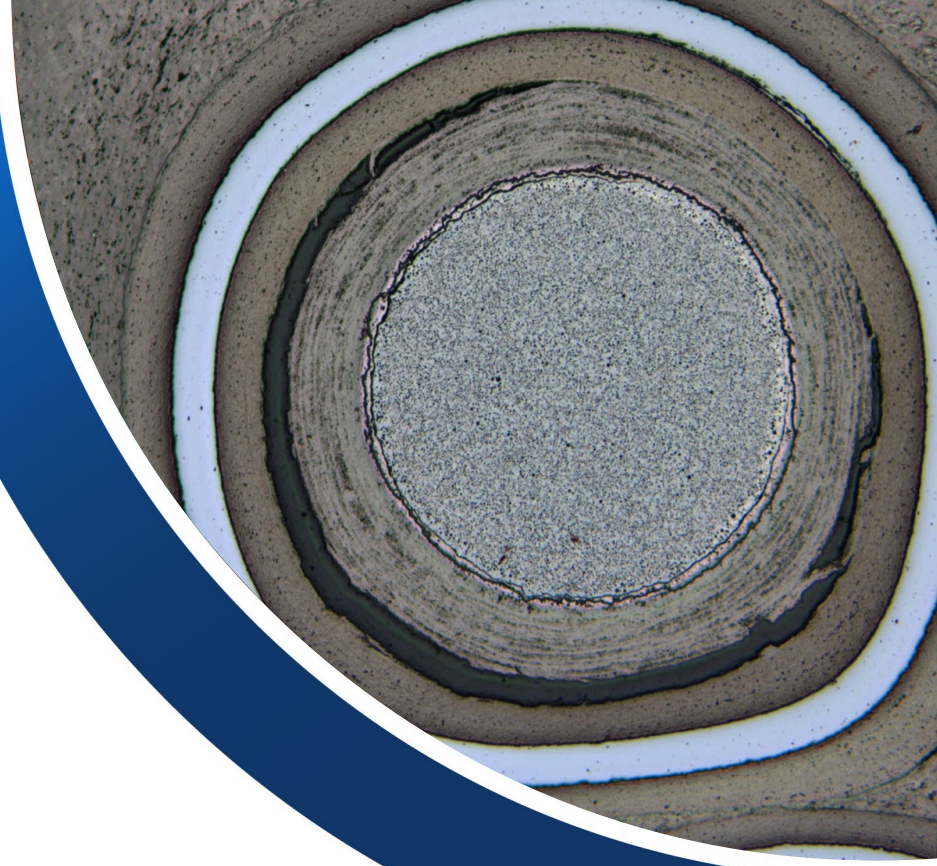
GAS-COOLED REACTOR
ADVANCED REACTOR TECHNOLOGIES PROGRAM



July 16, 2024

DOE Advanced Gas Reactor Fuel Development and Qualification Program Overview

Paul Demkowicz

AGR Program Technical Director

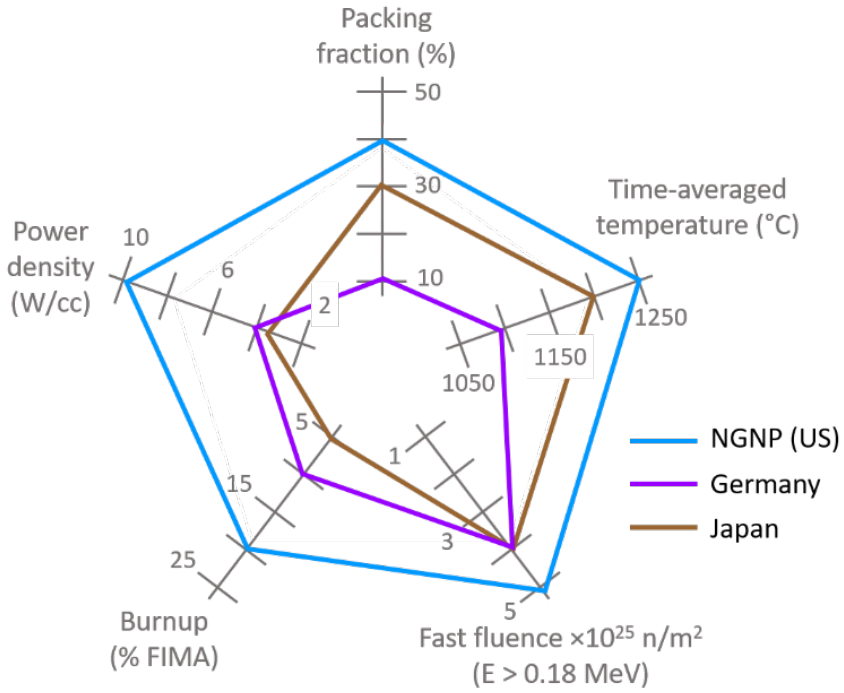
DOE ART GCR Review Meeting

Hybrid Meeting at INL

July 16–18, 2024

US-DOE TRISO Fuel Development

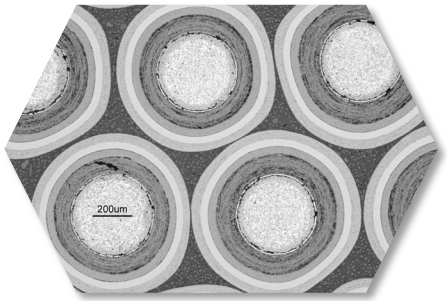
- *Advanced Gas Reactor* (AGR) *Fuel Development and Qualification Program* started in 2002 to address historically poor US TRISO fuel performance relative to German fuel
