BWXT Advanced Nuclear Reactor
Advanced Reactor Demonstration Program
Fuel Qualification– 2026 Q3 Update

September 22, 2026

Acknowledgement and Disclaimer

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Agenda

- Introductions
- Overview of BWXT BANR Technology
- Advanced Reactor Demonstration Project Risk Reduction Scope
- Review of Past Submittals
- Path Forward
- Non-proprietary Q&A

01 - Introductions

Introductions

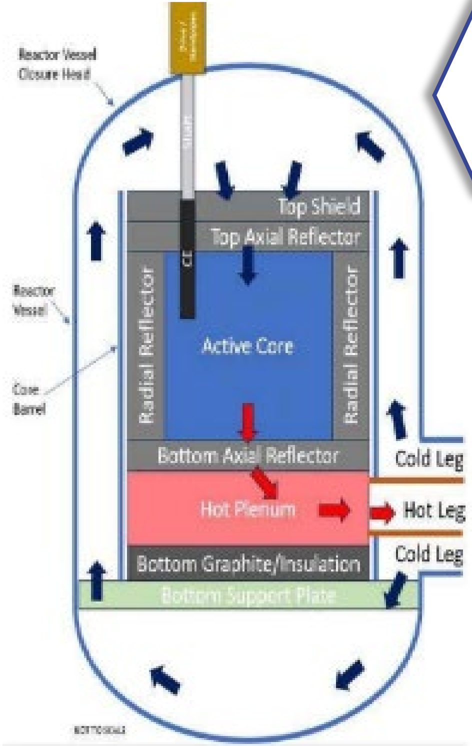
- NRC Staff
  - Maggie Chauhan, Licensing PM
  - Scott Krepel, Technical BC
  - Pravin Sawant, Fuel Tech Reviewer
  - Michelle Hayes, Licensing BC

- BWXT Advanced Technologies Staff
  - Steve Schilthelm, BWXT Director Regulatory & Mission Assurance
  - Mike Haggerty PMP, BANR Program Manager
  - Abbey Donahue PE, BANR Chief Engineer
  - Brian Powers, ARDP Project Manager

02 – Overview of BWXT Advanced Nuclear Reactor (BANR)

Reactor System Design Overview

BANR reactor simplified diagram

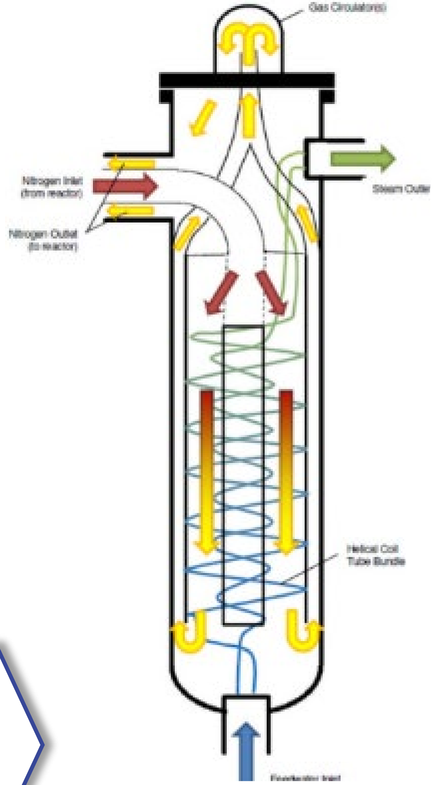


Reactor Coolant flow

- Flows in the cold leg (from the steam generator),
- Up and around the core, between vessel and core barrel,
- Down through the active core (picking up heat from fission),
- Through hot plenum,
- Out hot leg (back to steam generator)

Helical design steam generator

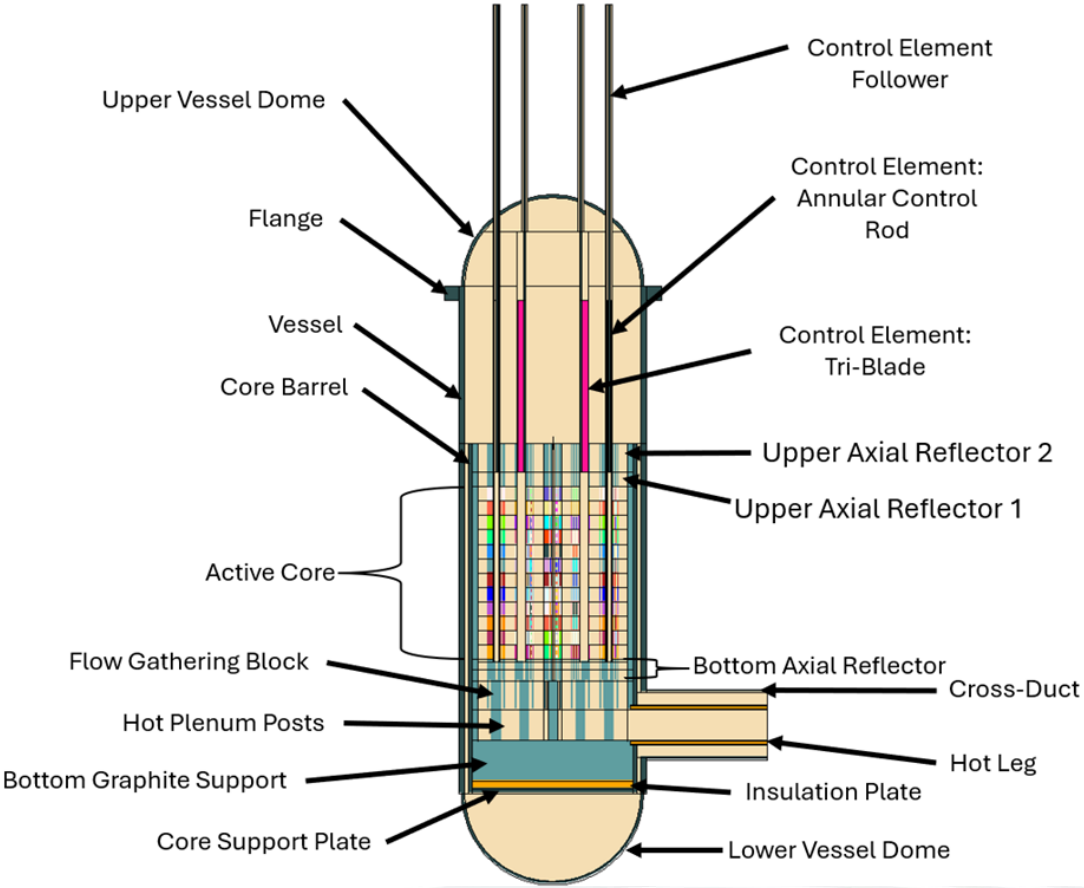
- Integral circulators provide mode of force
- Nitrogen gas flows into main cavity
- Helical tubing contains water
- Water in tubes boils and steam emits from tubes
- Nitrogen gas flows back out to reactor



