

July 25, 2023

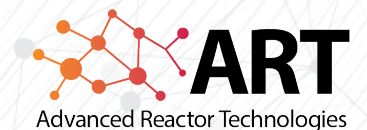
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DOE Advanced Gas Reactor Fuel Development and Qualification Program Overview

DOE ART Gas-Cooled Reactor (GCR) Review Meeting

Virtual Meeting

July 25 – 27, 2023

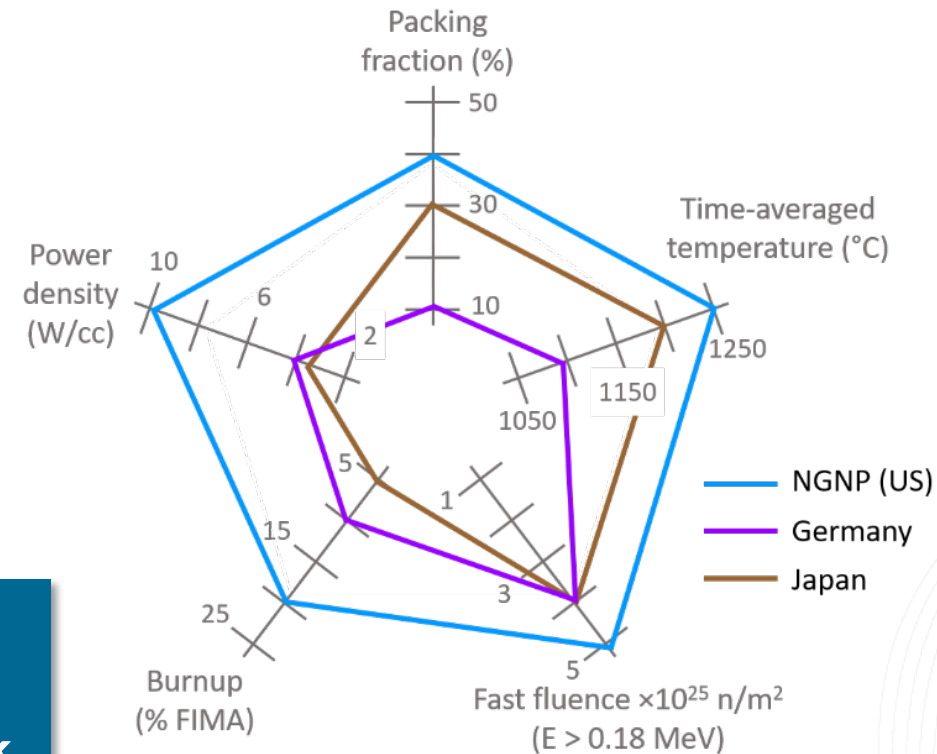


US DOE Advanced Gas Reactor (AGR) Fuel Development and Qualification Program