- Focus on LEU UCO TRISO fuel in cylindrical compacts, consistent with prismatic reactor designs pursued in the US
- Pursued a more aggressive performance envelope compared to German and Japanese programs
- Objectives and Motivation:
  - Provide data for fuel qualification in support of reactor licensing
  - Establish a domestic commercial TRISO fuel fabrication capability



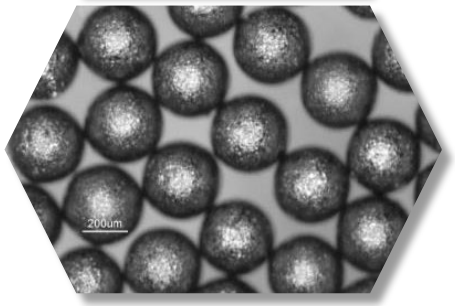
Reduce market entry risk

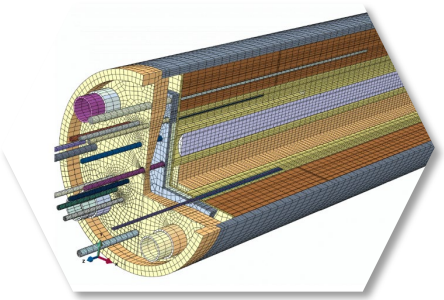
TRISO Fuel Qualification Program Elements