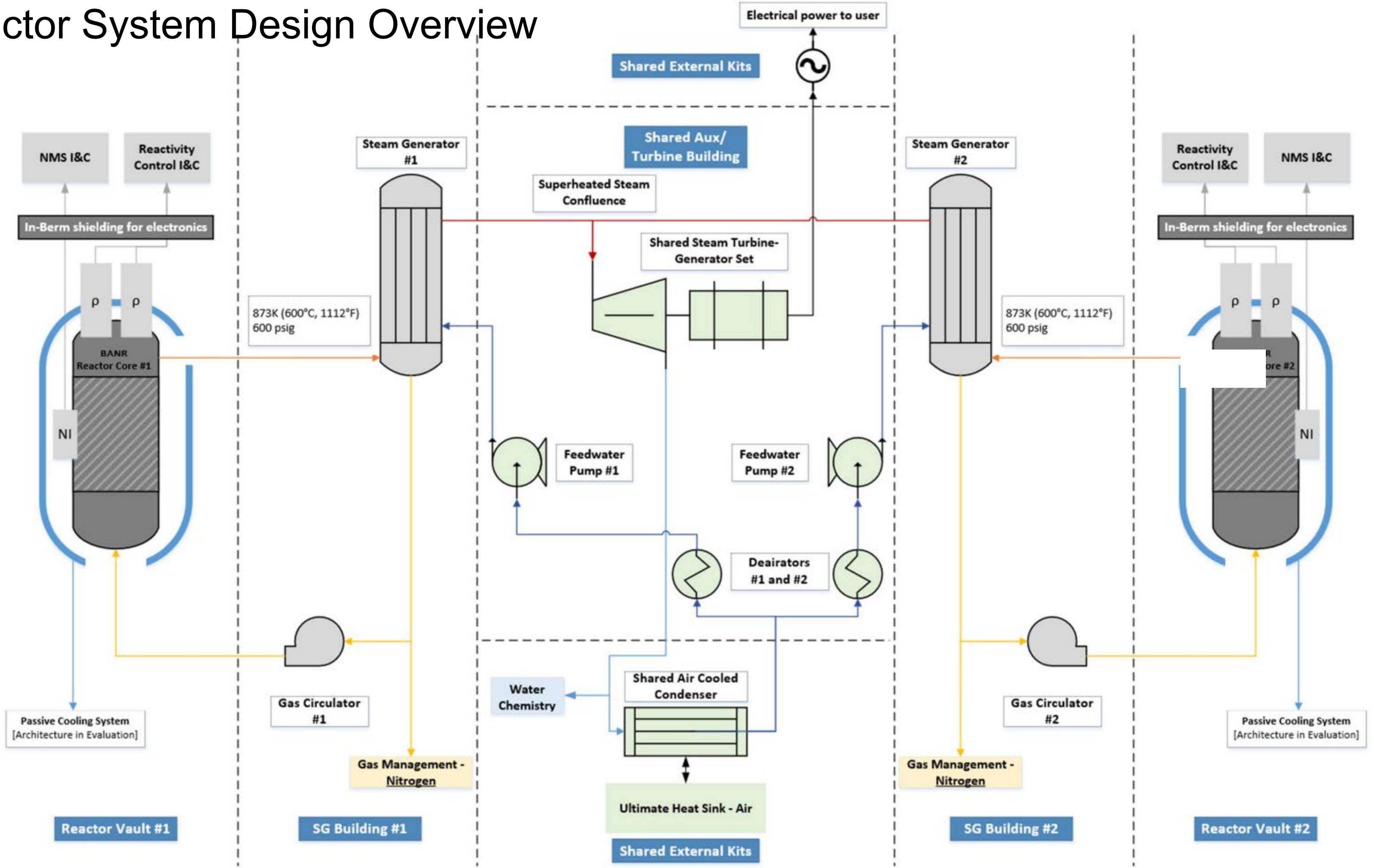
Simplified diagram of helical coil steam generator

Reactor System Design Overview

- Vessel will hold:
  - Active fueled core
  - Graphite moderator
  - Core barrel
  - Upper and lower reflectors
  - Flow gathering block
  - Reactivity control rods

