GAS-COOLED REACTOR
ADVANCED REACTOR TECHNOLOGIES PROGRAM

July 16, 2024

AGR-5/6/7 Safety Testing and Compact Destructive Exams at ORNL

William F. Cureton, PhD

TRISO PIE Specialist- Oak Ridge National Laboratory

DOE ART GCR Review Meeting

Hybrid Meeting at INL

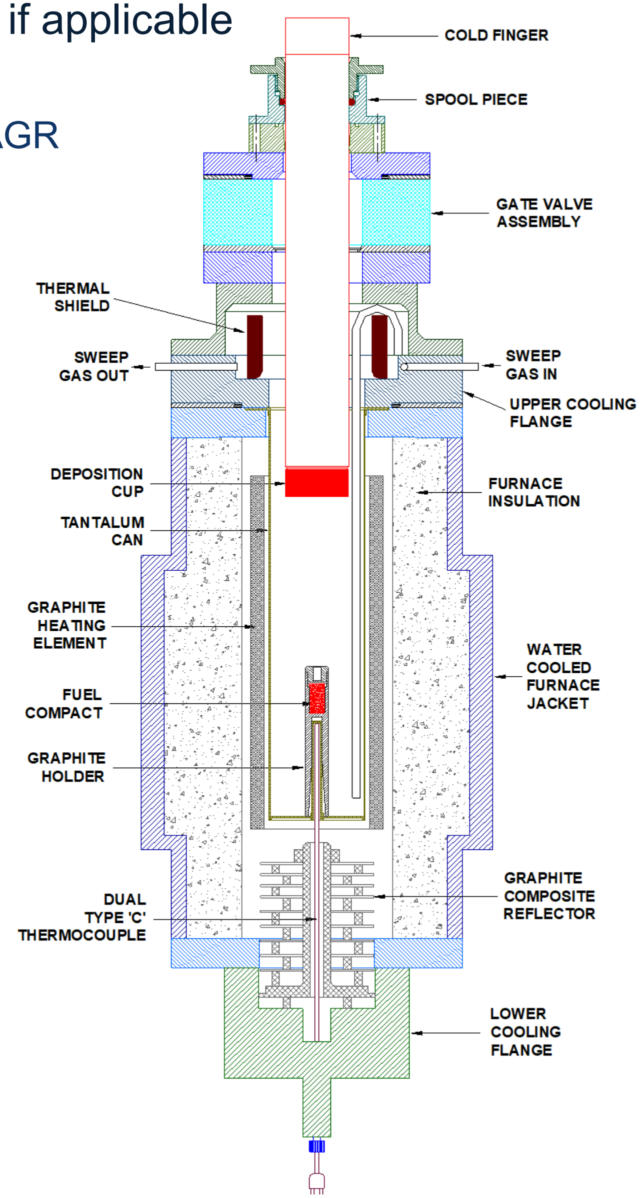
July 16–18, 2024

ORNL Coauthors and Contributors

- John Hunn — ORNL Fuels Lead
- Tyler Gerczak — Electron microscopy and Furnace for Irradiated TRISO Testing (FITT)
- Will Cureton — Safety testing in the Core Conduction Cooldown Test Facility (CCCTF)
- Stephen Trewhitt — Safety testing in the CCCTF and particle heating in FITT
- Fred Montgomery — Deconsolidation Leach-Burn-Leach (DLBL) and burnup analysis
- Martino Hooghkirk — Irradiated Microsphere Gamma Analyzer (IMGA) and materialography
- Grant Helmreich — X-ray Computed Tomography (XCT)
- Jesse Werden — Electron microscopy
- Katherine Montoya — Electron microscopy, analysis of oxidation of FITT specimens
- Bob Morris (consulting) — IMGA, gamma scanning, and CCCTF systems
- Chuck Baldwin (consulting) — IMGA, gamma scanning, materialography, and CCCTF systems
- Irradiated Fuels Examination Laboratory (IFEL) hot cell operators
- Radioactive Materials Analytical Laboratory (RMAL) chemists and supporting staff

Standard ORNL PIE Process

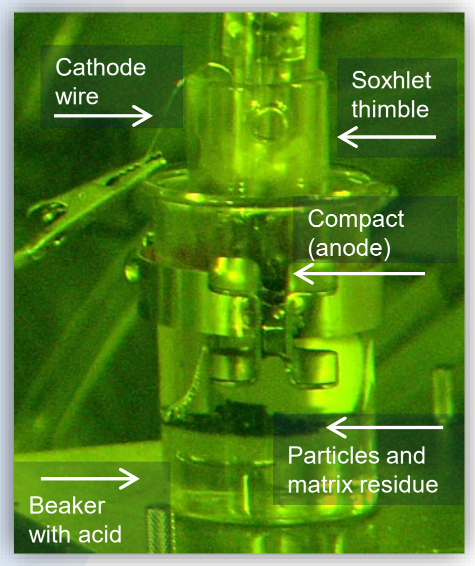
- Perform safety test in ORNL Core Conduction Cooldown Test Facility (CCCTF) if applicable
  - modernized version of the same in cell furnace used for TRISO fuel tests predating AGR
  - cylindrical fuel compact is placed in graphite holder
  - compact in holder positioned on thermocouple finger
  - copper-plated deposition cup screwed on water-cooled cold finger at top
  - compact heated in flowing helium up to 1800°C
  - ^{85}Kr release monitored in He exhaust
  - metallic fission products (FP) collected on cup
    - ^{90}Sr, ^{110m}Ag, ^{134}Cs, ^{137}Cs, ^{154}Eu, ^{155}Eu
  - deposition cup exchanged every 12–24 h to monitor FP release
  - Ta furnace liner, Ta gas inlet tube, graphite holder, and compact matrix are analyzed after the test to provide information on compact release and TRISO performance



