INL/MIS-20-59872-Revision-0

Status of U.S. DOE Deliverables for the VHTR Fuel and Fuel Cycle Project Management Board

Paul A Demkowicz

September 2020

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Paul A Demkowicz

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Paul Demkowicz
Idaho National Laboratory

16th Official Meeting of the Generation IV International Forum
VHTR Fuel and Fuel Cycle Project Management Board
September 29-30, 2020

ART
ADVANCED REACTOR TECHNOLOGIES

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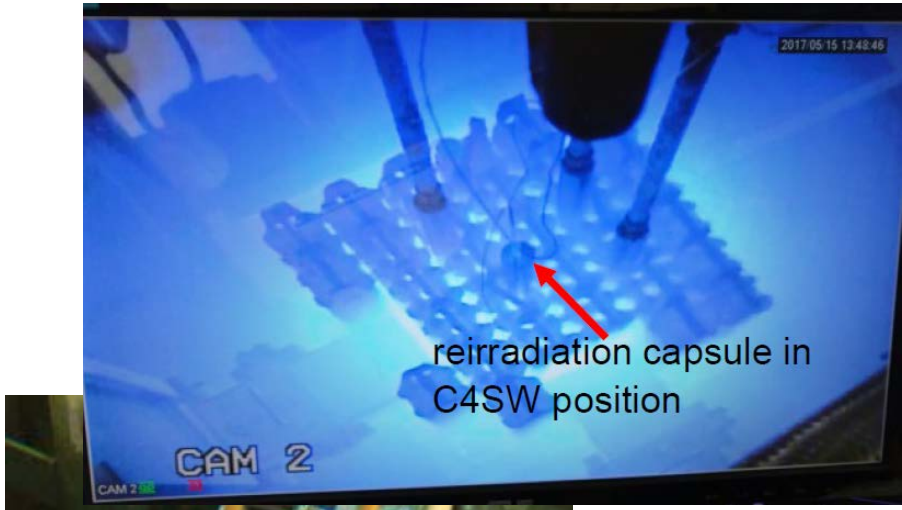
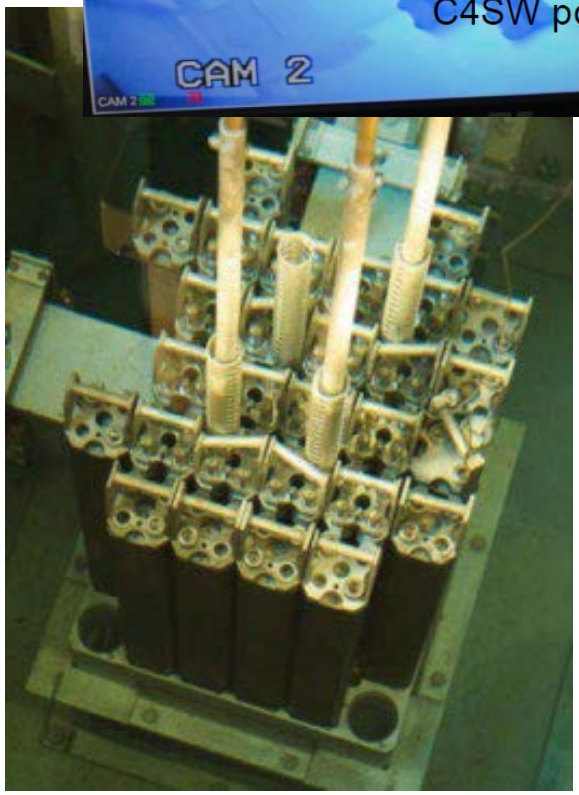
Presentation Outline: Progress 2019 – 2020

- Task 1-1
  - Establish capability for reirradiation of loose particles and compacts
- Task 1-4
  - AGR-2 post-irradiation examination
  - AGR-5/6/7 irradiation
- Task 2-3:
  - LBL round robin
- Task 2-4:
  - Accident test benchmark
- Task 3-2:
  - Develop furnace system for air/steam tests on irradiated fuel
- Task 3-3:
  - AGR-2 safety testing
- Task 3-4:
  - AGR-3/4 PIE
  - AGR-3/4 heating tests
  - Individual particle heating tests
- Task 3-5:
  - Moisture oxidation tests on matrix material
- Task 3-6:
  - Licensing topical report on UCO TRISO fuel performane

Task 1-1: Irradiation Devices and Procedures

- Established capability to insert small numbers of loose particles and intact AGR-3/4 fuel compacts (~1,900 particles) into the NRAD TRIGA reactor core to reirradiate prior to safety tests to measure ^{131}I and ^{133}Xe release
- Completed reirradiation + heating tests:
  - 4 tests with loose particle3/kernels
  - 3 tests with AGR-3/4 compacts
- Paper on AGR-3/4 fuel compact reirradiation and heating tests submitted to HTR2020
- Tests conducted under Tasks 3-2 and 3-3 and described in later slides





Task 1-4: Irradiation and Post-Irradiation Examination Results

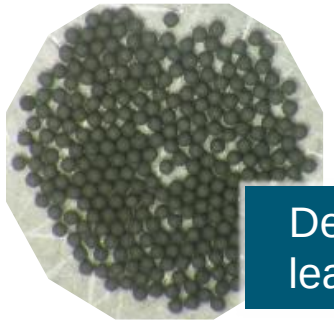
AGR-2 PIE

- AGR-2 PIE is nearing completion
- Destructive compact examination complete or in-progress:

Fuel type	# compacts
UCO	12
UO_2	2

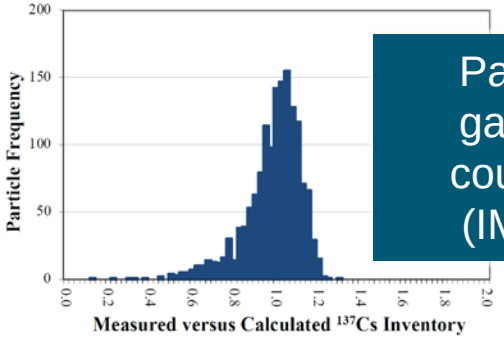
- Final PIE report is planned for 2021

Simplified AGR-2 Compact Destructive Exam Flowchart



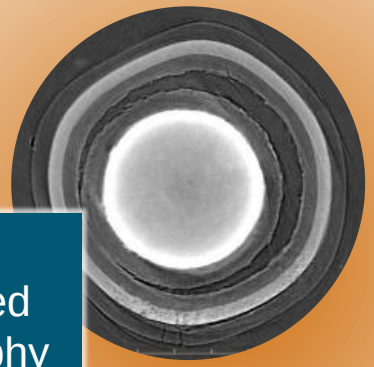
Compact gamma scanning

Deconsolidation-leach-burn-leach



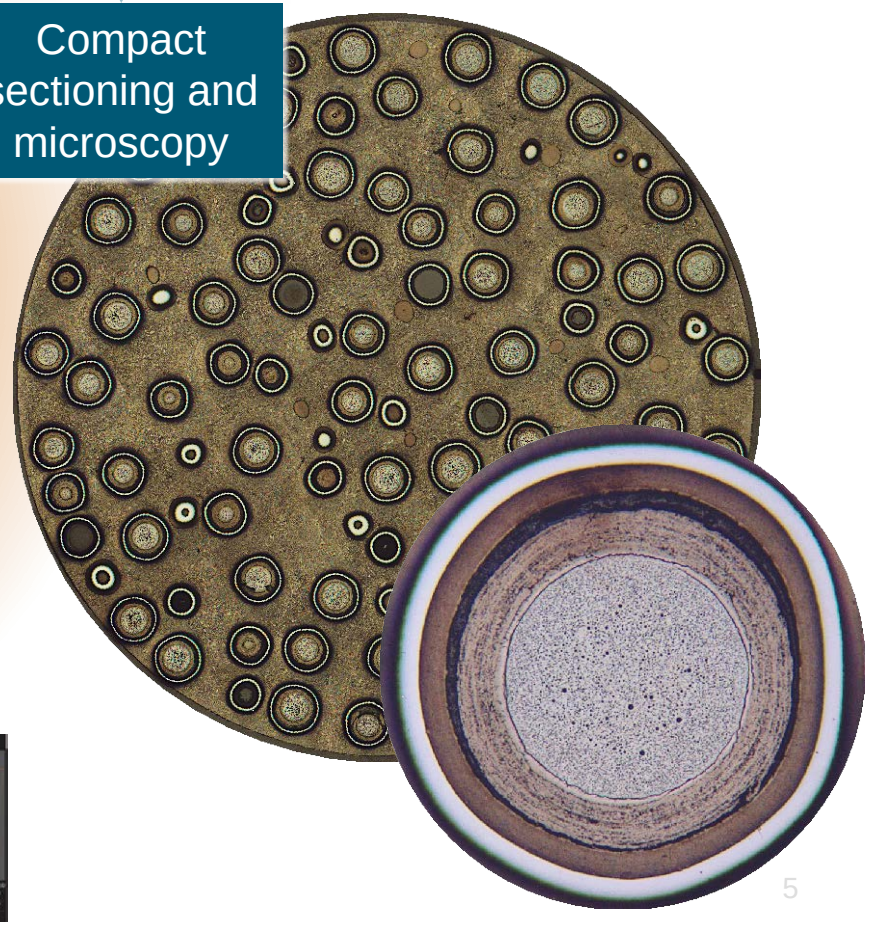
Particle gamma counting (IMGA)