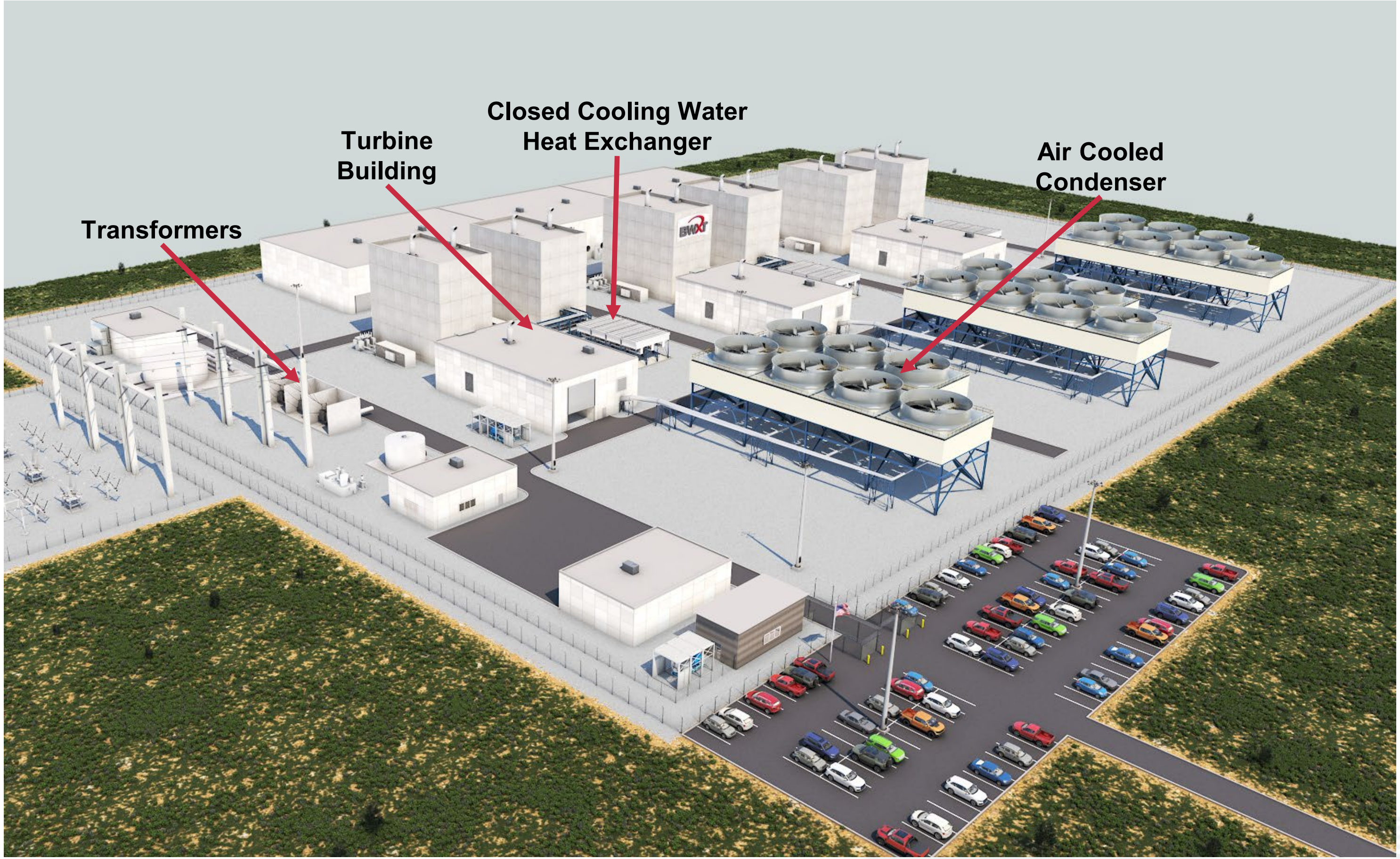


Reactor System Design Overview



Site Layout

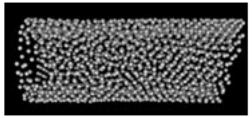
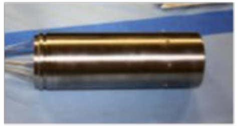
Site Layout



Closed Cooling Water
Heat Exchanger
Turbine
Building
Air Cooled
Condenser
Transformers

03 – Advanced Reactor Demonstration Program Risk Reduction Scope

BANR ARDP Program Scope


2022-2026 — **Fuel Development**
- Reactor design and manufacturing of fuel test specimens

2027 - 2028 — **Demonstration**
- Irradiation testing and in-process analysis of fuel integrity

2029 - 2030 — **Fuel Qualification**
- Post irradiation examination
- Development of licensing basis

2030+ — **Production**
- Demonstration decision
- Commercial implementation

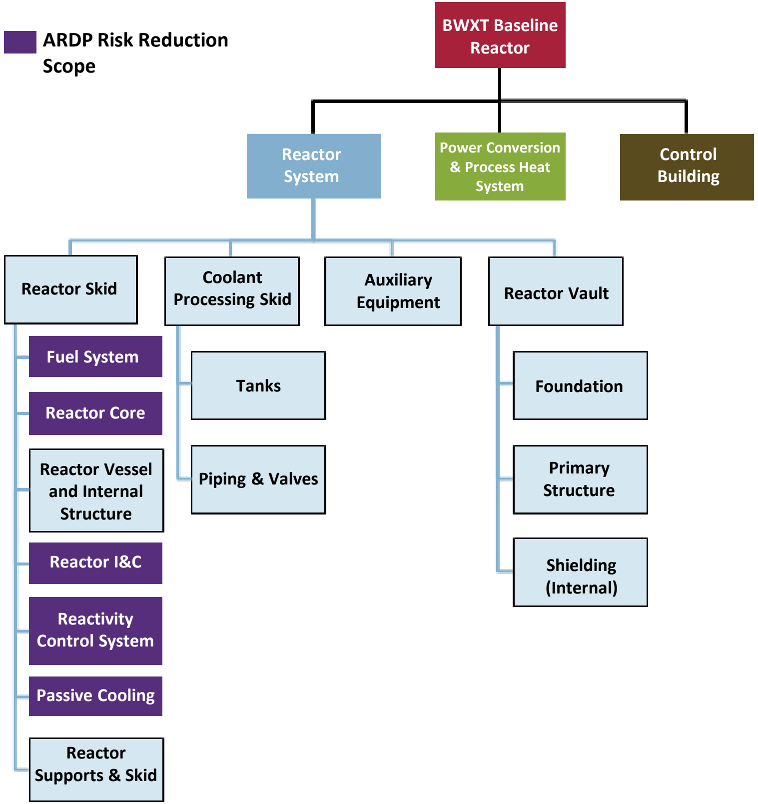
Risk Reduction Program Scope

- Mature design and manufacturing technologies, improving commercial viability
- Demonstrate advanced technology applications to reduce reactor costs
- Develop and demonstrate high-power density TRISO fuel form for microreactors
- Focus on reactor skid: fuel system, core design, reactivity control, passive cooling, I&C

Fuel-Specific Scope

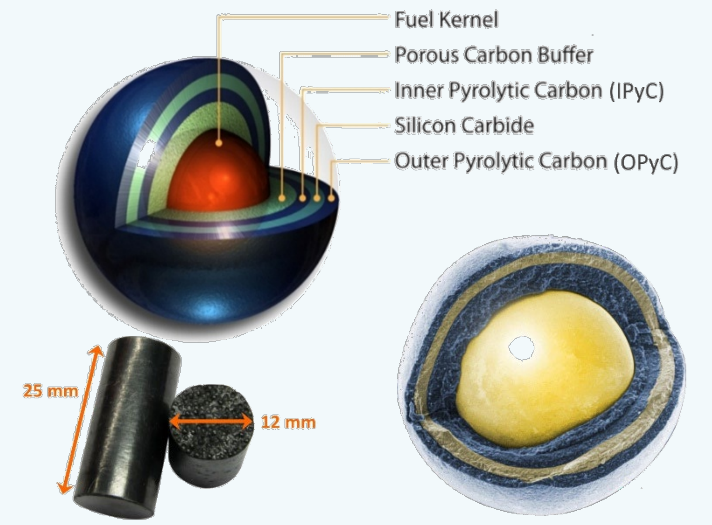
- HALEU fuel acquisition; TRISO fuel production
- Knowledge transfer from INL's AGR program and ORNL's TCR program
- Iterative manufacturing and testing of fuel elements, e.g. AM using CVI densification, element testing and characterization
- Irradiation (INL) and examination (ORNL) to advance UN fuel performance
- Licensing activities to advance fuel form regulatory case

Technology Assessment - BANR Design



Qualifying New Fuel Form is Major Focus

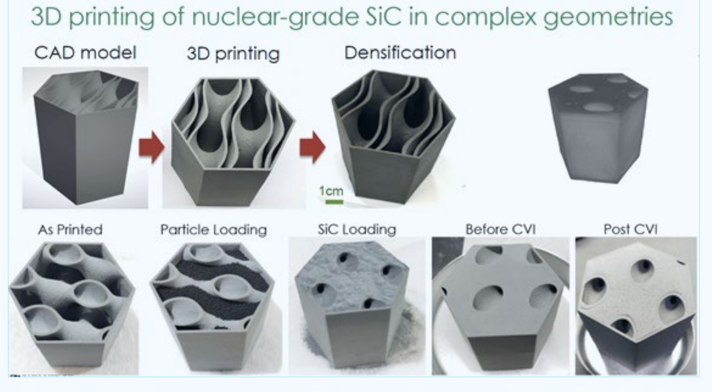
Baseline based on Advanced Gas Reactor (AGR) TRISO Fuel