Program participants:
- *INL*
- *ORNL*
- *BWXT*
- *General Atomics*

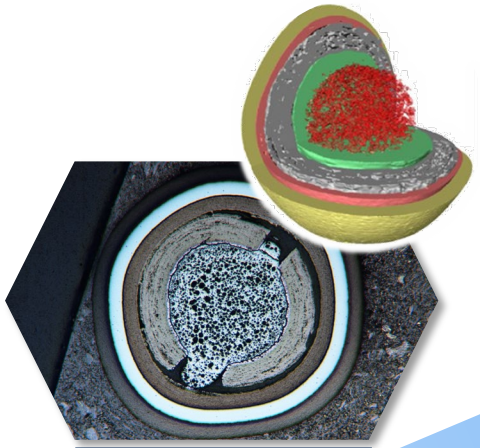


Fabrication

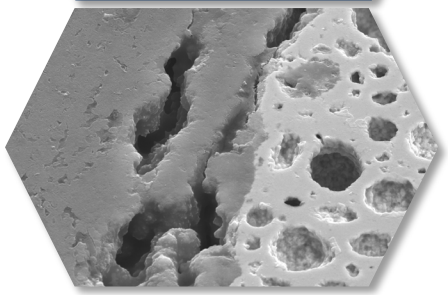




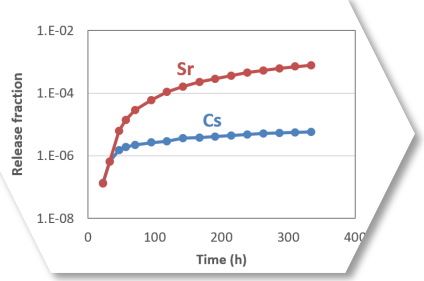
Irradiation



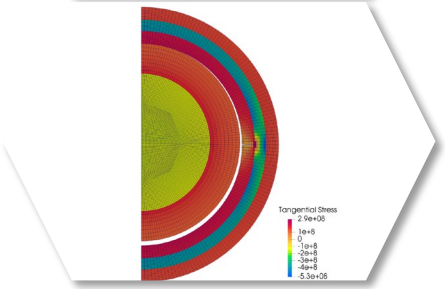
Post-Irradiation Examination

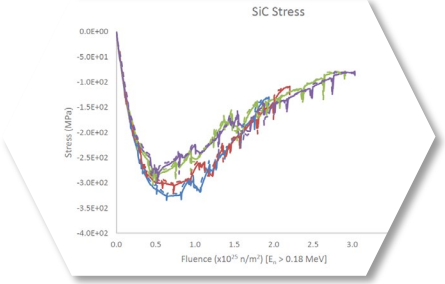


Safety Testing



Modeling and Simulation





AGR Program Timeline

Early test of lab-scale UCO fuel performance; shakedown of test train design.

Engineering-scale particles in lab-scale compacts. Includes UCO and UO_2 fuel.

"Designed-to-fail" (DTF) fuel to assess fission product retention and transport in reactor graphite and fuel matrix.

Fuel qualification test. Engineering-scale UCO particles and compacts.

Program participants:
INL
ORNL
BWXT

Fuel Fabrication

AGR-1 | AGR-2 | AGR-3/4* | AGR-5/6/7

Irradiation (in ATR)

AGR-3/4
AGR-1
AGR-2
AGR-5/6/7

Future schedule is notional

2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029

PIE

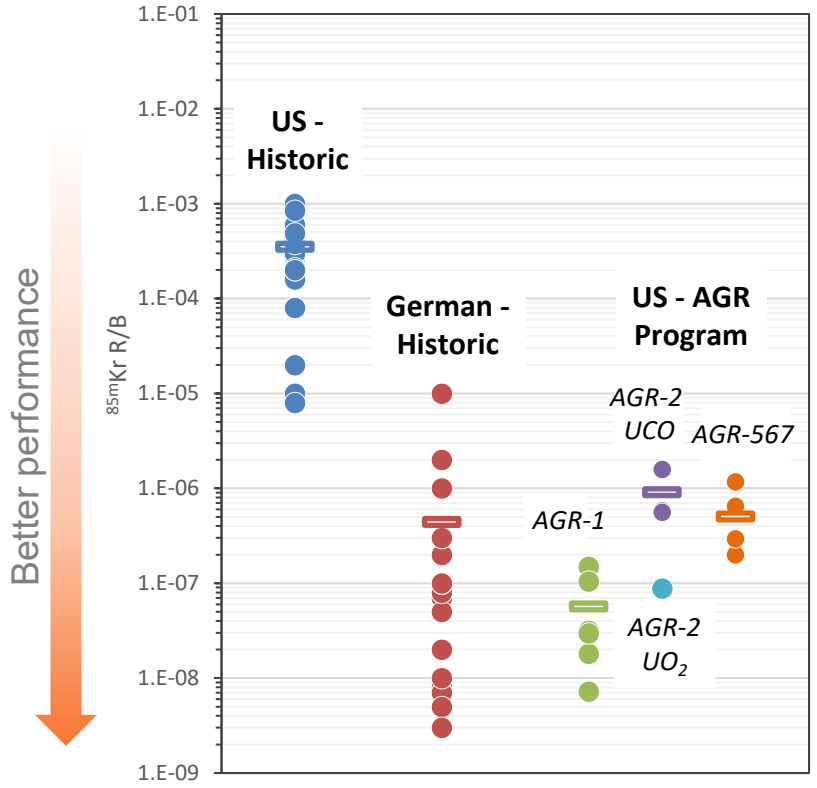
AGR-1
AGR-5/6/7 Reporting
AGR-2
AGR-3/4 Reporting and analysis