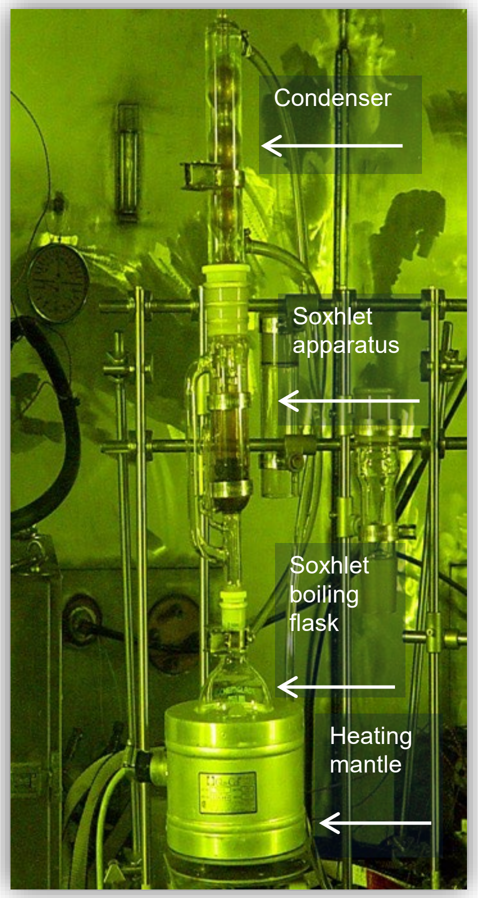
Key Personnel: Stephen Trewhitt, Will Cureton
Safety Testing in the CCCTF

Standard ORNL PIE Process

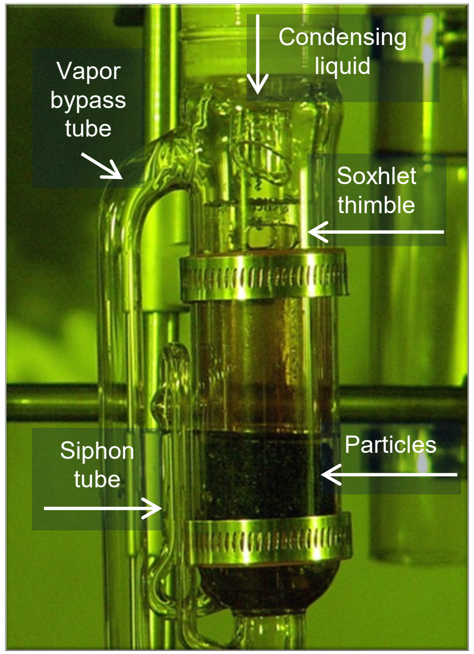
- Perform safety test in ORNL Core Conduction Cooldown Test Facility (CCCTF) if applicable
- Deconsolidate and leach (DL) compact



Deconsolidation Rig



Soxhlet extractor for LBL

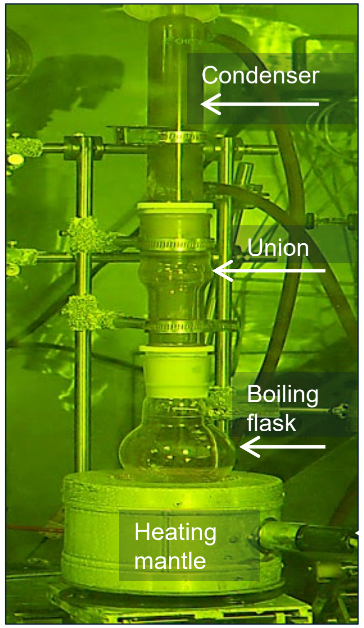


Particles leached in Soxhlet extractor

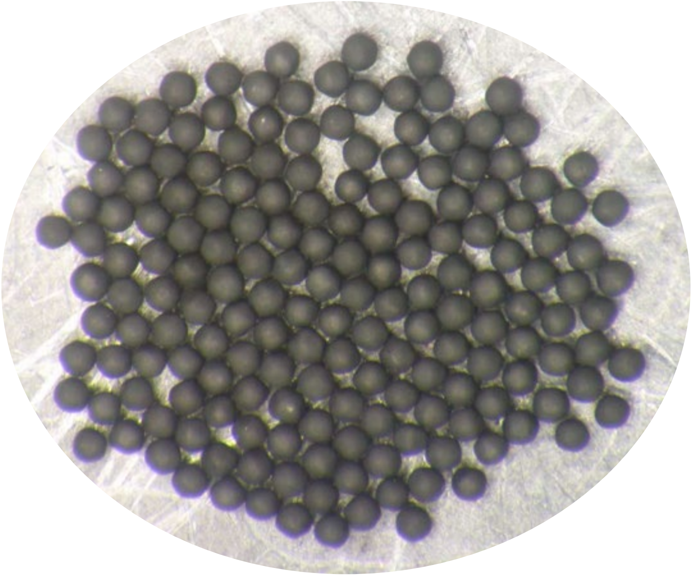
Key Personnel: Fred Montgomery
Deconsolidation Leach-Burn-Leach and Burnup Analysis

Standard ORNL PIE Process

- Perform safety test in ORNL Core Conduction Cooldown Test Facility (CCCTF) if applicable
- Deconsolidate and leach (DL) compact
- Further digest matrix in boiling acid, wash and sieve out TRISO particles, burn-leach (BL) matrix