TRISO particle and compact image credit: INL

- 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

BWXT's ARDP Award upgrades BANR to a higher density UN TRISO Fuel



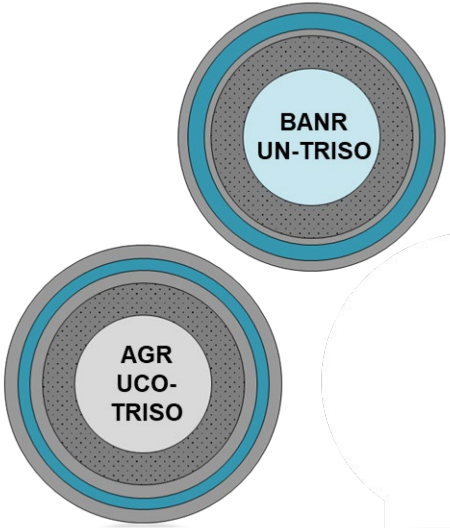
TCR Fuel Elements – Photo from ORNL

- UN fuel kernel contains ~+30% U235 density compared to UCO kernel
- UN-TRISO increased kernel U density combined with higher particle packing fraction (~60 vol%) provides for ~2X fuel form U-density compared to UCO…increasing power and extending core life
- Advanced manufacturing optimizes design, reduces cost & improves throughput
- Commercializes previous DOE fuel development work

BWXT ARDP UN-TRISO Particle Design

- **Design Goal**: Optimize the uranium density (gU/cc) within a BANR fuel element, while maintaining low particle failure rate during operation.
- BWXT AT sampled >1,000 UN-TRISO/Operating-Condition pairs and performed >134,400 2D TRISO particle BISON models

	Metric	BANR UN-TRISO [um]	AGR UCO-TRISO [um]
	Kernel diameter	425 ± 10	425 ± 10
thickness	C-Buffer	100 ± 15	100 ± 15
thickness	IPyC	20 ± 4	40 ± 4
thickness	SiC	50 ± 3	35 ± 3
thickness	OPyC	30 ± 4	40 ± 4
	Particle diameter (nominal)	825	855
	Kernel/Particle volume ratio	0.1367	0.1228



Particles to scale, relative to each other

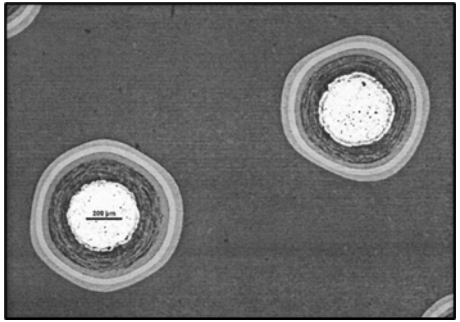
Attractive Attributes of UN

- Higher U-loading than UCO
- Increased thermal conductivity
- Potentially improved fission product retention

BWXT UNTRISO Particle Design & Manufacturing Progress

Uranium conversion → **Solution Preparation** → **Internal Gelation** → **Carbothermic Reduction & Calcining** → **Nitriding** → **TRISO Coating**

UN-TRISO Particle Manufacturing Process



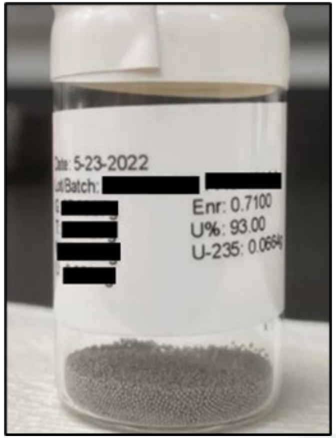
BWXT-manufactured, naturally-enriched UN-TRISO particles

2021 – 2022

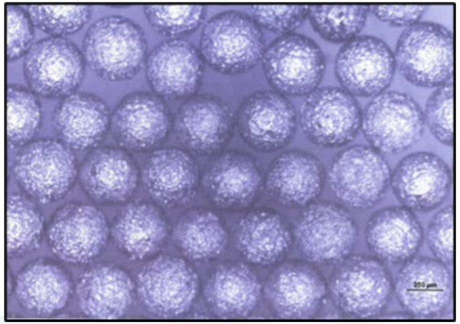
- ✓ UN-TRISO design optimization

2022 – 2025

- ✓ UN kernel nitride conversion (natU)
- ✓ UN-TRISO coating development (natU)
- ✓ UN kernel nitride conversion (HALEU)
- ✓ UN kernel coating (HALEU)
- ✓ UN-TRISO tabling (HALEU)
- ✓ UCO-TRISO acquisition (HALEU)