Selected particles

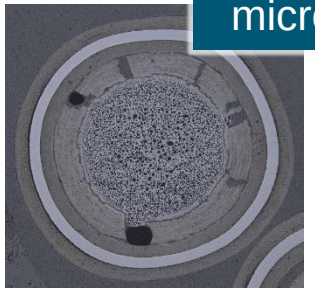


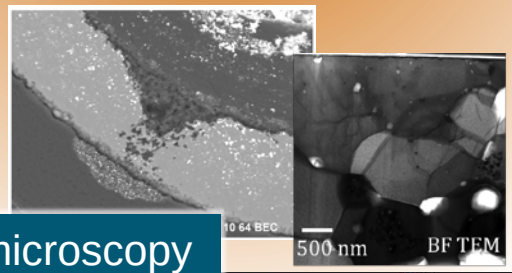
X-ray computed tomography

Compact sectioning and microscopy



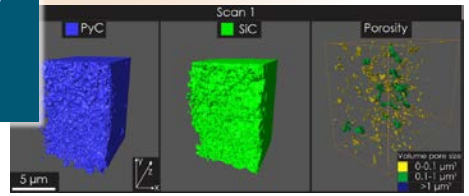
Optical microscopy





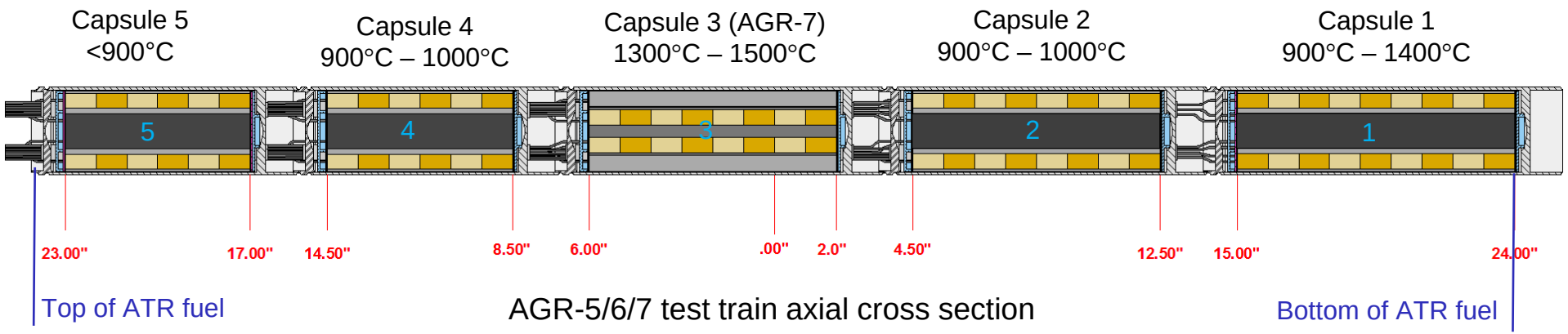
Burnup analysis

Electron microscopy and advanced microanalysis



AGR-5/6/7 irradiation

- Final fuel qualification irradiation and performance margin test
- 194 UCO fuel compacts (~570,000 particles)
- Large increases in fission gas release from Capsule 1 in Oct 2019 indicate significant number of particle failures
- Cause remains unknown, but nature of the release suggests it is induced by the experiment (i.e., this is most likely not intrinsic fuel failure); PIE needed to fully understand this behavior
  - **Capsule 1 PIE is considered highest priority activity**
- Experiment terminated early in July 2021 after approximately 360 EFPD and peak burnup ~15% FIMA
- PIE will begin in early 2021



AGR-5/6/7 test train axial cross section

Task 2-3: Characterization Techniques of Fuel Attributes

- LBL round robin (US, China, KAERI)
  - All experimental work completed: Update provided by John Hunn (this meeting)

Task 2-4: Fuel Performance Modeling

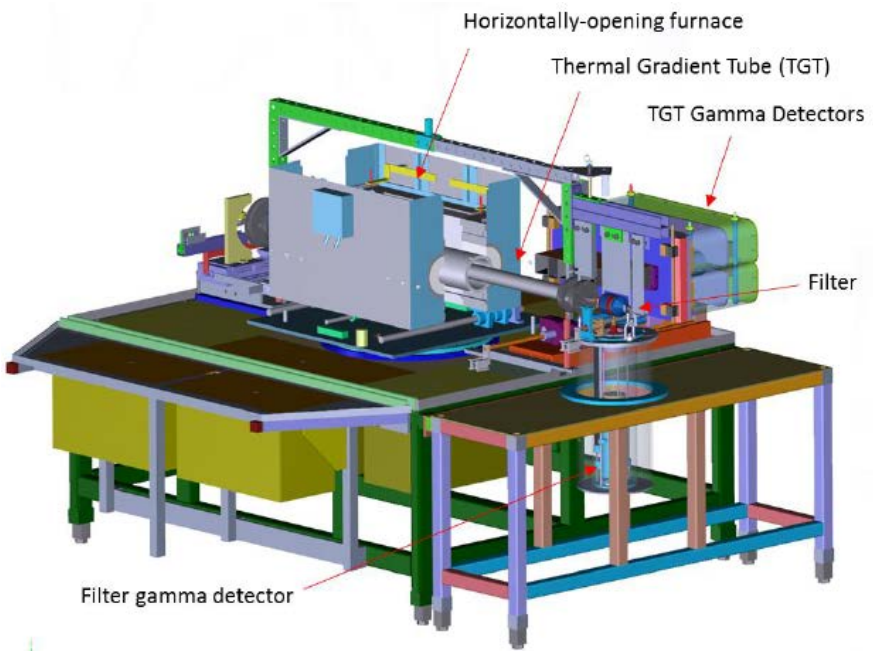
- Accident Test Benchmark (US, JAEA, KAERI):
  - Report completed; navigating issues with releasing this with unlimited distribution in the US.

Task 3.2: Establishment of Heating Test Capabilities

System for testing irradiated fuel in air or steam atmospheres

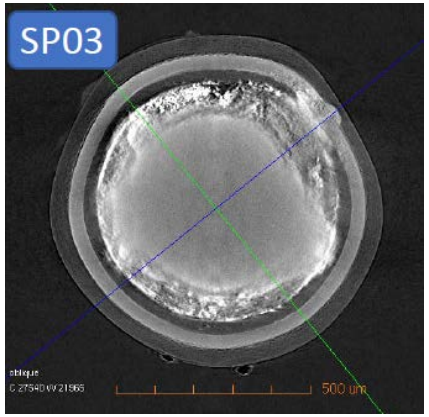
- Air/Moisture Ingress Experiment (AMIX) development continues
- In-cell testing of irradiated fuels and materials in atmospheres with vary air or moisture partial pressures up to ~1600°C
- Start operations ~June 2021