Digestion and Matrix BL Rig

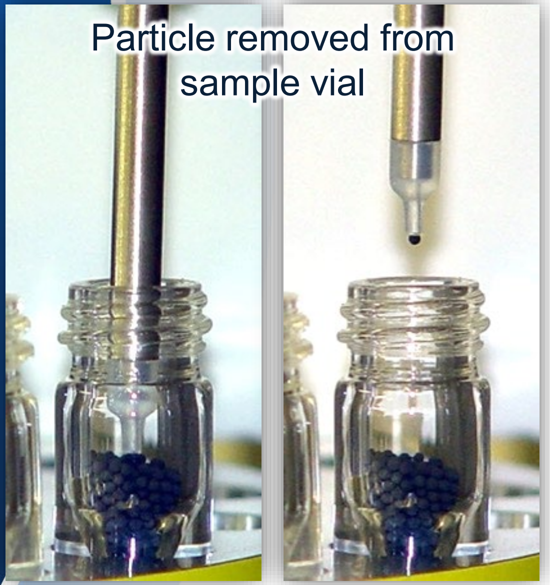


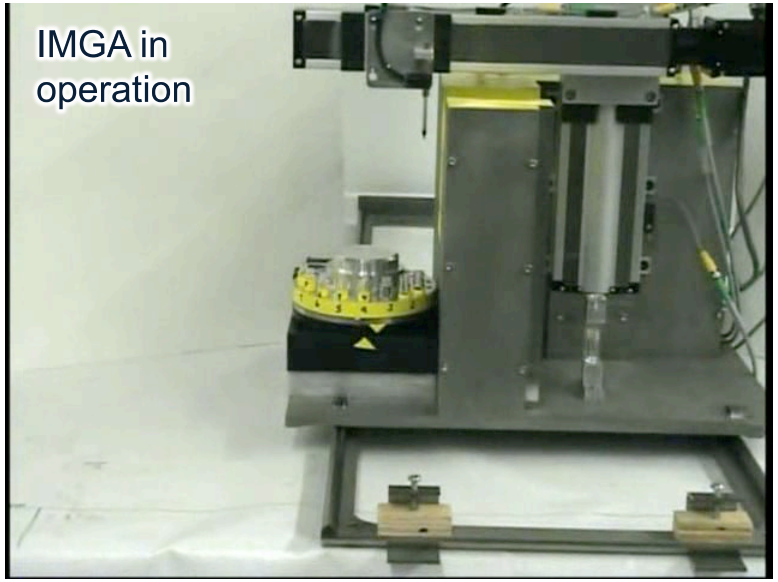
Clean TRISO particles

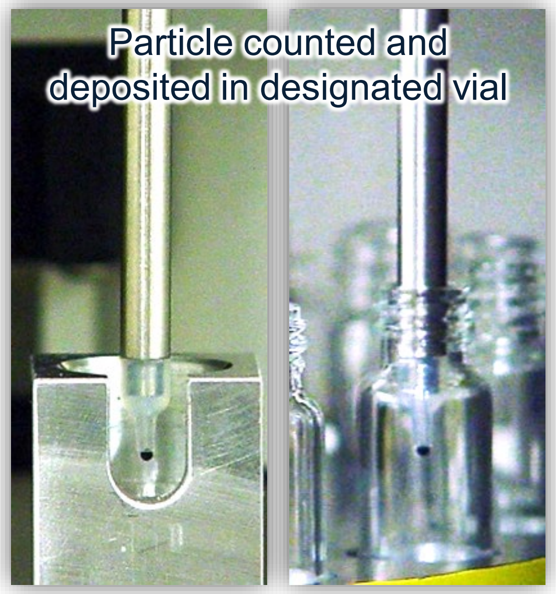
Key Personnel: Fred Montgomery
Deconsolidation Leach-Burn-Leach and Burnup Analysis

Standard ORNL PIE Process

- Perform safety test in ORNL Core Conduction Cooldown Test Facility (CCCTF) if applicable
- Deconsolidate and leach (DL) compact
- Further digest matrix in boiling acid, wash and sieve out TRISO particles, burn-leach (BL) matrix
- Gamma scan TRISO particles with Irradiated Microsphere Gamma Analyzer (IMGA)
  - 1–5-minute quick survey of all particles to find low-Ce and low-Cs particles
  - 4–6-hour extended scans to measure particle inventories (^{106}Ru, ^{110m}Ag, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{154}Eu)



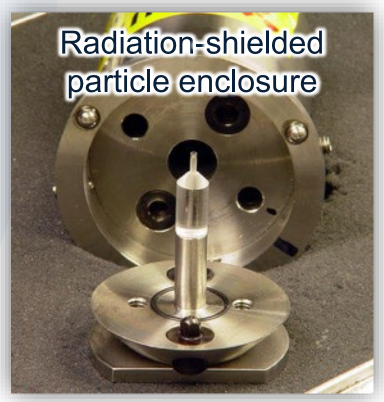


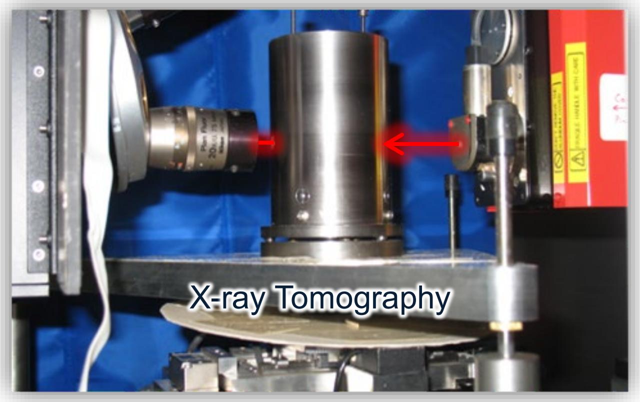


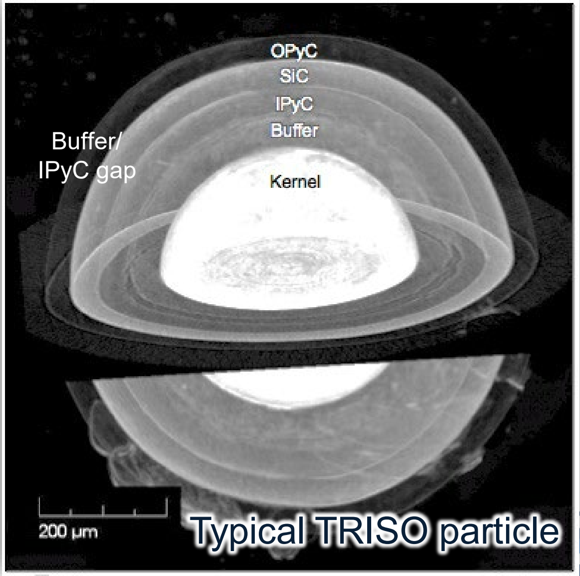
Key Personnel: Martino Hooghkirk
IMGA; Particle Mounting, Cross Sectioning, and Optical Microscopy

Standard ORNL PIE Process

- Perform safety test in ORNL Core Conduction Cooldown Test Facility (CCCTF) if applicable
- Deconsolidate and leach (DL) compact
- Further digest matrix in boiling acid, wash and sieve out TRISO particles, burn-leach (BL) matrix
- Gamma scan TRISO particles with Irradiated Microsphere Gamma Analyzer (IMGA)
  - 1–5-minute quick survey of all particles to find low-Ce and low-Cs particles
  - 4–6-hour extended scans to measure particle inventories (^{106}Ru, ^{110m}Ag, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{154}Eu)
  - Burn-leach 90% of the particles after IMGA survey, saving 10% unburned TRISO as an archive
- Analyze select particles with nondestructive 3D x-ray computed tomography (XCT)
  - XCT of particles with low-Ce or low-Cs that may have failed TRISO or failed SiC
  - XCT of particles with varied inventories (e.g., high vs low Ag or Eu retention)