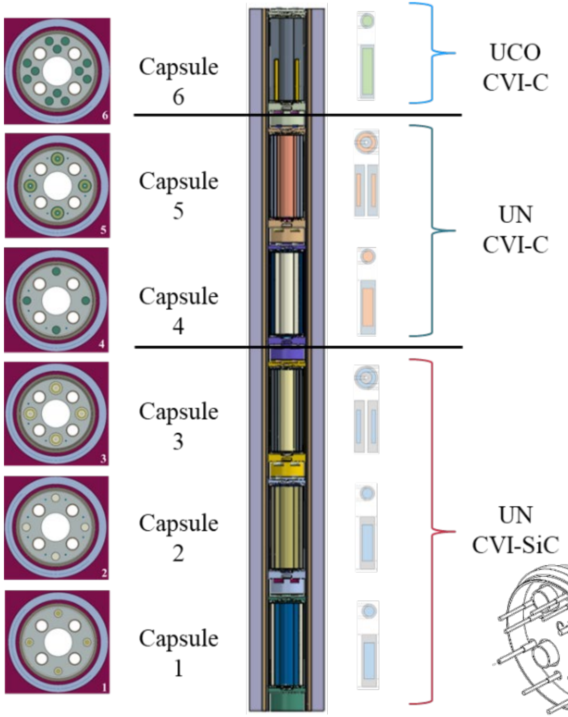
Naturally-enriched UN kernels

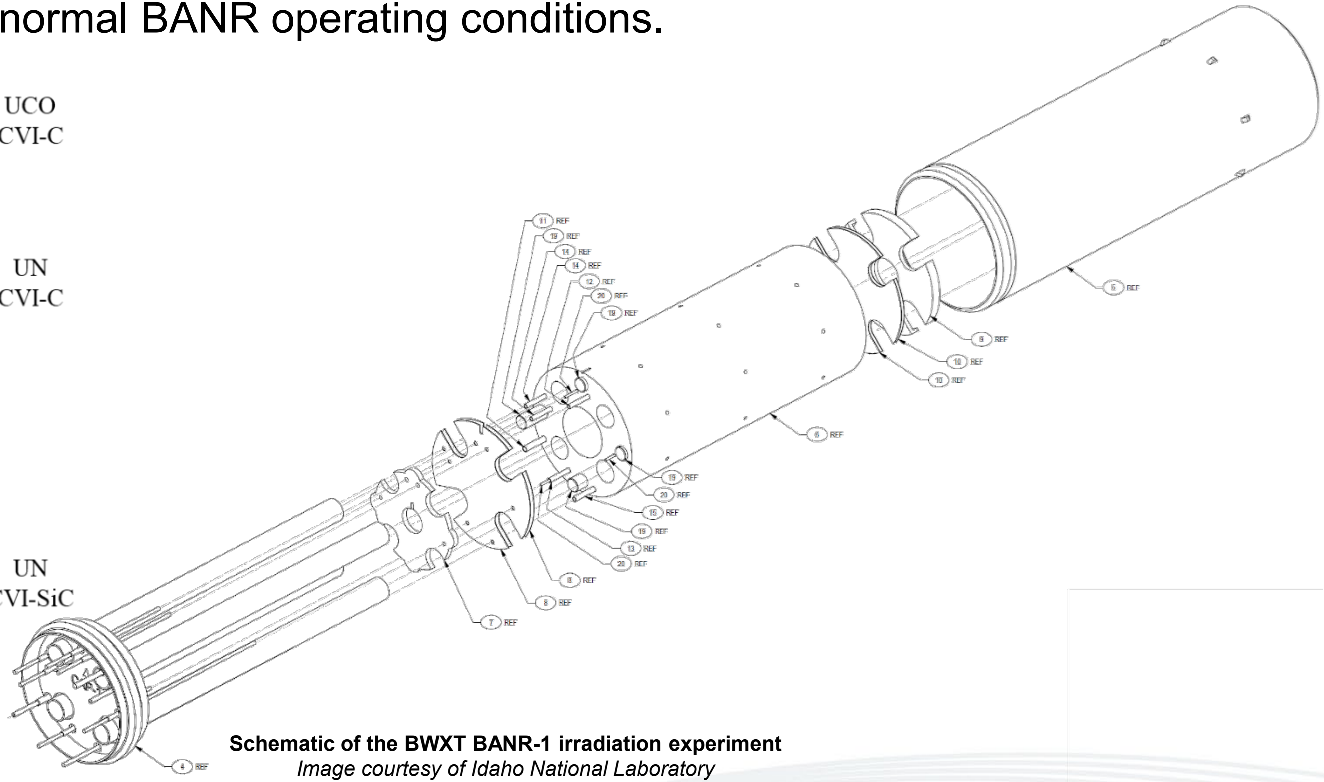


HALEU UN Loose Kernels

BANR-1 Irradiation Experiment - Goal

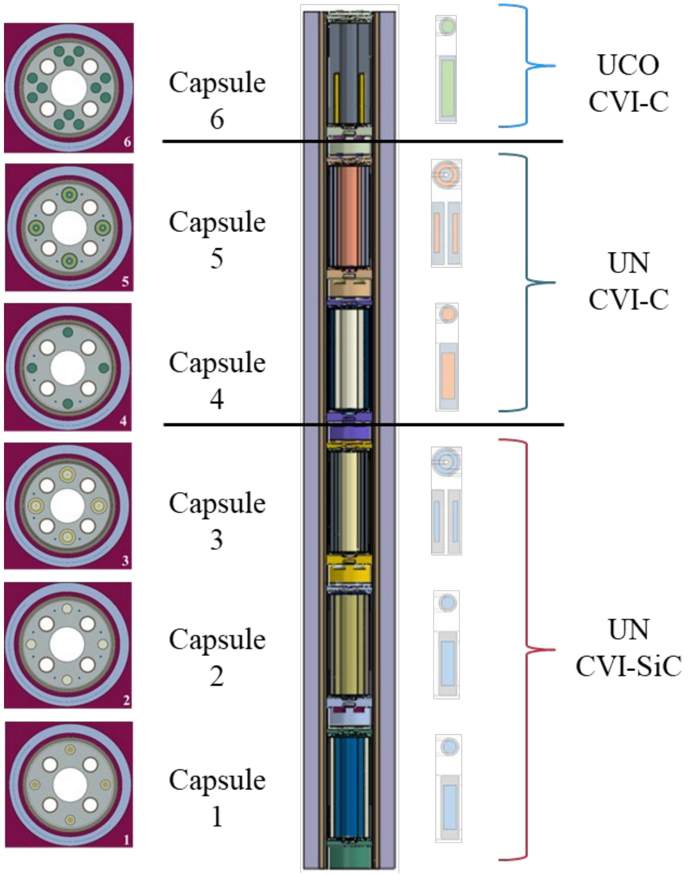
- Qualify UN-TRISO fuel by testing and evaluating the performance of the fuel form at normal and off-normal BANR operating conditions.





Schematic of the BWXT BANR-1 irradiation experiment
Image courtesy of Idaho National Laboratory