**Includes fabrication of DTF particles; driver fuel taken from AGR-1 fabrication campaign*

Irradiation Test Results

- **Four** irradiation experiments (three dedicated to fuel performance assessment)
- **~1,000,000** particles irradiated in ~300 fuel compacts
- Burnup to **~20% FIMA**
- Time-average temperature to **1432 °C**
- ^{85m}Kr R/B values are **10^{-8} – 10^{-6}**

Comparison of US and German ^{85m}Kr R/B data



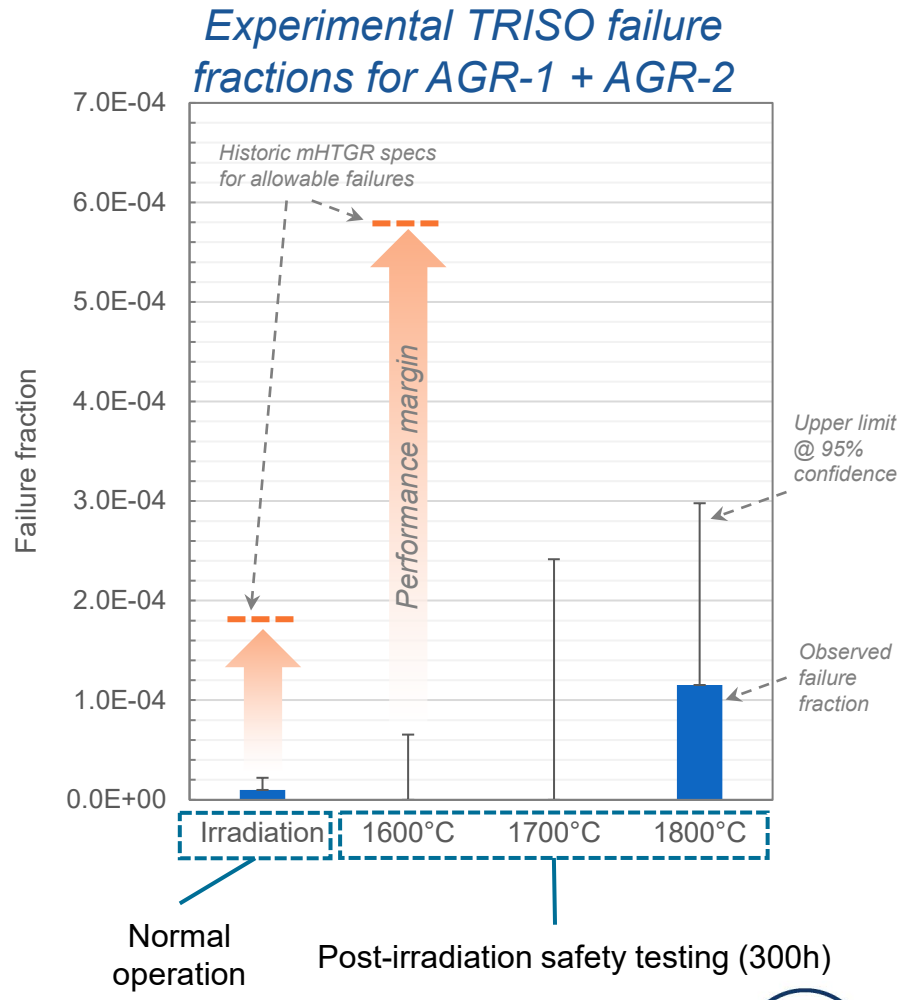
R/B is the fission gas release-rate-to-birth-rate ratio

AGR-2 R/B values are through the first ~1/4 of the irradiation (149 EFPD)

AGR-567 R/B values are through the first ~1/2 of the irradiation (174 EFPD)