Key Personnel: Grant Helmreich—XCT

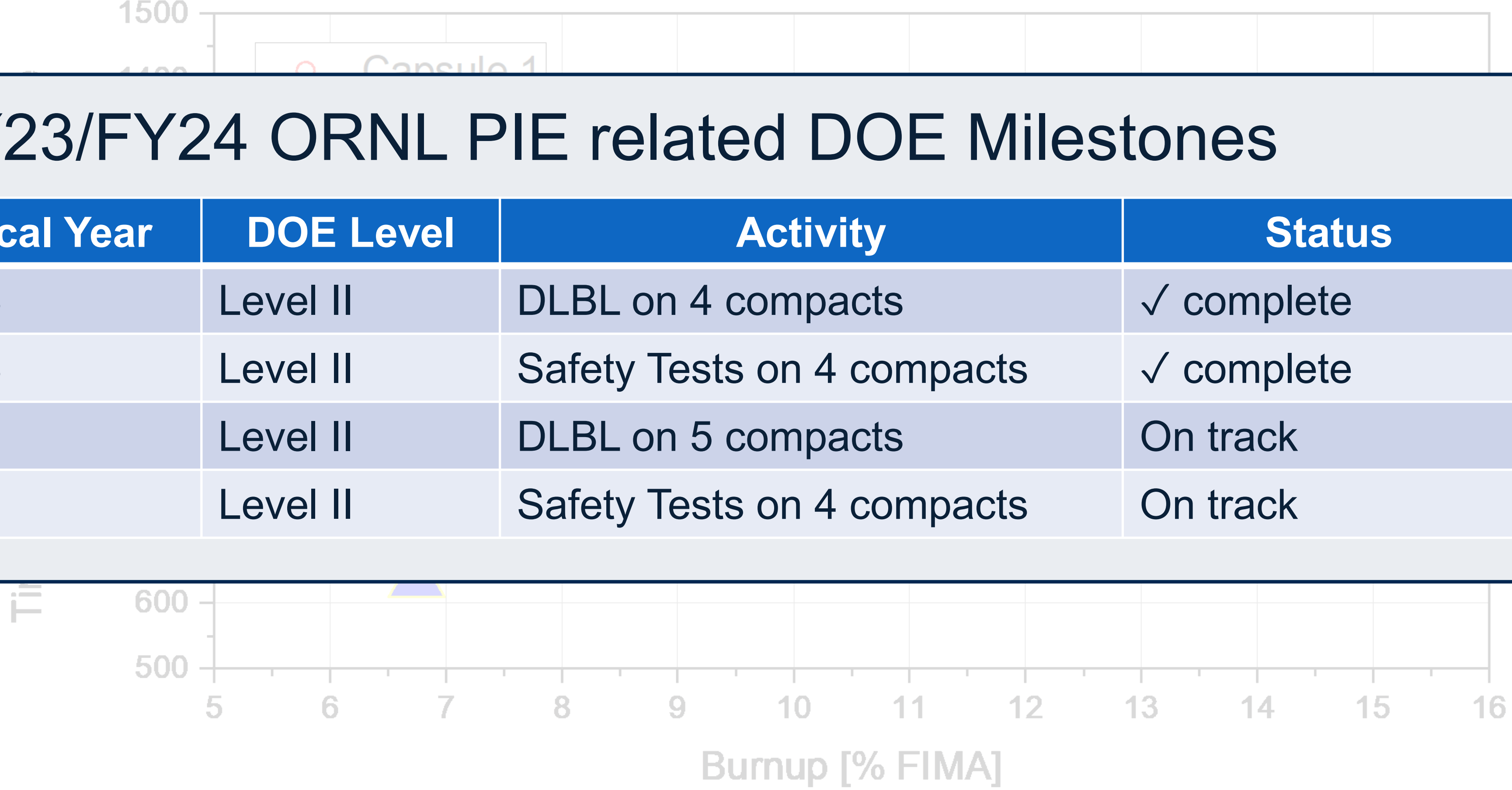
Standard ORNL PIE Process

- Perform safety test in ORNL Core Conduction Cooldown Test Facility (CCCTF) if applicable
- Deconsolidate and leach (DL) compact
- Further digest matrix in boiling acid, wash and sieve out TRISO particles, burn-leach (BL) matrix
- Gamma scan TRISO particles with Irradiated Microsphere Gamma Analyzer (IMGA)
  - 1–5-minute quick survey of all particles to find low-Ce and low-Cs particles
  - 4–6-hour extended scans to measure particle inventories (^{106}Ru, ^{110m}Ag, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{154}Eu)
  - Burn-leach 90% of the particles after IMGA survey, saving 10% unburned TRISO as an archive
- Analyze select particles with non-destructive 3D x-ray computed tomography (XCT)
  - XCT of particles with low-Ce or low-Cs that may have failed TRISO or failed SiC
  - XCT of particles with varied inventories (e.g., high vs low Ag or Eu retention)
- Perform materialographic examination (optical and electron microscopy of polished sections)
  - guided sectioning for targeted examination of regions of interest observed with XCT
  - random midplane cross sections of particles with varied inventories
  - scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS) for microstructural and elemental information, as well as 3D SEM using focused ion beam (FIB) technology

Key Personnel: Tyler Gerczak, Jesse Werden, and Katherine Montoya
SEM, EDS, and FIB-SEM

FY22Q3–FY24Q3 AGR-5/6/7 Progress at ORNL

- 12 Safety-tested compacts to date
- 7 As-received compacts deconsolidated to date



FY23/FY24 ORNL PIE related DOE Milestones

Fiscal Year	DOE Level	Activity	Status
FY23	Level II	DLBL on 4 compacts	✓ complete
FY23	Level II	Safety Tests on 4 compacts	✓ complete
FY24	Level II	DLBL on 5 compacts	On track
FY24	Level II	Safety Tests on 4 compacts	On track

- Fissions per initial metal atoms (FIMA) burn-up from p. 42 of Sterbentz, J.W., "JMOCUP Physics Depletion Calculations for the As-Run AGR-5/6/7 TRISO Particle Experiment in ATR Northeast Flux Trap," ECAR-5321, Rev. 0.
- Temperatures from Hawkes, G.L., "AGR-5/6/7 Daily As-Run Thermal Analyses," ECAR-5633, Rev. 0