BANR-1 Irradiation Experiment – Test Train Capsule Design



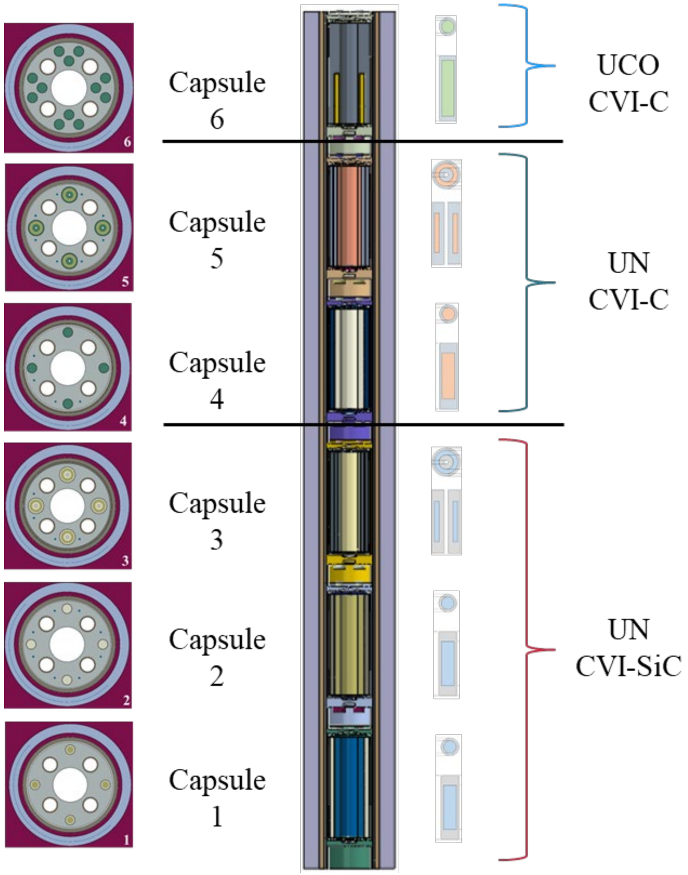
BANR-1 Experiment Objectives

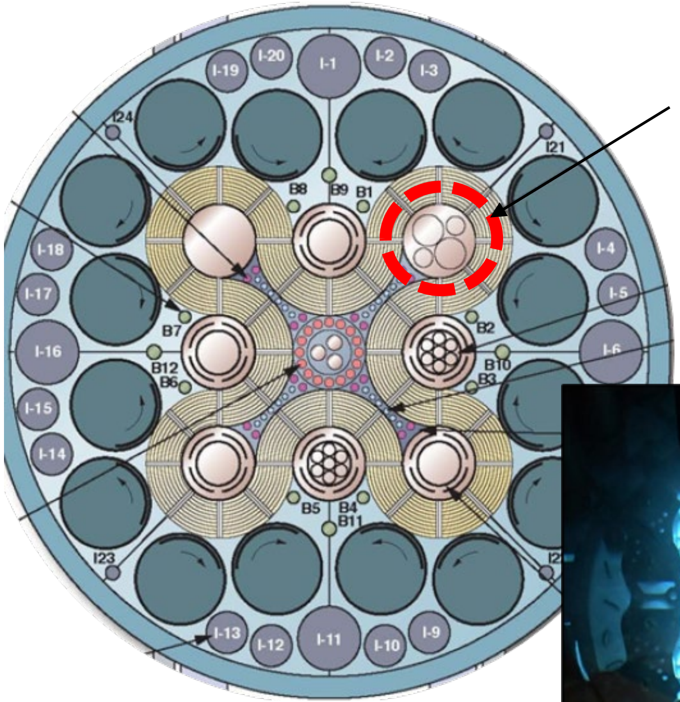
1. Burnup – amount of uranium that has fissioned (max 15% FIMA)
2. Fast Fluence (E>0.18MeV) – neutron damage to materials (2.2-5.6E25 n/m^2)
3. Temperature (550-1250 C)
4. Time at Temperature (~300 EFPD)

Capsule number	Purpose	TRISO Type (UCO/UN)	Matrix Material	Pellet geometry
6	Tertiary Fuel Form	UCO	CVI-carbon	solid
5	Secondary Fuel Form	UN	CVI-carbon	annular
4		UN	CVI-carbon	solid
3	Primary Fuel Form for BANR 2.0	UN	CVI-SiC	annular
2		UN	CVI-SiC	solid
1		UN	CVI-SiC	solid

BANR-1 Irradiation Experiment - Test Train Capsule Descriptions

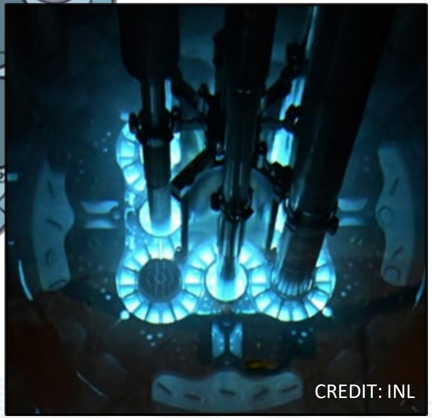
BANR-1 Irradiation Experiment – Test Train Capsule Design





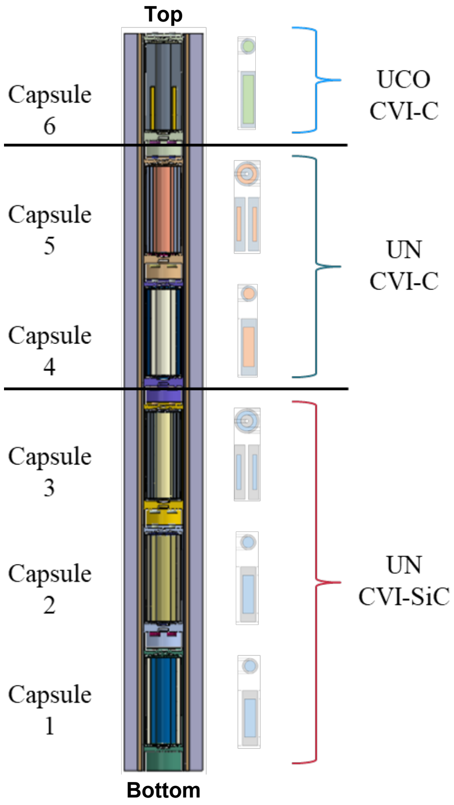
CREDIT: INL

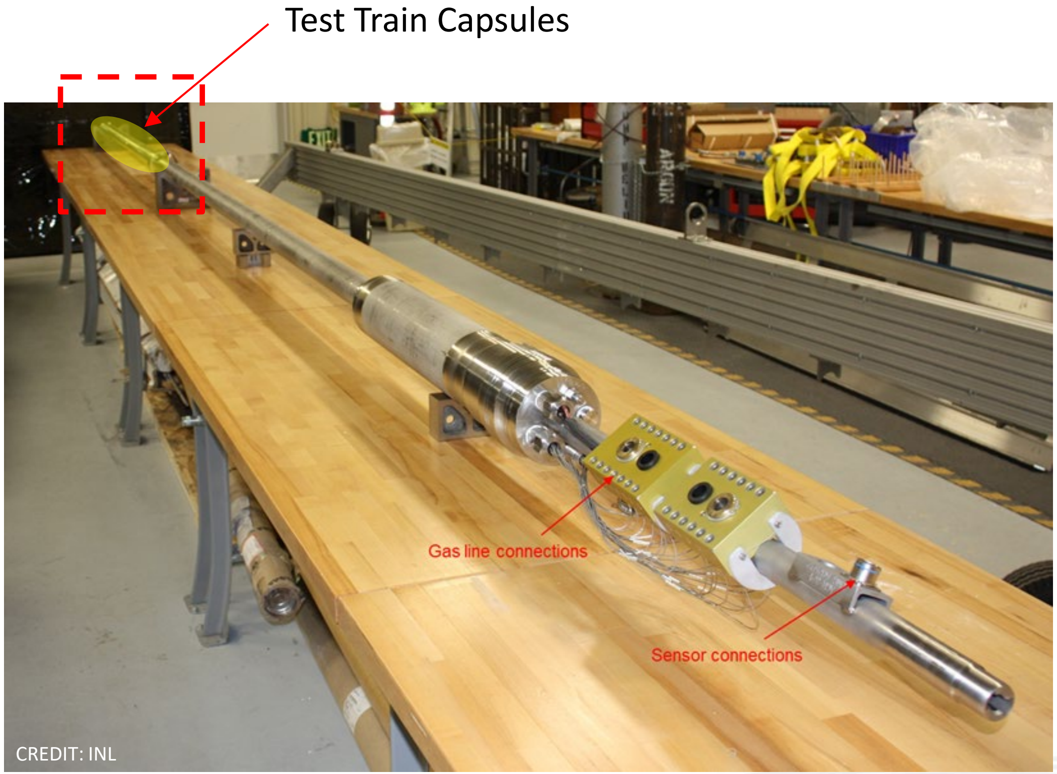
ATR northeast lobe
Each of the four lobes of the reactor can be controlled somewhat independently of the others



INL's Advanced Test Reactor (ATR)