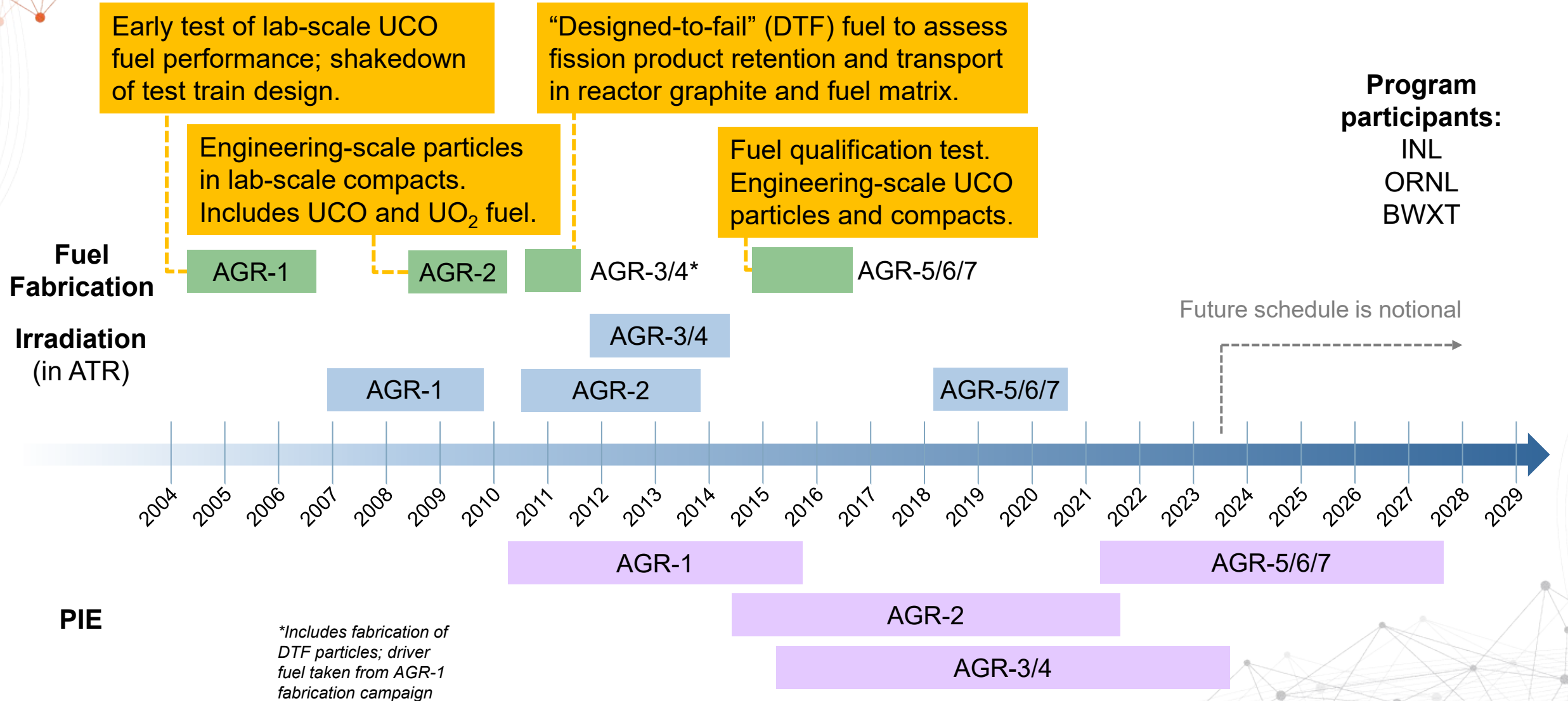
- Focus on LEU UCO TRISO fuel in cylindrical compacts, consistent with prismatic reactor designs pursued in the US
- Pursued a more aggressive performance envelope compared to German and Japanese programs
- Objectives and Motivation:
 - Provide data for fuel qualification in support of reactor licensing
 - Establish a domestic commercial TRISO fuel fabrication capability