Cumulative Safety Test Releases

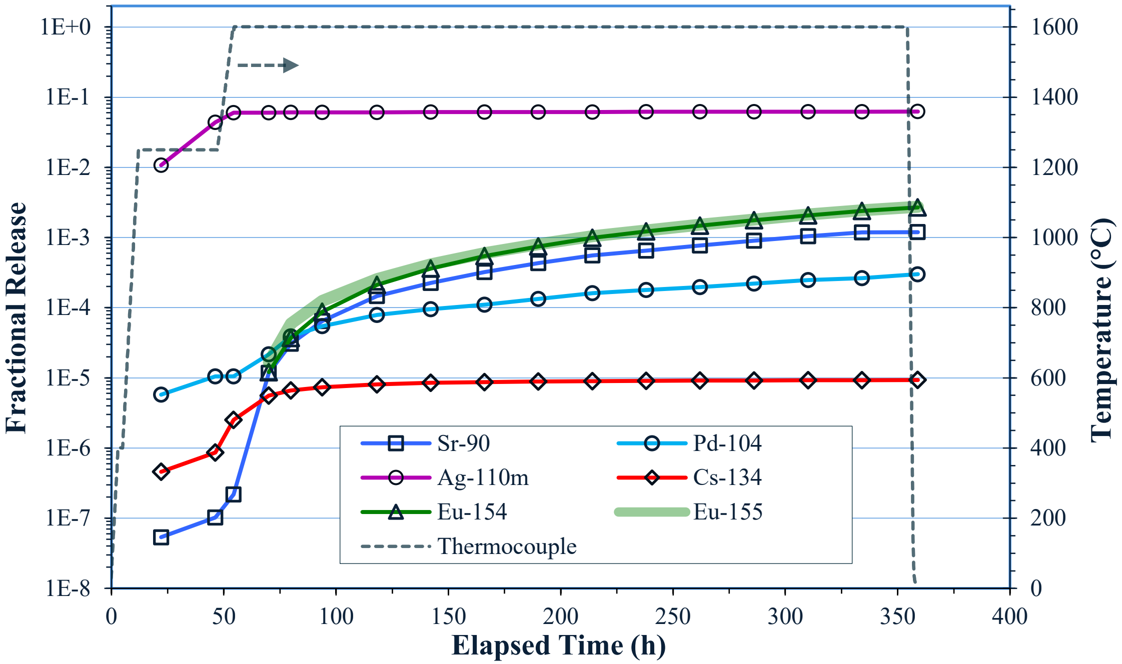
Compact	^{110m}Ag	^{134}Cs	^{154}Eu	^{90}Sr	^{104}Pd	^{85}Kr
AGR-5/6/7 2-2-2 @1600°C	2.6E-2	8.3E-6	6.5E-3	2.8E-3	1.8E-3	<MDA
	59	0.019	15	6.3	4.2	--
AGR-5/6/7 2-2-4 @1600°C	2.1E-2	7.2E-6	6.9E-3	3.0E-3	9.4E-4	<MDA
	48	0.016	16	6.8	2.1	--
AGR-5/6/7 2-3-2 @1800°C	9.9E-3	1.1E-3	1.0E-1	7.1E-2	3.1E-2	2.4E-4
	22	2.5	232	160	70	0.53
AGR-5/6/7 2-5-1 @1600°C	6.3E-2	9.3E-6	2.7E-3	1.2E-3	3.0E-4	<MDA
	137	0.02	5.9	2.6	0.66	--
AGR-5/6/7 3-1-2 @1600°C	5.0E-3	4.8E-4	9.5E-3	1.3E-2	9.1E-4	3.4E-5
	11	1.1	21	30	2.1	0.076
AGR-5/6/7 4-1-2 @1600°C	2.0E-1	3.9E-5	2.0E-3	1.4E-3	4.5E-4	<MDA
	444	0.085	4.5	3.0	0.99	--
AGR-5/6/7 5-2-2 @1800°C	3.3E-1	5.3E-4	4.0E-3	1.7E-3	3.0E-2	4.8E-4
	1128	1.8	13	5.8	103	1.6
AGR-5/6/7 5-5-3 @1600°C	1.8E-3	1.3E-5	6.6E-5	8.3E-6	4.8E-4	<MDA
	6.2	0.045	0.22	0.028	1.6	--
AGR-5/6/7 5-6-2 @1600°C	1.7E-2	2.0E-4	1.4E-4	7.0E-5	3.2E-4	5.5E-5
	56	0.66	0.48	0.24	1.1	0.19

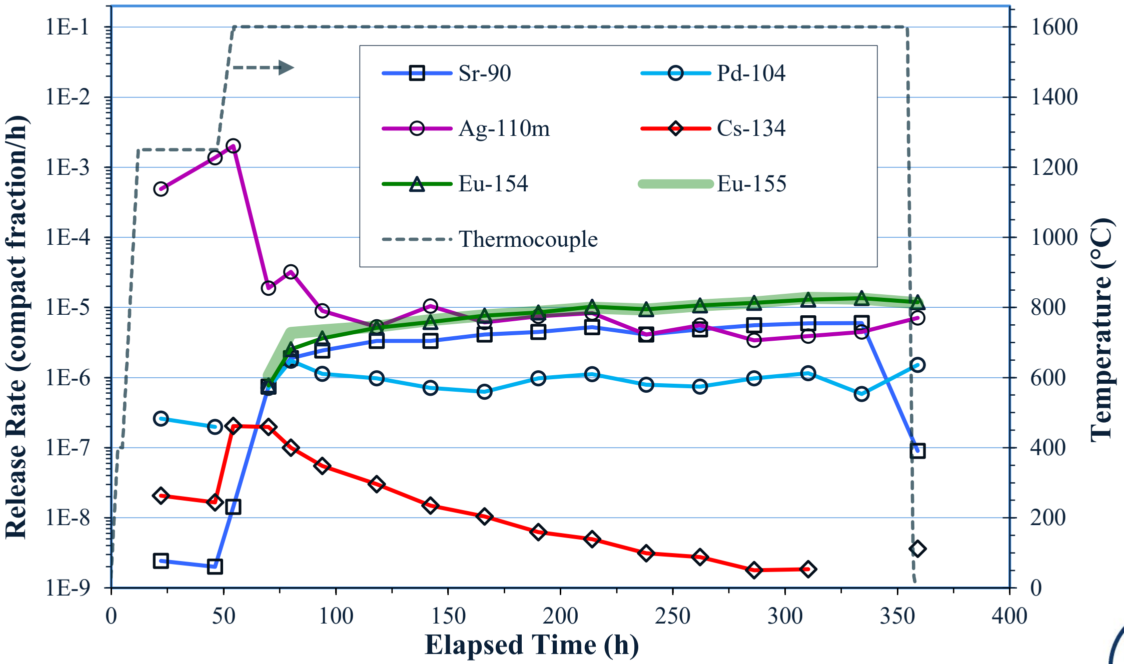
Values are presented as compact fraction and particle-equivalent highlighted (relative highlight: green – lower release, red – higher release)
Estimated uncertainty in solute analysis is ±10% and less than values for ^{110m}Ag are estimated from first leach.