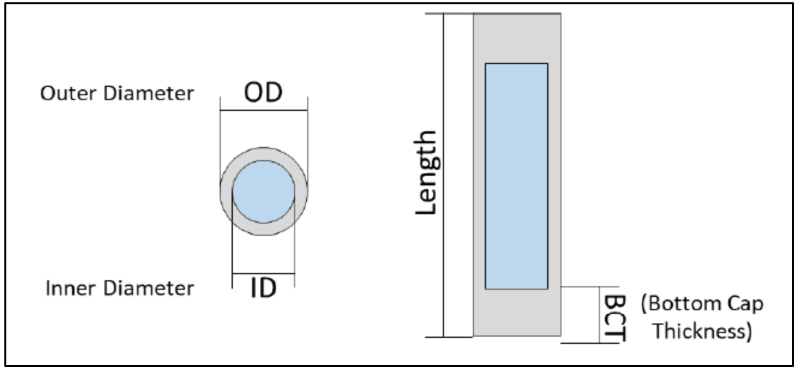
BANR-1 Irradiation Experiment – Test Train Capsule Design



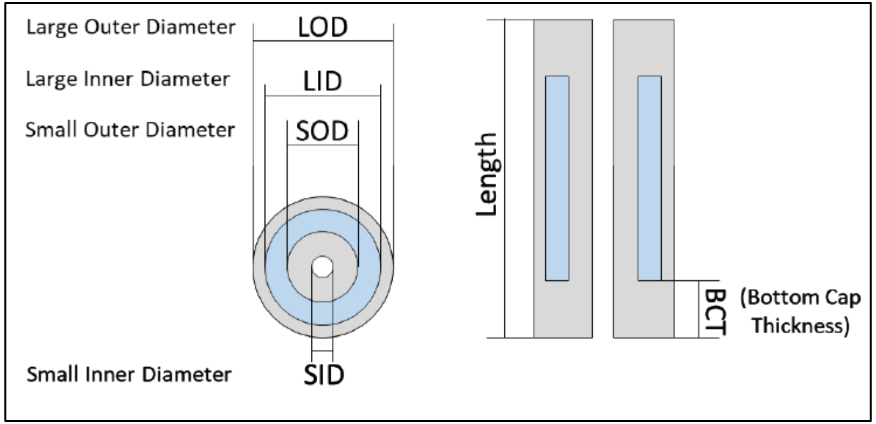


- BANR-1 test train based on the AGR-5/6/7 test train.
- Experiment located in bottom ~4 feet of test train.
- In-pile gas and temperature monitoring
- Advanced sensor testing
  - pressure
  - thermal conductivity
  - neutron fluence
  - temperature

BANR-1 Irradiation Specimen Geometries



Solid Pellet Design



Annular Pellet Design

- Gray – unfueled preform "shell"
- Blue – fueled volume (packed TRISO particles; SiC or carbon matrix)

Fuel Element Fabrication

1. **CAD Model**: A fuel element shell geometry is created in modeling software.

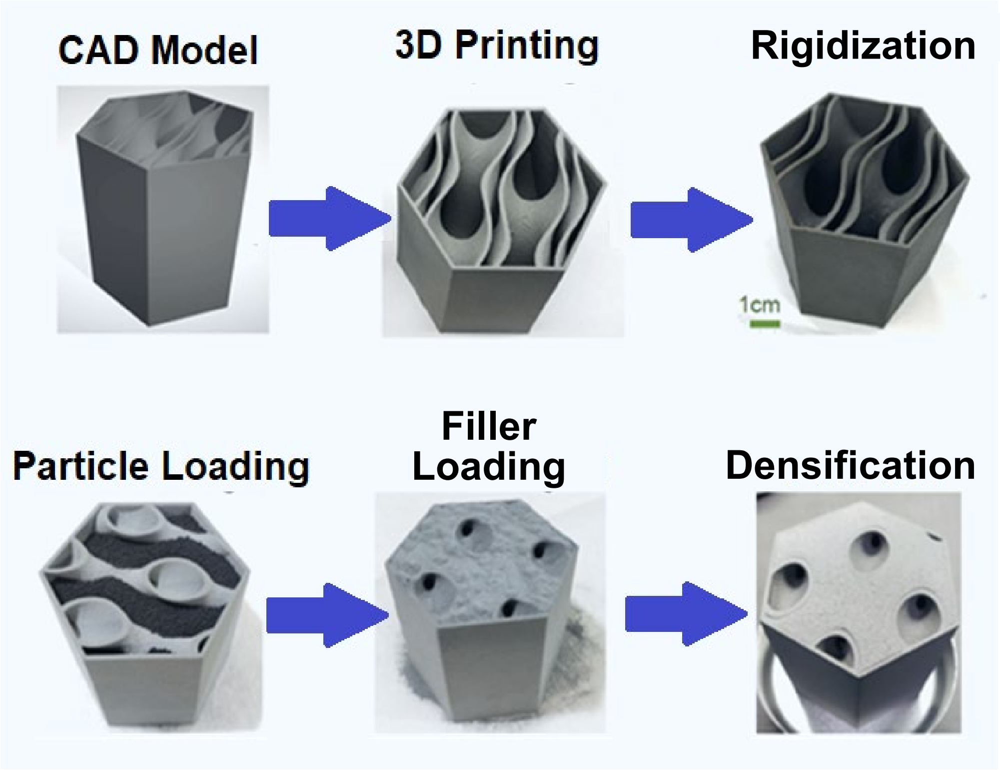
2. **3D Printing**: Using a 3D binder jet printer, the fuel shell is built by selectively depositing a liquid binding agent onto a thin layer of powder particles. This is repeated layer by layer until the fuel element shell is complete.

3. **Rigidization**: Partial CVI densification step provides strength to the fuel element shell so that fuel can be loaded.

4. **Particle Loading**: TRISO particles are placed into the empty fuel element shell.

5. **Filler Loading**: Filler powder is packed into the fuel element, filling the spaces around the TRISO particles.

6. **Densification:** The interior structure is densified into an immobile matrix, via CVI.



TCR Fuel Element Photos, courtesy of ORNL

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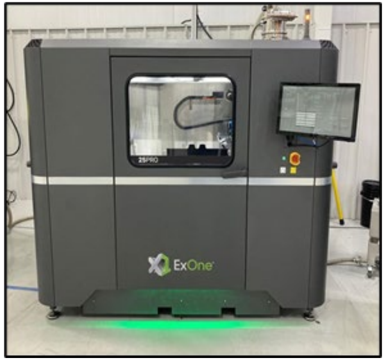
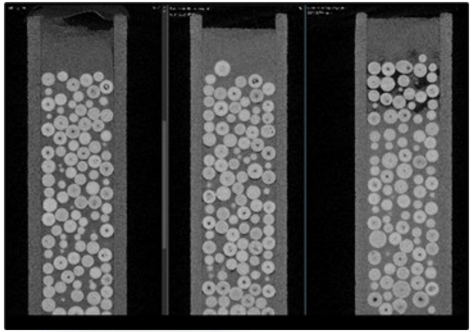


BWXT's Binder Jet

BWXT CVI Furnace

BWXT CVI furnace retort loaded with carbon matrix HALEU specimens.