Fuel Performance Evaluation Results

- Demonstrated low in-pile particle failure fractions (≤ 1/50,000 particles[1])
- Fuel can withstand hundreds of hours at 1600 °C without significant particle failures (≤ 1/15,000 particles[1])
- Fuel effectively retains fission products within the coated particles

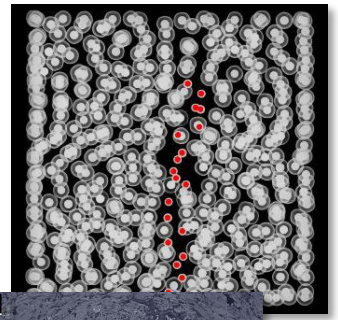


[1] *Values are upper bound at 95% confidence*

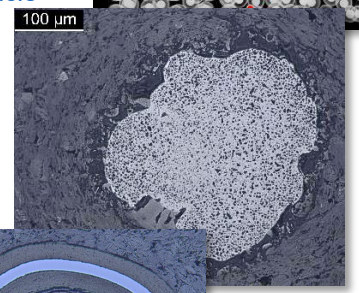
AGR-3/4: Fission Product Transport Experiment

- Fission product mass balance in 12 capsules
- Fission product profiles from 8 capsules
  - (inner and outer rings)
- Fuel compact microscopy
- Fuel compact heating tests
  - 4 as-irradiated (post-ATR irradiation)
  - 5 re-irradiated (post-TRIGA re-irradiation)
    - Assess short-lived fission product release (^{131}I, ^{133}Xe)
- Fuel compact radial deconsolidation
  - 21 compacts
  - Detailed report on as-irradiated compact radial DLBL issued in 2024
- Effort is currently focused on data analysis to refine fission product transport parameters for graphite and fuel matrix

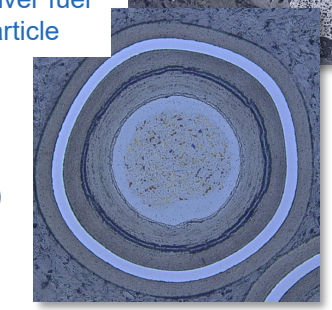
X-radiograph of unirradiated AGR-3/4 compact; DTF highlighted by red dots