1600°C Safety Test of Compact 2-5-1
(14.8% FIMA, 851°C TAVA Temperature)

	^{110m}Ag	^{134}Cs	^{154}Eu	^{90}Sr	^{104}Pd	^{85}Kr
Compact Fraction	6.3E-2	9.3E-6	2.7E-3	1.2E-3	3.0E-4	<MDA
Particle Equivalents	137	0.02	5.9	2.6	0.66	--

- Liquid nitrogen supply issues for ^{85}Kr traps caused longer pause at 1250°C.
- No indication of TRISO failure — ^{85}Kr below MDA of 5.5E-7 (<0.0013 particle equivalents).
- No indication of SiC failure — ^{134}Cs release of <0.02 particle equivalents.
- ^{154}Eu, ^{90}Sr, and ^{104}Pd release similar to other Capsule 2 compacts tested at 1600°C.
- Moderate ^{110m}Ag release at the beginning of the safety test related to a high inventory outside the SiC at the end of the irradiation test.



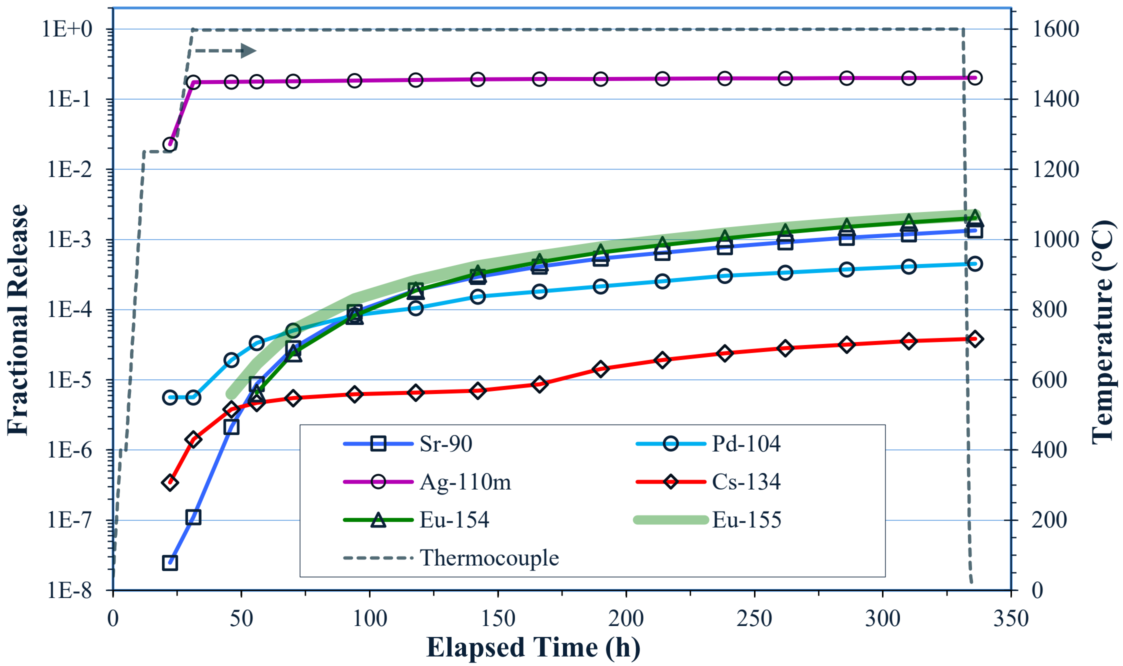


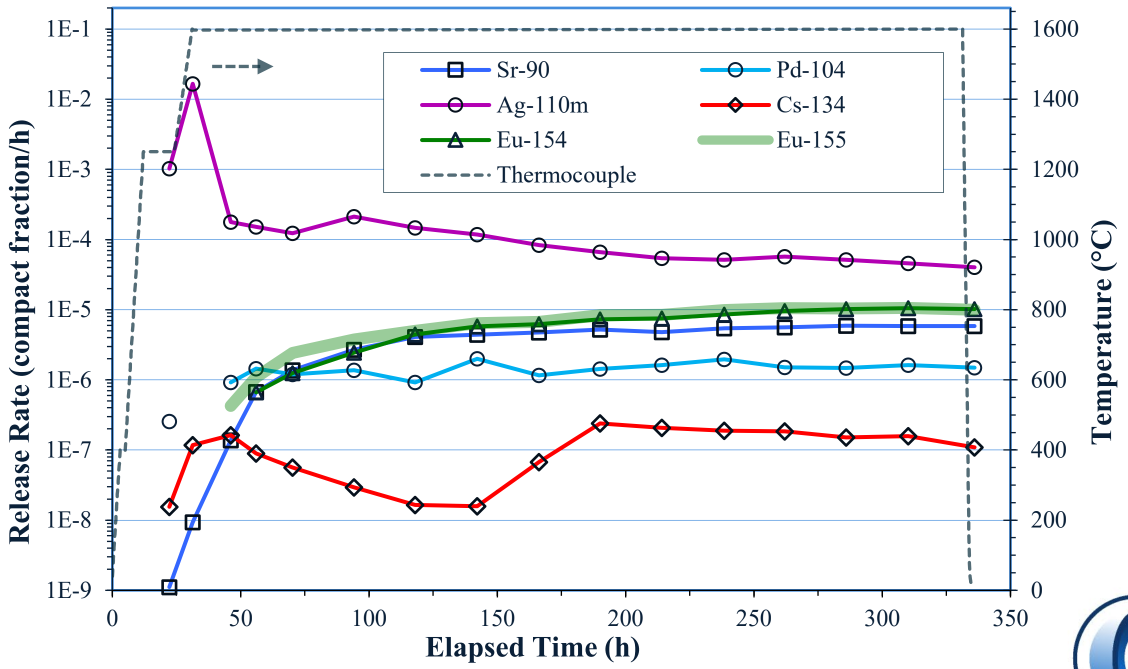
1600°C Safety Test of Compact 4-1-2

(13.7% FIMA, 774°C TAVA Temperature)