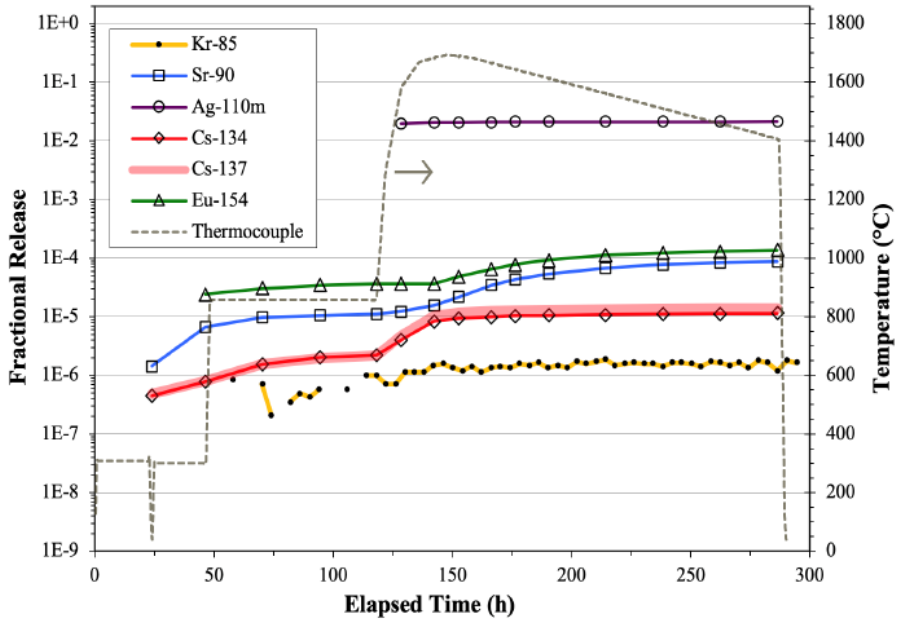

Furnace

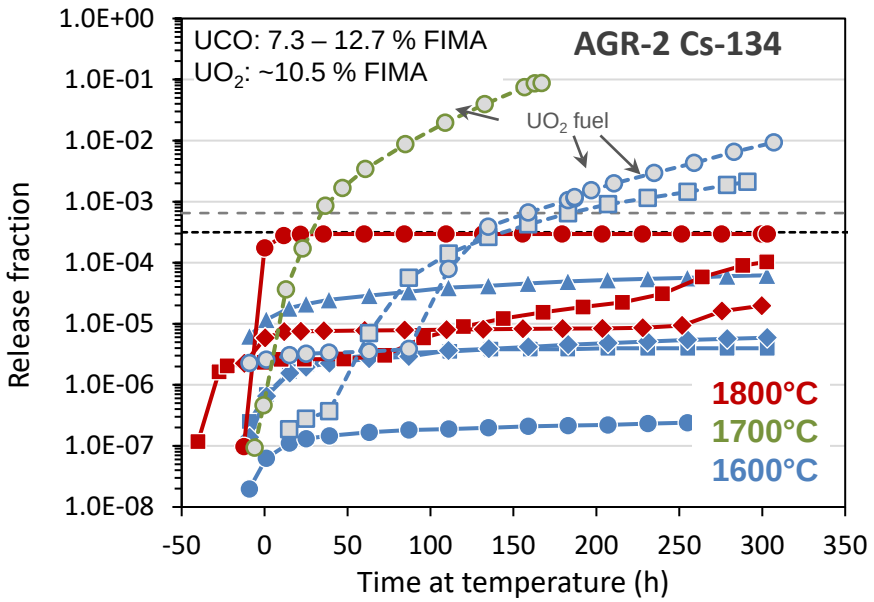


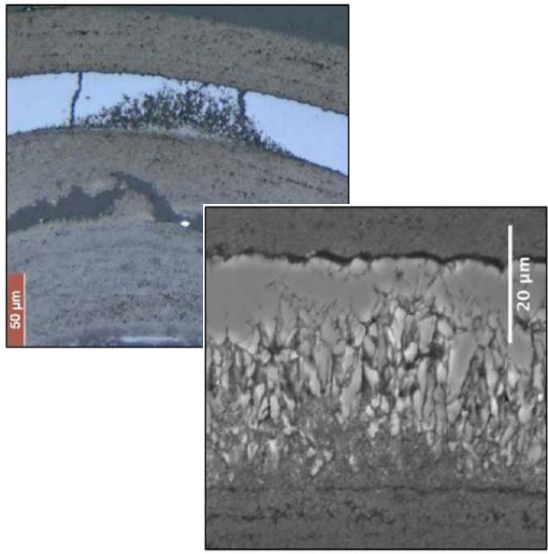
Task 3-3: Heating tests

- All AGR-2 fuel compact safety tests are complete
  - 11 UCO and 4 UO_2 tests completed at 1500, 1600, 1700, or 1800°C
  - Transient temperature test performed with 3 UCO compacts
  - Almost all compacts undergo extensive destructive examination following tests
  - AGR-2 UCO fuel generally behaves similar to AGR-1 UCO
  - AGR-2 UO_2 exhibits higher Cs release related to CO corrosion of SiC





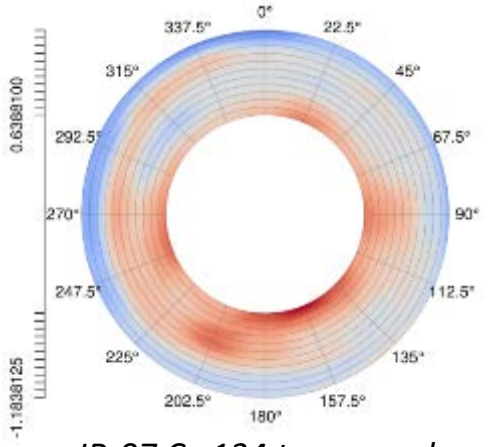




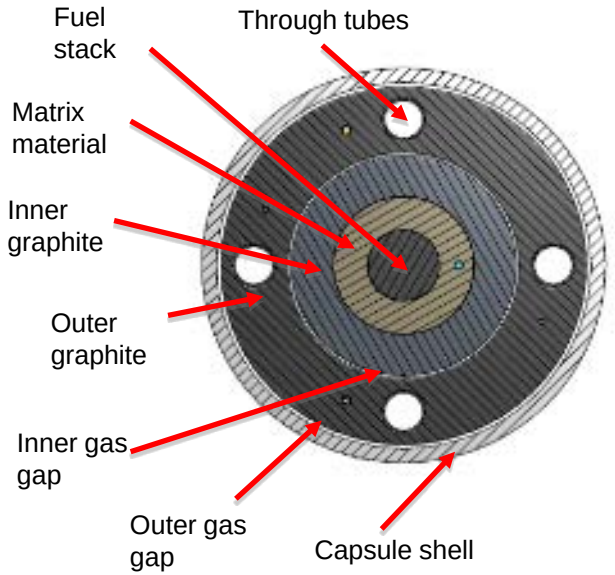
CO corrosion of SiC in UO_2

Task 3-4: Source Term Experiments

- AGR-3/4 PIE is in progress
  - Mass balance of all fission products outside of fuel compacts in capsule components is complete (all 12 capsules)
  - Gamma scanning of the graphite and matrix rings to evaluate fission product inventory and distribution is complete (new data analysis method developed)
  - Physical sampling of inner and outer rings to determine fission product profiles is complete
  - Cross-section analysis of irradiated compacts is complete
  - Destructive examination of compacts by radial deconsolidation is in progress: **9 completed**