Reduce market entry risk



AGR Program Timeline



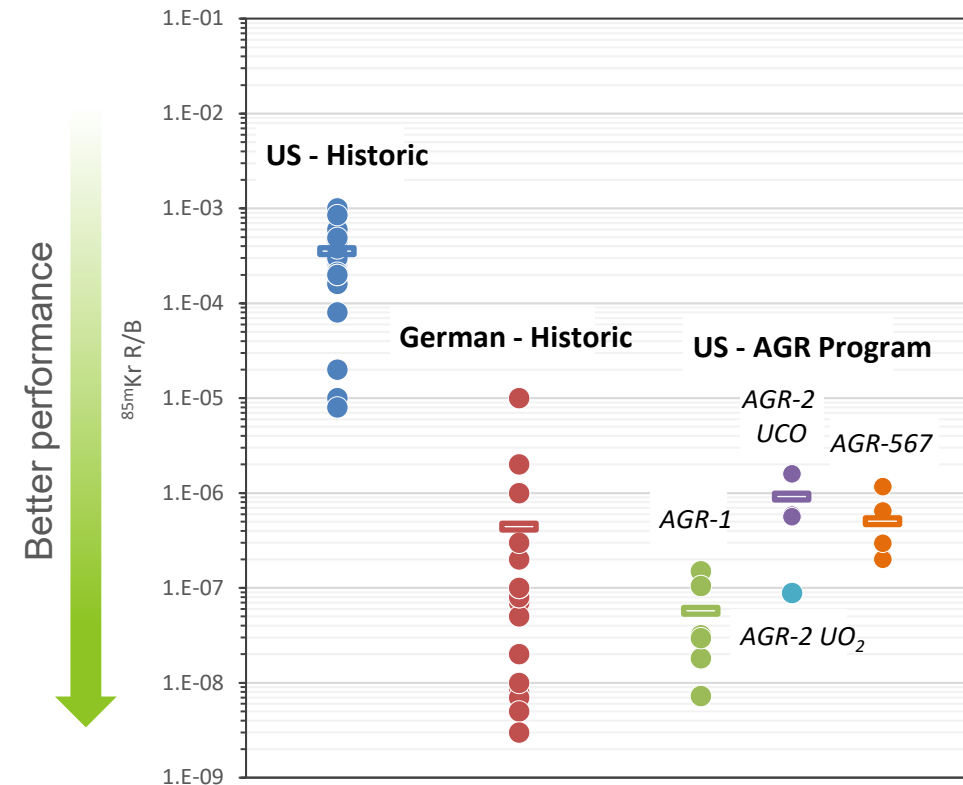
Major AGR Program Highlights

- Developed fuel performance models based on past observed behavior
- Study to understand differences between US and German fuel
- Developed and improved fuel fabrication and characterization methods
- Fabricated lab-scale fuel (AGR-1) with very high quality; excellent in-pile and post-irradiation high-temperature fuel performance
- Successful pilot-scale coating fabrication (AGR-2) with excellent in-pile performance and post-irradiation high-temperature fuel performance
- Topical report on UCO TRISO fuel particle performance
- AGR-3/4 fuel fabrication, irradiation experiment, and PIE to assess FP transport behavior
- Pilot-scale matrix fabrication (AGR-5/6/7) and irradiation; fuel performance evaluation in progress

Irradiation Testing Results

- $\sim 10^6$ UCO TRISO particles in ~ 300 fuel compacts irradiated under a broad range of HTGR conditions
- ^{85m}Kr R/B of $\sim 10^{-8} - 10^{-6}$ at peak burnup of 19.6% FIMA
- Operational issues with AGR-2 and AGR-5/6/7 impaired R/B measurement during later cycles