	^{110m}Ag	^{134}Cs	^{154}Eu	^{90}Sr	^{104}Pd	^{85}Kr
Compact Fraction	2.0E-1	3.9E-5	2.0E-3	1.4E-3	4.5E-4	<MDA
Particle Equivalents	444	0.085	4.5	3.0	0.99	--

- No indication of TRISO failure — ^{85}Kr below MDA of 5.5E-7 (<0.0013 particle equivalents).
- No indication of SiC failure — ^{134}Cs release of <0.085 particle equivalents.
- ^{110m}Ag release highest observed among all AGR-5/6/7 1600°C safety-tested compacts at ORNL. Low irradiation temperature causes higher retention in the matrix post irradiation.
- ^{154}Eu, ^{90}Sr, and ^{104}Pd release similar to Capsule 2 compacts tested at 1600°C.



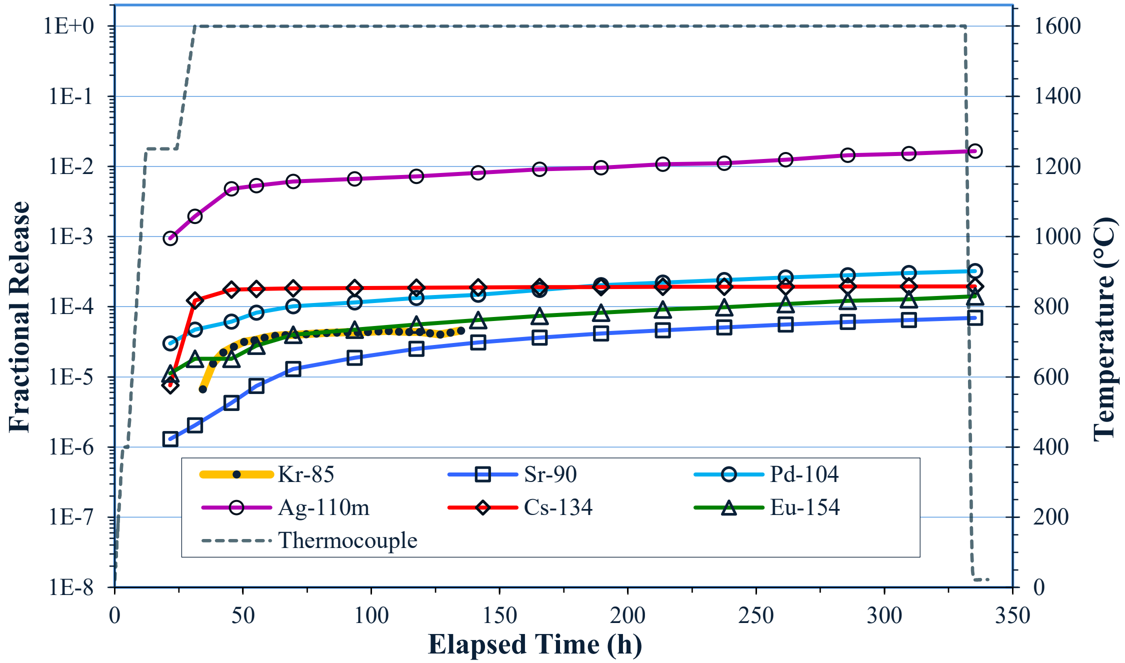


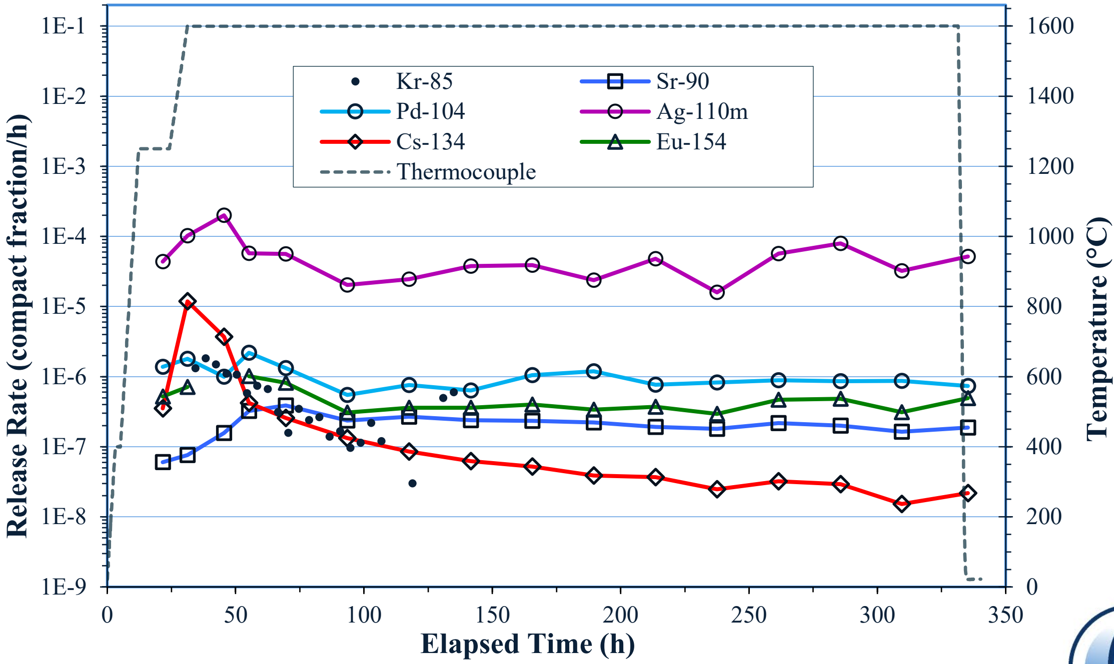
1600°C Safety Test of Compact 5-6-2

(6.8% FIMA, 634°C TAVA Temperature)