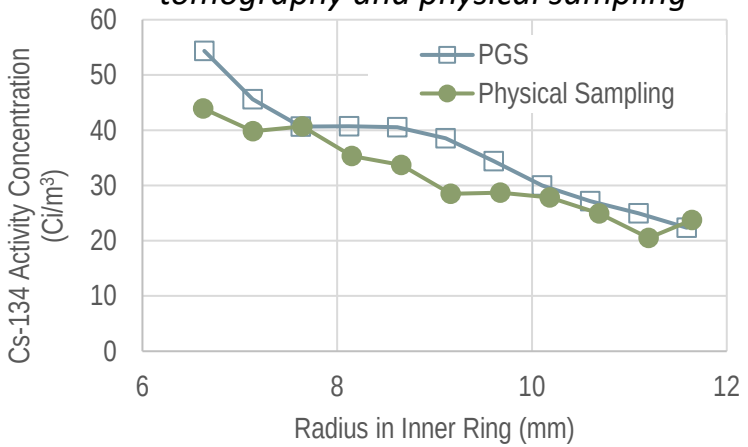


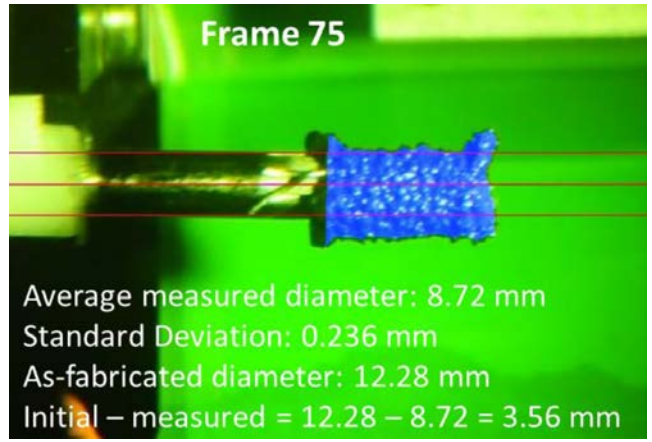
IR-07 Cs-134 tomograph



AGR-3/4 Capsule Cross Section

Radial profiles determined from gamma tomography and physical sampling





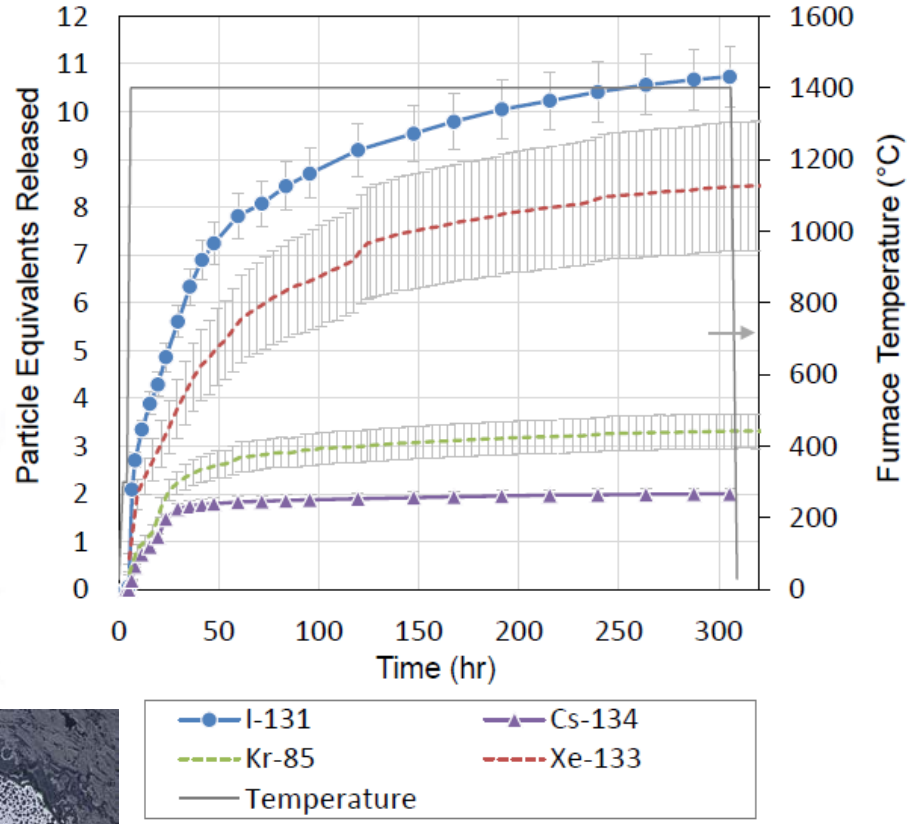
Compact after several deconsolidation steps, leaving only the core