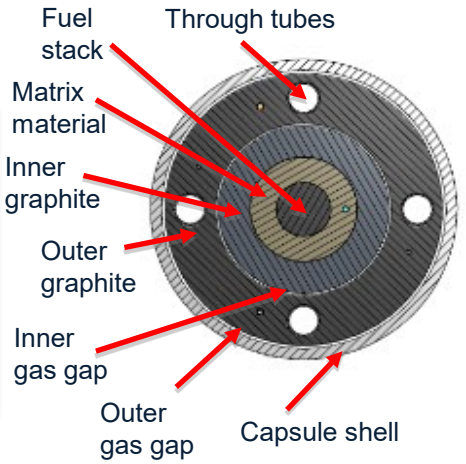


Irradiated designed-to-fail particle

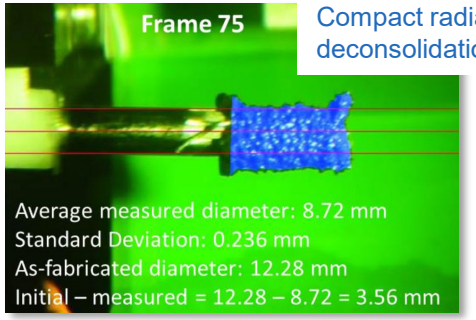


Irradiated driver fuel particle

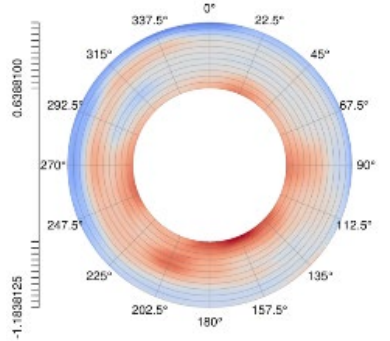




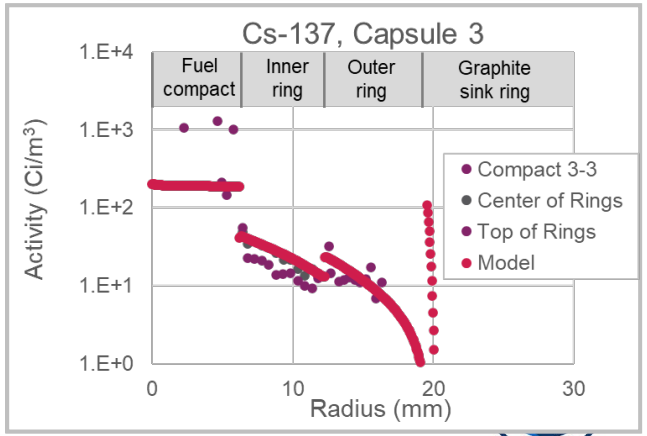
AGR-3/4 Capsule Cross Section



Compact radial deconsolidation



IR-07 Cs-134 activity distribution



Major Accomplishments and Milestones – Last 12 Months

AGR-5/6/7

- Completed 2 compact shipments to ORNL (total 8 compacts)
- Completed analysis of AGR-5/6/7 capsule leaching solutions at INL
- Completed 3 safety tests in FACS (INL)
- Completed 4 safety tests in CCCTF (ORNL)

→ Total to date: 17 tests (19 compacts)

- Completed 5 compact deconsolidation leach-burn-leach (DLBL) analyses at INL
- Completed ~6 DLBL at ORNL

→ Total to date: Approx 16 as-irradiated and 8 post-safety test

Major Accomplishments and Milestones – Last 12 Months

AGR-3/4

- Issued "*Radial Deconsolidation and Leach-Burn-Leach of Eight As-Irradiated AGR-3/4 TRISO Fuel Compacts*," (INL/RPT-24-77357) Apr 2024
- Issued "*Status of Modifications to the AGR-3/4 Fission Product Transport Model*," (INL/RPT-23-74853) Sep 2023

Fuel Performance Modeling

- Issued "*Fuel Performance Modeling Plan to Support the Advanced Gas Reactor Program*," Rev. 1 (INL/RPT-22-66390) Mar 2024
- Issued "*PARFUME/BISON Fission Product Release Predictions versus AGR-3/4 Heating Test Measurements*," (INL/RPT-23-74505) Sep 2023

Major Accomplishments and Milestones – Last 12 Months

Other Areas

- Published NDMAS Online User Guide https://ndmashome.inl.gov/htr/ArtUserGuide/SitePages/Home.aspx
- Issued "*AGR TRISO Fuel Fission Product Release Data Summary*," (INL/RPT-23-74651) Sep 2023
- Issued "*Evaluation of Radiography for TRISO Buffer Layer Density Measurement*," (ORNL/TM-2024/3401) May 2024
- Issued "*Evaluation of XCT for Matrix Density Measurement of Particle Fuel Forms*," (ORNL/TM-2024/3389) May 2024
- Issued "*Quality Control Methods for Measurement of UCO Kernel Composition and SiC Microstructure,*" (ORNL/TM-2023/3205) Dec 2023

Major AGR Program Activities – FY24 and Beyond

- **Complete AGR-3/4 data analysis and reporting**
  - Determine key takeaways in terms of fission product transport
- **Continue/complete AGR-5/6/7 PIE and safety testing**
  - Confirm performance of pilot-scale fuel, including performance at extreme high and low temperature regimes
- **Oxidation tests**
  - Determine fuel and fission product behavior under oxidizing conditions
- **Reporting**
- **Compile AGR datasets for use by reactor designers, e.g.:**
  - Fission product retention characteristics of the fuel (*separate presentation today*)
  - Fuel failure analyses under all tested conditions
  - Oxidation behavior and impact on fission product retention
- **Fuel performance and fission product transport modeling**
- **Support industry interaction with the regulator during licensing activities**