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

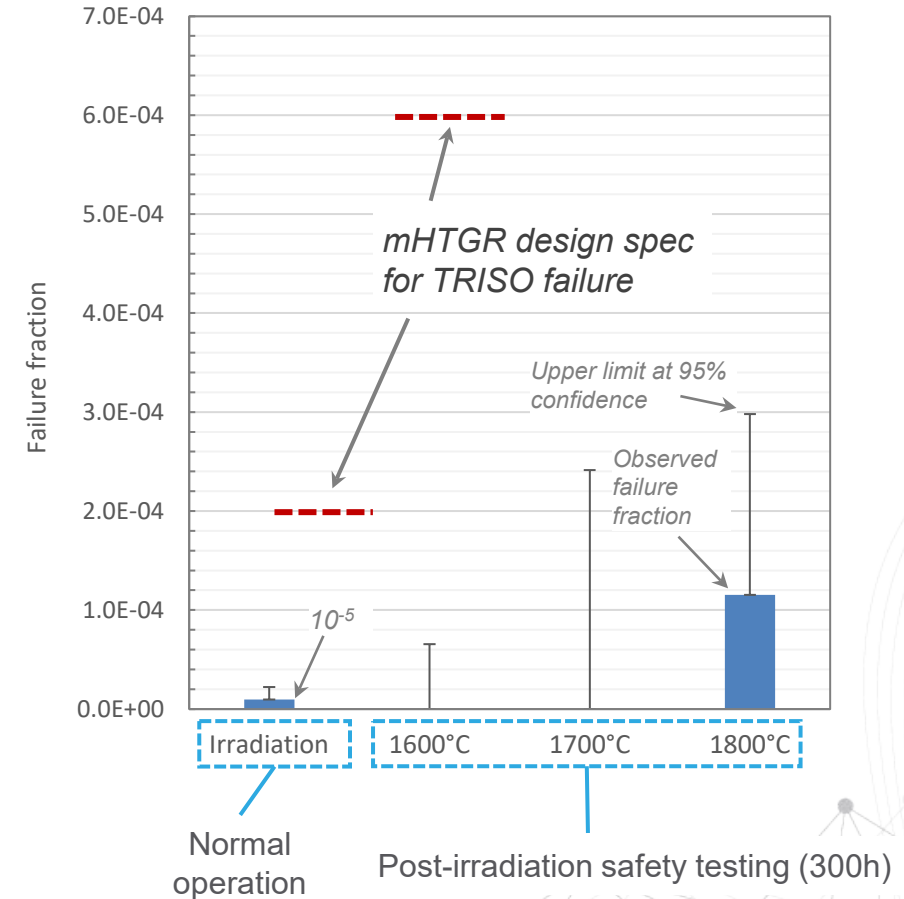


AGR-2 R/B values are through the first $\sim 1/4$ of the irradiation (149 EFPD)
AGR-567 R/B values are through the first $\sim 1/2$ of the irradiation (174 EFPD)

Fuel Performance Summary

- Very low in-pile particle failure rates
- Fuel withstands temperatures of 1600°C and beyond for 100s of hours without significant TRISO failure
- Large quantity of data collected on condensable fission product release
- Improved understanding of coating layer behavior during irradiation
- There is significant performance margin in terms of time at temperature

Experimental TRISO failure fractions for AGR-1 + AGR-2



Current Program Activities

- AGR-3/4 PIE data analysis
- AGR-5/6/7 PIE and safety testing
- Supplemental fuel analysis and method development
- Fuel oxidation testing
 - Single particle testing in FITT at ORNL
 - Air/moisture Ingress Experiment (AMIX) system development at INL (deployed in FY24)
- Fuel performance modeling
- Data management and analysis

Major Accomplishments – Last 12 Months

AGR-5/6/7 Irradiation

- Capsule 1 thermal analysis with non-uniform gas gaps (INL/RPT-23-73074)

AGR-5/6/7 PIE and Safety Testing

- AGR-5/6/7 Disassembly and Metrology First Look Report (INL/RPT-23-71033)
- Completed leaching of all capsule hardware
- Completed gamma scanning of all fuel compacts and graphite holders
- Revised AGR dimensional change data analysis report (INL/EXT-16-37916 Rev. 1)
- Optical microscopy of **eight** compact cross sections
- Completed deconsolidation leach-burn-leach (DLBL) on **four** fuel compacts
- Completed **six** high-temperature safety tests

Major Accomplishments – Last 12 Months

AGR-3/4 PIE and data analysis

- Revised method for reconstructing fission product profiles in graphite/matrix rings from gamma tomographic scans (INL/RPT-22-67635 Rev. 1)
- Compared fission product measurements to transport models to assess diffusivities (INL/RPT-22-69040)
- Completed all fuel compact radial DLBL analysis (**21** compacts)

Fuel performance and fission product transport modeling

- Kernel/buffer volume fraction study (INL/RPT-23-71441)
- Compare PARFUME and BISON fission product release predictions with AGR-3/4 experimental data (INL/RPT-22-69003)

Other

- AGR Fuel Specification Bases Report (INL/RPT-23-71992)