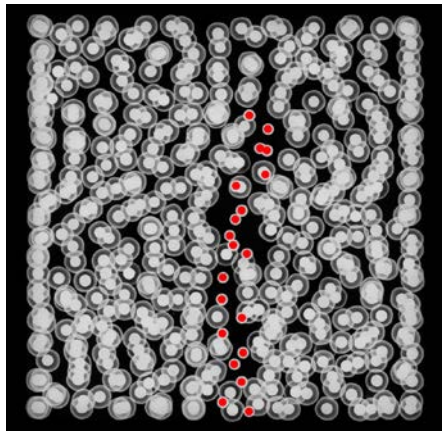
Task 3-4: Source Term Experiments

AGR-3/4 Compact heating tests

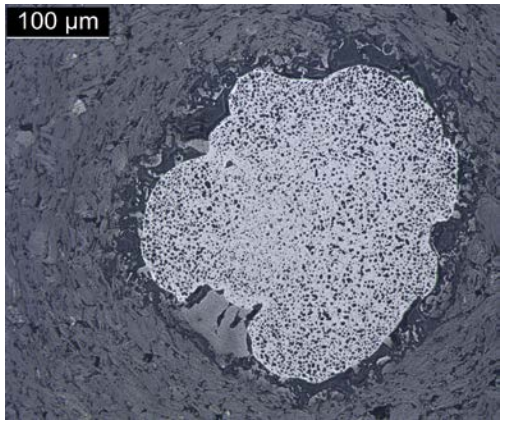
- Post-irradiation heating of AGR-3/4 compacts at 1200 – 1700°C while measuring fission product release in FACS furnace
- Some compacts are re-irradiated in the NRAD TRIGA reactor prior to heating tests
- Explore fission product release from “designed-to-fail” particles (exposed kernels) to help understand transport behavior
- Tests completed:
  - 4 “as-irradiated” compacts
  - 3 “re-irradiated” compacts

AGR-3/4 Compact 10-1 (1400°C)





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

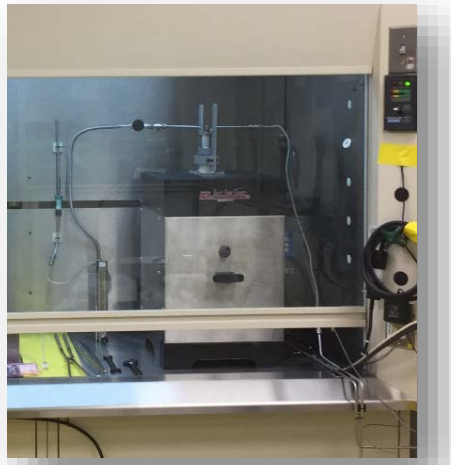


Irradiated DTF particle cross section

Task 3-4: Source Term Experiments

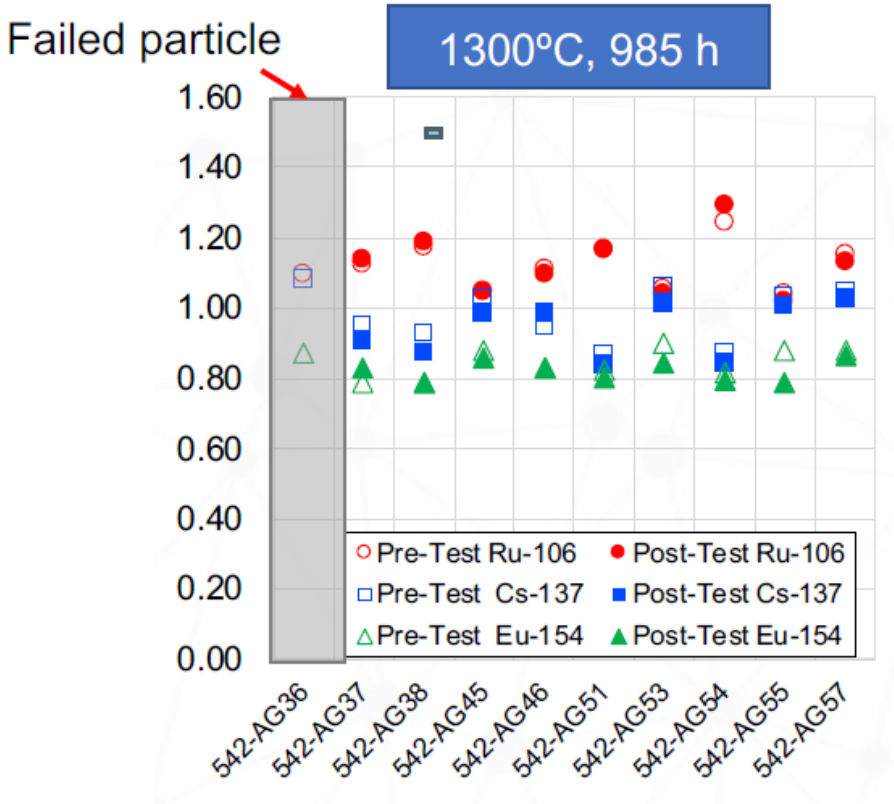
Loose-particle heating tests

- Heat sets of loose, intact, irradiated “burnback” AGR-2 particles (no OPyC) in inert atmosphere for long durations (t ≤ 1500 h)
- Gamma count each particle before and after heating to quantify loss of fission products
- Original motivation was ^{110m}Ag release, but shifted to ^{154}Eu because age of AGR-2 particles has resulted in low ^{110m}Ag inventories due to radioactive decay (^{110m}Ag to be explored with AGR-5/6/7 particles)



	T1 (h)	T2 (h)	T3 (h)	T4 (h)
1150 °C	100	500	1000	1500
1300 °C	100	500	985	1500
1500 °C	-	-	-	1500
1600 °C	84	500	1000	1500

Test incomplete

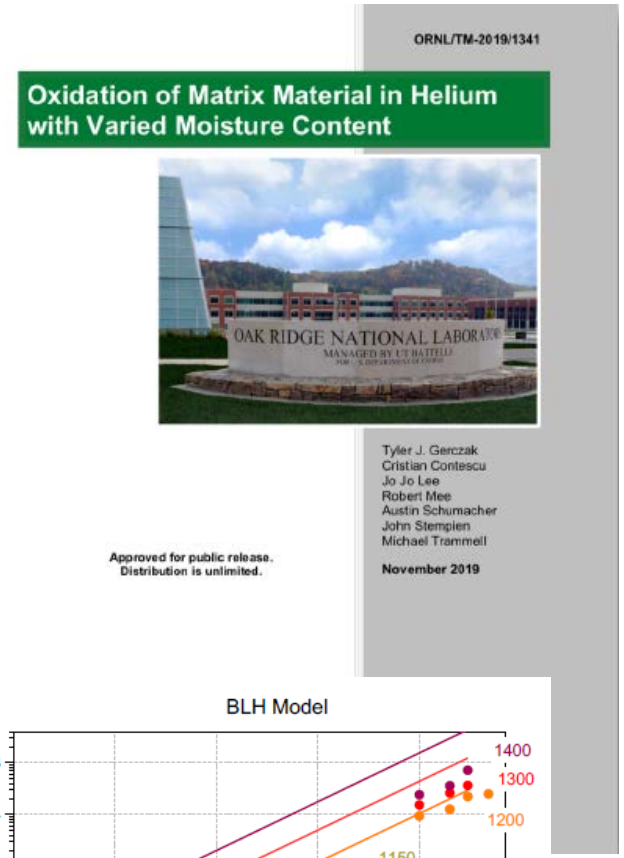


1300 °C, 985 h exposure of AGR-2 Compact 542 particles. Initial results indicate release of ^{154}Eu.