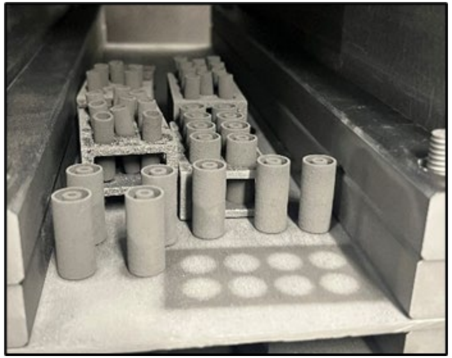


XCT of development carbon pellets loaded with surrogate particles

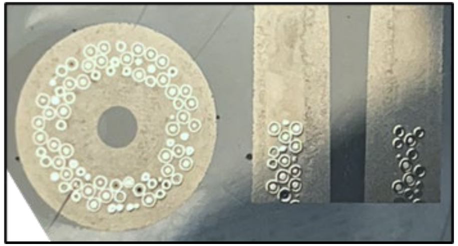
BANR Fuel Development: Current Status

- BWXT has a mature irradiation sample manufacturing process that has been stress-tested.
- BWXT's CVI furnace is operational and carbon-matrix HALEU irradiation specimen production is complete. <u>All carbon specimens have been shipped to INL.</u>
- BWXT SiC-matrix HALEU irradiation specimen production is in progress. Rigidization of HALEU SiC preforms is complete. Currently preparing for densification.
- ORNL's CVI furnace has been commissioned. ORNL has completed 4 development CVI-SiC runs to date.

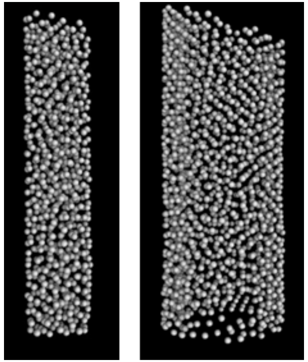
Development Carbon pellet preforms loaded onto tooling racks for insertion into BWXT's CVI furnace



SiC preforms loaded into the BWXT CVI furnace



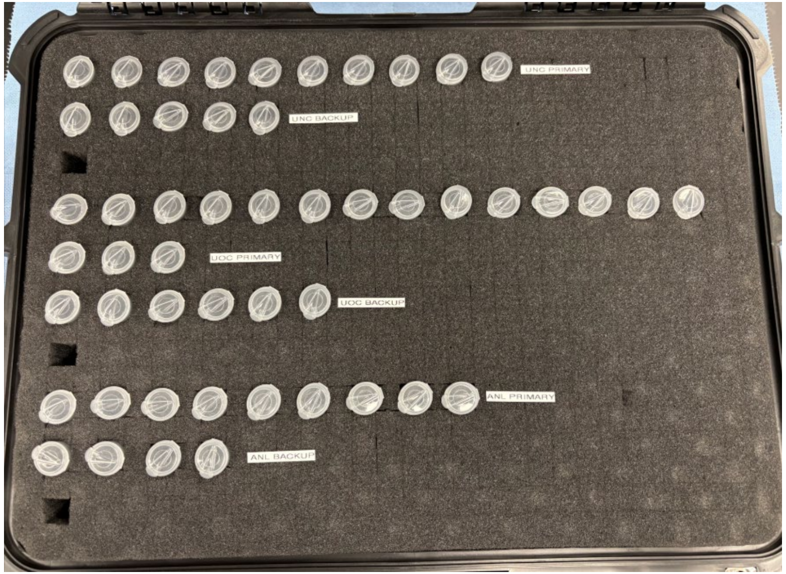
Cross section of a naturally-enriched UN-TRISO filled, annular geometry specimen.



XCT of Printed preforms filled with natU UN-TRISO particles

Shipment of Specimens to INL

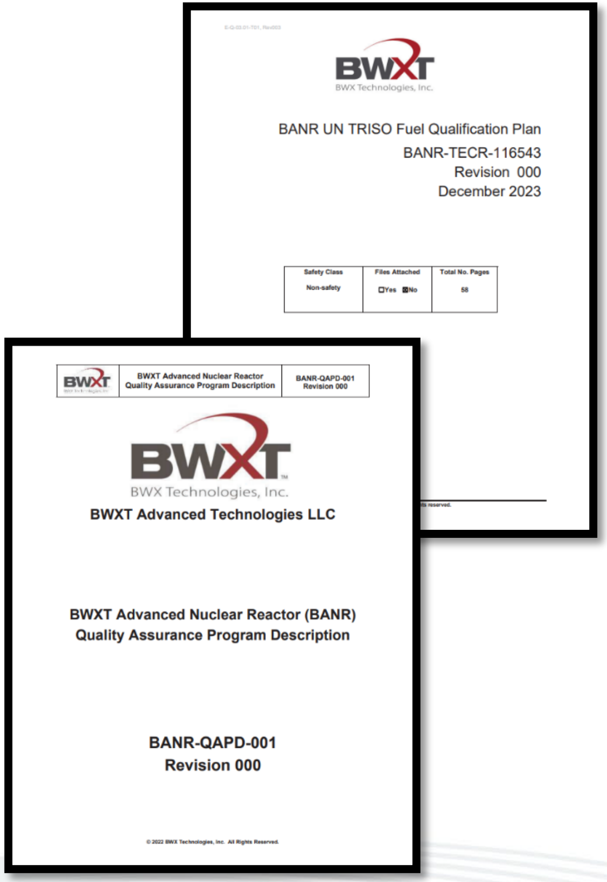
- First shipment of test specimens were shipped to INL in July 2026



04 – Review of Past Submittals

Past Submittals

- Regulatory Engagement Plan for BANR
  - Accession Number: ML22243A112
  - Date Submitted: August 31, 2022
  - Revision coming soon
- Quality Assurance Program Description Topical Report for BWXT BANR Project
  - Accession Number: ML22335A417
  - Date Submitted: November 30, 2022
  - Final safety evaluation approval issued in January 2024, Accession Number ML24113A192
- BANR UN TRISO Fuel Qualification Plan – White Paper
  - Accession Number: ML24004A170
  - Date Submitted: December 20, 2023
  - Feedback and Observations received October 2024, Accession Number ML24278A131



BWX Technologies, Inc.

BANR UN TRISO Fuel Qualification Plan

BANR-TECR-116543

Revision 000

December 2023

Safety Class	Files Attached	Total No. Pages
Non-safety	☐Yes ☒No	58

BWXT	BWXT Advanced Nuclear Reactor Quality Assurance Program Description	BANR-QAPD-001 Revision 000

BWX Technologies, Inc.

BWXT Advanced Technologies LLC

BWXT Advanced Nuclear Reactor (BANR) Quality Assurance Program Description

BANR-QAPD-001

Revision 000

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05 – Next Steps

Next Steps

- REP Update
  - Expected Q3; annually thereafter
- Fuel Qualification Methodology Topical Report
  - Limited to methodology only
  - Will not contain irradiation or PIE data
  - Expected 2027
  - Pre-submission meeting
  - Additional meetings if necessary
- Fuel Qualification Topical Report
  - To include manufacturing, characterization, irradiation testing, safety testing (AMIX) and PIE data.

06 – Non- Proprietary Q&A