AGR Program Review Agenda

AGR-3/4 Fuel Compact Fission Product Concentration Profiles	AGR-3/4 status and results
AGR-3/4 PIE and Data Analysis	
AGR-5/6/7 PIE Overview	AGR-5/6/7 status and results
AGR-5/6/7 Partial Mass Balance	
AGR-5/6/7 Compact Destructive Exams and Safety Testing - ORNL	
AGR-5/6/7 Compact Destructive Exams and Safety Testing - INL	
Supplemental PIE Activities Supporting Mechanistic Understanding of TRISO Performance	Fuel characterization and performance studies
Microtensile Specimen Analysis	
X-ray Computed Tomography of TRISO Fuel	
TRISO Thermal Properties Measurement	
Overview of New Quality Control Methods Development at ORNL in FY24	
AGR Fuel Oxidation Testing Plans	Other key program topics
AGR-1/2/3/4 Fission Product Release Data Report	
Fuel Performance Modeling Status Update and Potential Model Improvements	
NDMAS Portal Updates	

DOE-Funded, University-Led TRISO-Fuel-Related Research Projects

Project ID	Lead Institution	PI	Title
24-31266	University of Wisconsin-Madison	Yongfeng Zhang	Correlating buffer microstructure with failure progression into the SiC layer in TRISO (*Phase II NEUP Continuation*)
23-29490	Brigham Young University	Troy Munro	Improving Reliability of Novel TRISO Fuel Forms for Advanced Reactors via Multiscale, High-Throughput Characterization and Modeling
21-24111	Texas A&M University	N.K. Anand	Experimental Investigations of HTGR Fission Product Transport in Separate-effect Test Facilities Under Prototypical Conditions for Depressurization and Water-ingress Accidents
20-19556	University of Wisconsin-Madison	Yongfeng Zhang	Statistical modeling of the effect of microstructural heterogeneity on the irradiation behavior of TRISO fuel buffer layer
20-19205	Missouri University of Science and Technology	Muthanna Al-Dahhan	Robust bullet-time tagging and tracking system based on computer vision for individual ex-core TRISO-fueled pebble identification
19-17251	Idaho State University	Mary Lou Dunzik-Gougar	Measuring Mechanical Properties of Select Layers and Layer Interfaces of TRISO Particles via Micromachining and In-Microscope Tensile Testing
18-15171	Missouri University of Science and Technology	Haiming Wen	Oxidation behavior of silicon carbide and graphitic materials
18-15039	The University of Texas at San Antonio	Elizabeth Sooby Wood	Oxidation of Tristructural Isotropic fuel forms in low oxygen and steam partial pressures and the role of matrix burn off in the oxidation rate at high temperature
18-15097	Virginia Tech	Kathy Lu	Oxidation Study of High Temperature Gas-Cooled Reactor TRISO Fuels at Accidental Conditions
17-12710	University of Central Florida	Yongho Sohn	Mechanisms of Retention and Transport of Fission Products in Virgin and Irradiated Nuclear Graphite
17-12830	University of Missouri-Columbia	Sudarshan K. Loyalka	Radioisotope Retention in Graphite and Graphitic Materials

Acknowledgements

Major thanks to the many staff members that have contributed to the AGR Program work this year

INL Core Staff

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Analytical Laboratory (AL)
Irradiated Materials Characterization Laboratory (IMCL)
North Holmes Lab
Fuel Condition Facility (FCF)
IF-688 (Gamma Lab)

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ORNL Facilities and Support Staff

Irradiated Fuels Examination Facility (IFEL)
Coated Particle Fuel Development (CPFD) Laboratory
Radioactive Materials Analytical Laboratory (RMAL)
Low Activation Materials Development and Analysis (LAMDA) Laboratory

DOE Organizational Changes Impacting AGR Program and Future Coated Particle Fuel Development

- Coated particle fuel activities are moving from NE-52 (Office of Advanced Reactors) to NE-42 (Office of Advanced Fuel Technologies)
- AGR Program separated from Advanced Reactor Technologies – Gas Cooled Reactor campaign and part of Advanced Fuels Campaign
- AGR Program Scope remains; transition to next-generation coated particle fuel development as AGR scope is completed

GAS-COOLED REACTOR

ADVANCED REACTOR TECHNOLOGIES PROGRAM

Thank you for your attention

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U.S. DEPARTMENT OF ENERGY