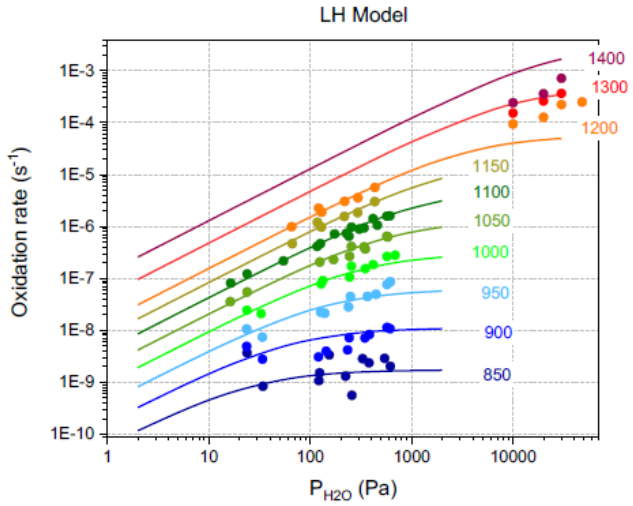
Task 3-5: Moisture and Air Oxidation Testing

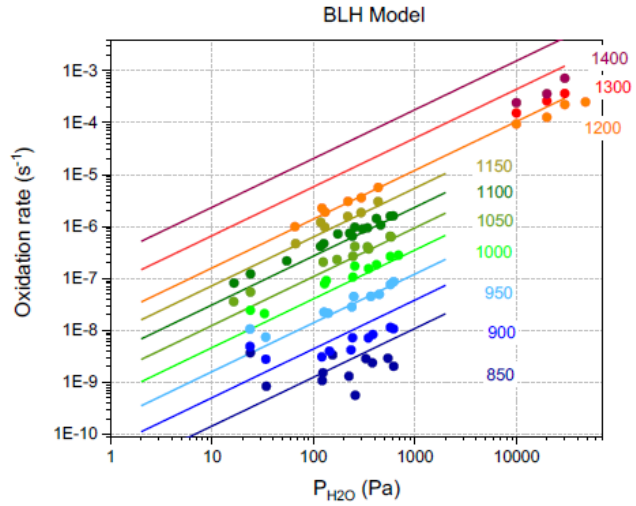
Oxidation HTGR Fuel Matrix Material

- Study oxidation of matrix-only specimens in various partial pressures of water
- Two studies have been completed
  - Kinetic analysis – 800–1200°C, low pressures ($3 < P_{H2O}$ (Pa) < 600, $3 < P_{H2}$ (Pa) < 90); conditions relevant to normal operation
  - Empirical rate analysis – 1200–1500°C, 10–50 kPa P H_2O; conditions relevant to accident scenarios



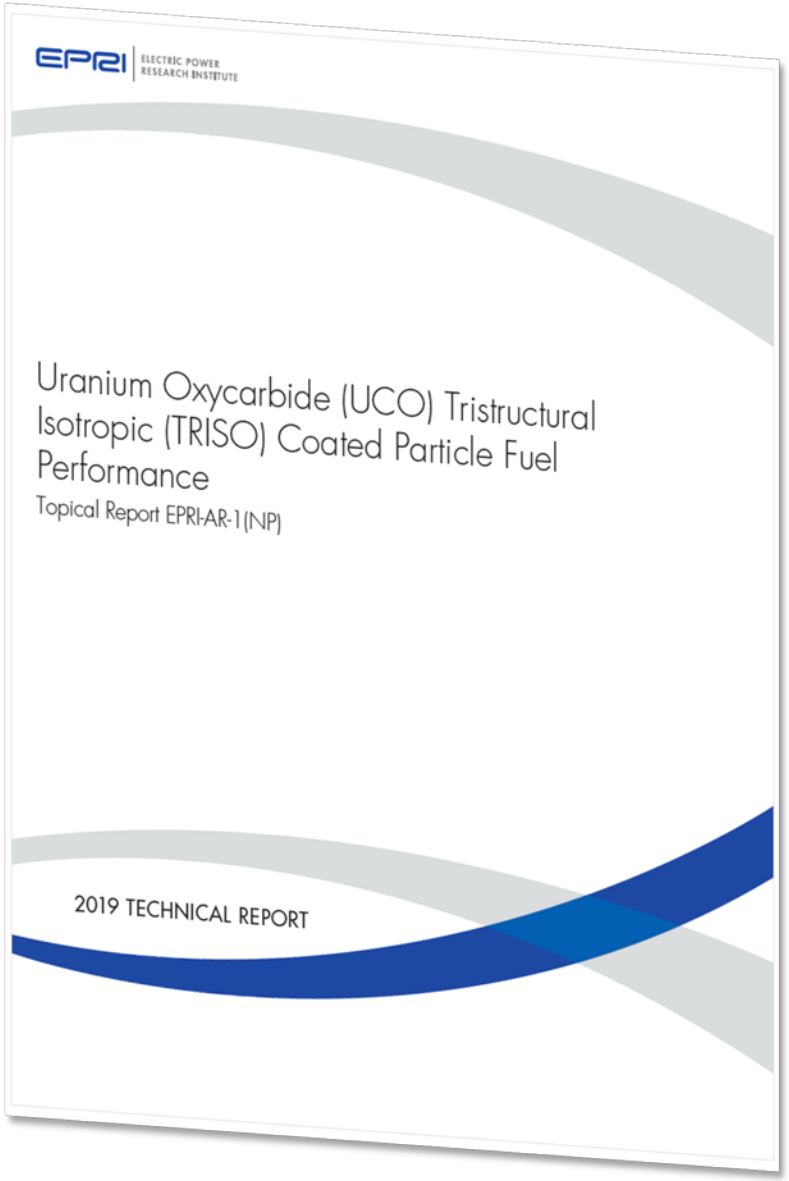
- Microstructural variations likely impact behavior at elevated temperatures (outside of kinetic regime, >1200°C)
- Boltzmann-Langmuir-Hinshelwood kinetic model fits rate data well at 1200 oC but overpredicts above 1200°C (no longer in kinetic regime)
- **Report published by ORNL**

