and differentiating BANR fuel and the AGR fuel
  - Expected Mechanical and structural performance
  - Effects of chemical, thermal, and irradiation
  - Manufacturing process

# 2 – Fuel Qualification Plan White Paper

- Fuel performance modeling
  - Defined analytical approach
    - Consider mechanical and structural performance
    - Consider chemical, thermal, and irradiation effects
- Fuel fabrication specifications
  - Define the manufacturing envelope
  - Tolerances
  - Quality assurance and quality control
- Test plans
  - Modeling and simulation
  - Manufacturing
  - Irradiation
  - Detailed irradiation test plan
  - Post-irradiation examination
- Fuel Performance
  - Irradiation history
  - Comparison of performance envelope to test envelope
  - Benchmark models for code V&V

# 2 – Fuel Qualification Plan White Paper – Approach (1/2)

- BWXT Design Verification-Validation
  - Defines a set of processes and associated terminology used to execute the engineering design stages of a system life cycle.
- EMDAP Principles
  - Determine requirements for EM
  - Develop and assess the adequacy of the EM
- Accelerated Fuel Qualification (AFQ)
  - Iterative engineering scale modeling
  - Iterative Separate Effects Test (SET) analysis
- Existing EMs supporting qualification
  - Systematically identify/evaluate existing EMs
  - Graded approach
  - Extent of design / operational changes requiring reanalysis

## *Objective*

- Core Analysis tasks in support of fuel qualification are:
  - Fuel element design
  - Assessment of neutronic, thermal, and mechanical fuel performance
  - Development of operational range of the reactor

- Models are used to confirm core designs operate and fuel damage does not occur within the range of conditions of the fuel irradiation program:
  - Burnup
  - Fluence
  - Time-averaged temperature and time-at-temperature
  - Power density
  - Packing fraction

# 4 - Fuel Manufacturing Development

## Primary Fuel Element Production Pathway

**Additive Manufacturing**

**Fuel Shell (cups)**

**TRISO Production**

**UN TRISO**

**Chemical Vapor Infiltration**

- Pre-CVI steps
- Fill with Fuel, Matrix
- Combined CVI

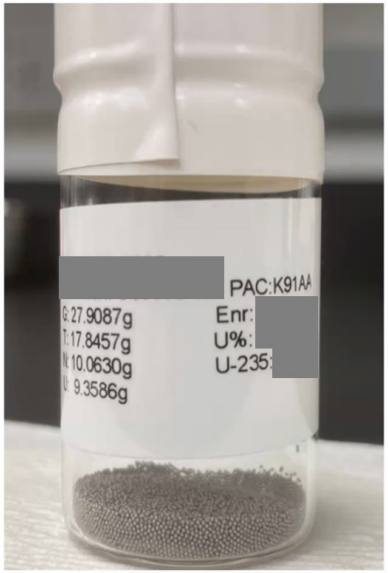
**Fuel Element**

filled with SiC

fully infiltrated with SiC

# 4 - Fuel Manufacturing Development

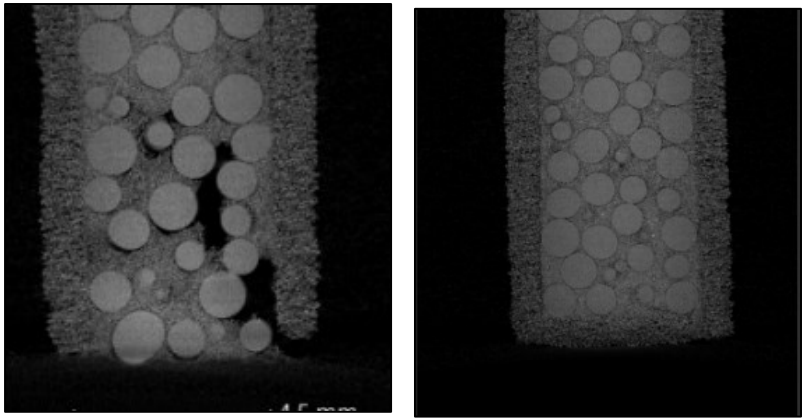
- UN-TRISO Particle Design
  - TRISO particle architecture design sampled
  - Operational parameter spaces sampled
    - >134,000 thermo-mechanical models performed
  - Identified relative impacts of design variables on TRISO particle failure
- UN Kernels Fabricated & Characterized
- Surrogate TRISO Particles Fabricated
- TRISO Furnace Modeling with CFD




*TRISO fuel kernels*

# 4 - Fuel Manufacturing Development

- Data Science and NDE
  - Goal is to detect anomalies and defects in-situ to improve quality and consistency
- Producing large quantities of CVI samples
  - Vital to reduce variance and characterize CVI relevant characteristics
- Leveraging CT Scanning to investigate 3D-printed green bodies
  - Detect anomalies and defects
  - Digital Reconstruction of physical parts



Computerized tomography (CT) scans of SiC preforms loaded with surrogate particles and SiC powder

# 5 – Irradiation Testing

- Irradiate fuel under a range of conditions around BANR operating envelope
- Continuous fission gas monitoring

- Primary PIE Goal
  - PIE is intended to supplement in-pile data to verify or contradict the hypothesis that the ARDP novel fuel form is safe for commercial/industrial use.
- Secondary PIE Goal
  - To better understand the physical phenomena that underpin the safety of the fuel and/or the mechanisms by which the fuel failed during testing.


*Advanced Test Reactor (ATR)*

*Materials and Fuels Complex (MFC)*

## *Integral Fuel Performance Criteria – PIRT Gap Analysis*

- Gap analysis is applied to a “modified” fuel or fuel form designs in order to assess the critical phenomena and methods associated with fuel performance.
- The procedure is designed to inform upon
  - Experimental data (ED) – fuel qualification
  - Evaluation Model (EM) - fuel qualification
  - Manufacturing – specification, SET/IET test specimens
- The procedure output is designed to inform and assess:
  - The modified fuel designs risks reduction strategy
  - Design based decisions

# 6 – Fuel PIRT

- Identification
  - Decision on whether the phenomena or method has been modified
  - Compile available applicable literature or database(s) covering the relevant experimental, analytical, and physical process data
- Importance, Knowledge, Criteria
  - Rank the magnitude and give a rationale in order to establish a hierarchy of the changes
- Closure
  - Identify studies, tests, databases or deliverables needed to fill in gaps in the phenomena or method

# Open Discussion, Questions, Actions, and Feedback