2023 Program Review Presentation Topics

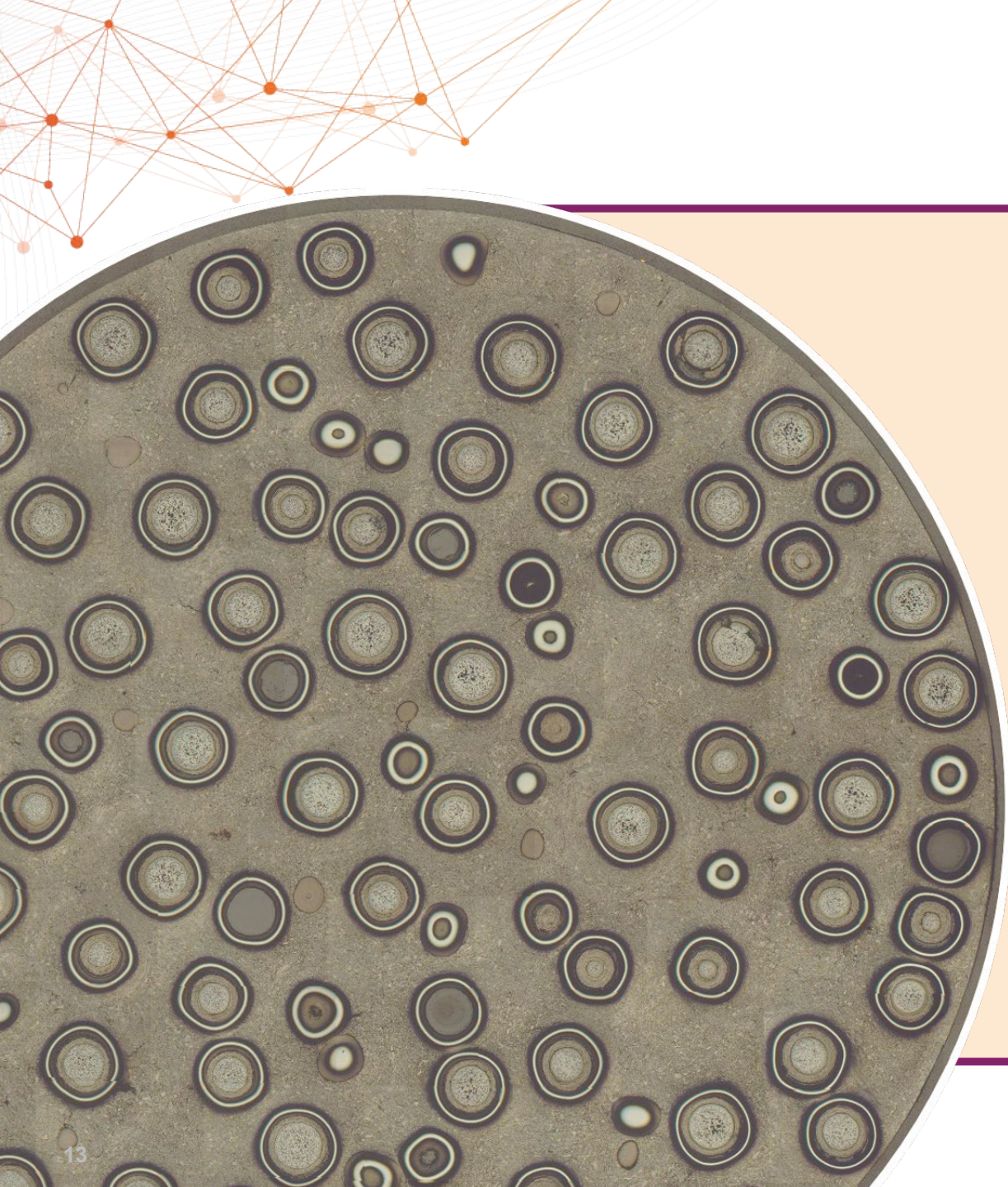
- AGR-3/4 PIE and Data Analysis
- AGR-5/6/7 PIE Overview
- AGR-5/6/7 Capsule 1 Temperature Re-analysis
- AGR-5/6/7 Disassembly and Metrology
- AGR-5/6/7 Compact Cross-section Microscopy
- FITT Testing: Particle Silver Release Behavior at 1100-1600°C
- AGR-5/6/7 Safety Testing and Compact Destructive Exams—INL
- AGR-5/6/7 Safety Testing and Compact Destructive Exams—ORNL
- AGR-5/6/7 Fission Product Release
- AGR-5/6/7 Electron Microscopy
- TRISO Fuel Performance Modeling in Bison
- NDMAS Overview

Major 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
- **Fuel 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
 - 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**

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

Project ID	Lead Institution	PI	Title
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



Thank you for your attention

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