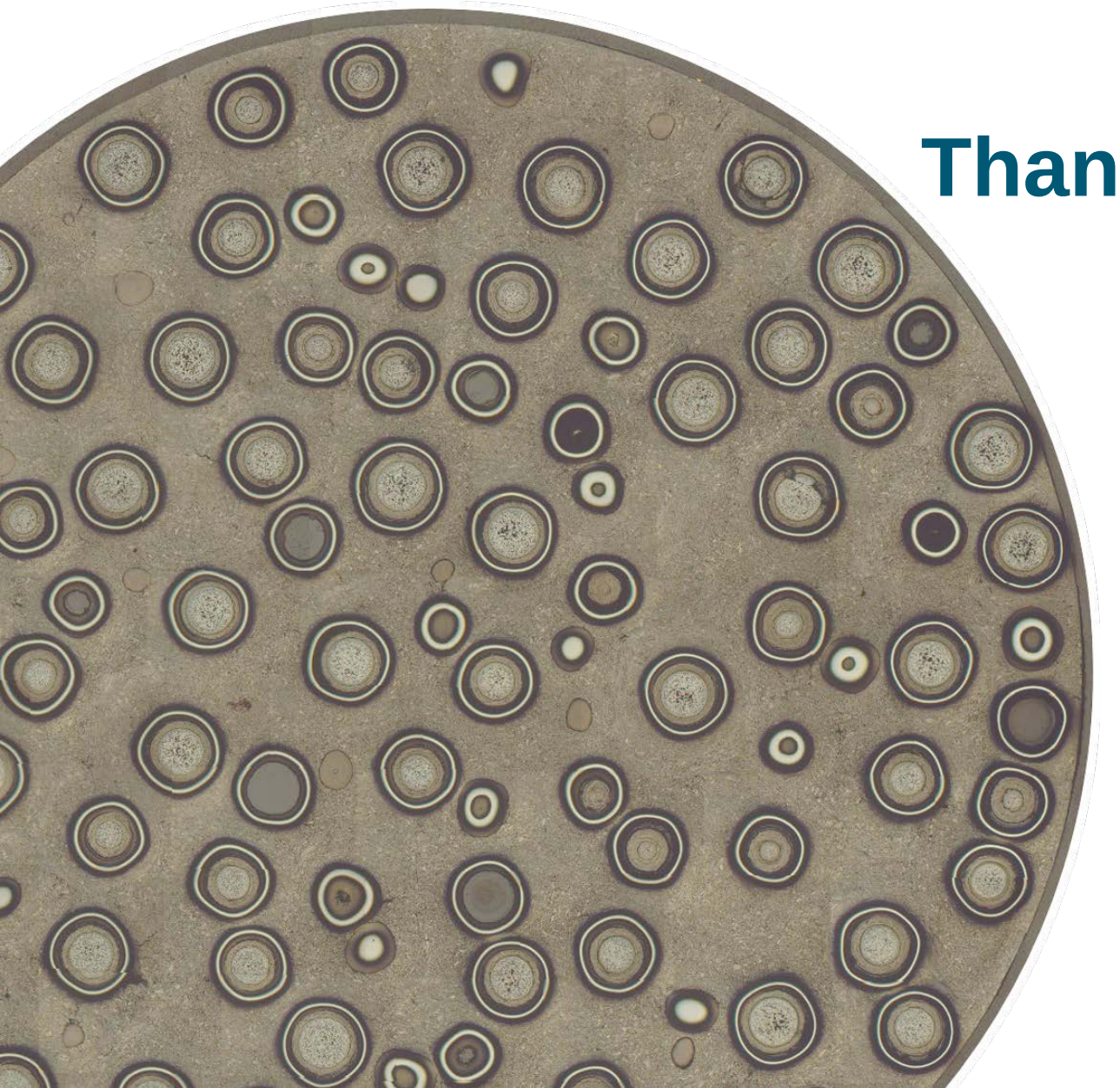




Task 3-6: Fuel Licensing Requirements

- AGR fuel program staff—in conjunction with U.S. HTGR reactor and fuel vendors and the Electric Power Research Institute (EPRI)—developed a Topical Report for review by the Nuclear Regulatory Commission to support reactor licensing
- Scope focused on UCO TRISO fuel particle irradiation and accident performance as demonstrated by the AGR-1 and AGR-2 irradiation, PIE, and safety test data collected to date
- Report asserts that UCO fuel particles with properties similar to the AGR-1 and AGR-2 particles will exhibit similar performance under similar condition
- ***Topical Report was submitted to the US NRC at the end of May 2019***
- ***NRC completed their review in early 2020 and issued the formal safety evaluation in August***
- ***EPRI to submit final version of the Topical Report by October 2020***
- ***The favorable NRC safety evaluation is expected to accelerate reactor licensing by demonstrating NRC acceptance of the AGR program fuel performance demonstration data***





Thank you for your attention

paul.demkowicz@inl.gov