	^{110m}Ag	^{134}Cs	^{154}Eu	^{90}Sr	^{104}Pd	^{85}Kr
Compact Fraction	1.7E-2	2.0E-4	1.4E-4	7.0E-5	3.2E-4	5.5E-5
Particle Equivalents	56	0.66	0.48	0.24	1.1	0.19

- Initial ^{134}Cs release of 2/3 particle equivalent indicates degraded or defective SiC, likely from a single particle given time-dependent rate
- ^{85}Kr accumulation of 5.5E-5 (0.19 particle equivalents) indicative of degraded or defective TRISO.
- Early ^{110m}Ag release dominated by early release of matrix inventory. Relatively constant rate of release through the rest of the test.
- ^{154}Eu, ^{90}Sr, and ^{104}Pd had typical rate trends related to slow transport to cups and some diffusive release from particles.

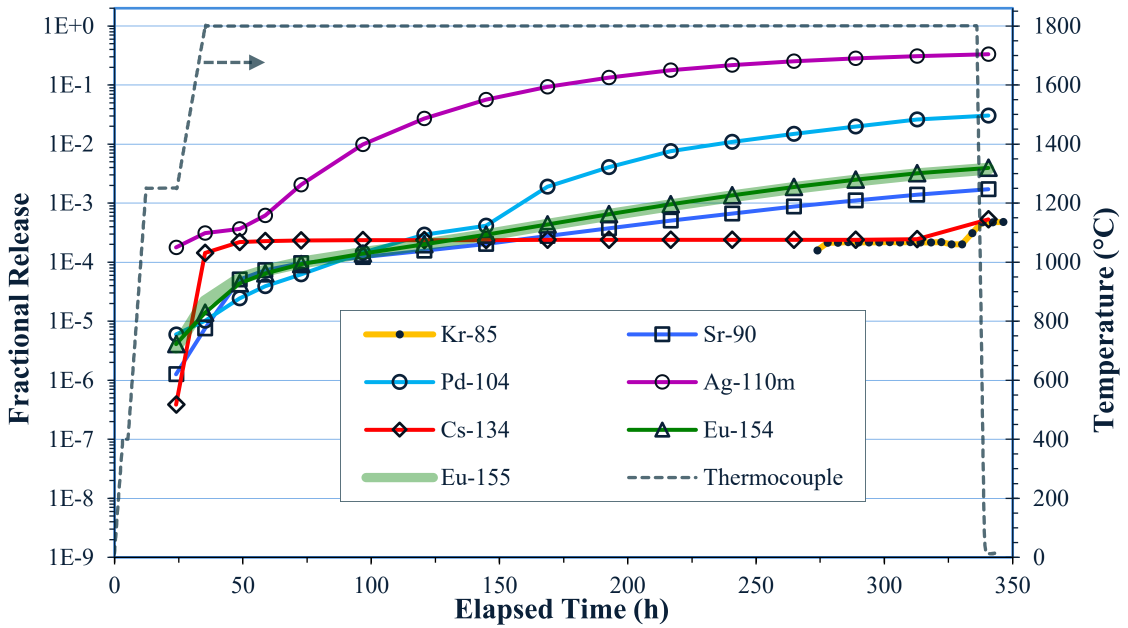


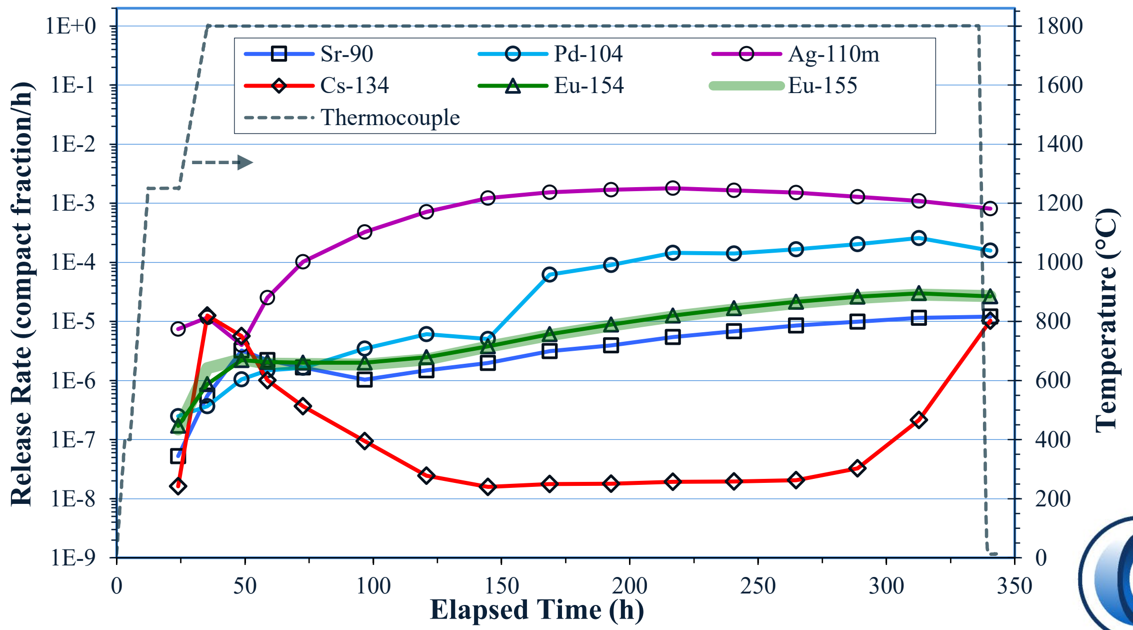


1800°C Safety Test of Compact 5-2-2
(8.8% FIMA, 789°C TAVA Temperature)

	^{110m}Ag	^{134}Cs	^{154}Eu	^{90}Sr	^{104}Pd	^{85}Kr
Compact Fraction	3.3E-1	5.3E-4	4.0E-3	1.7E-3	3.0E-2	4.8E-4
Particle Equivalents	1128	1.8	13	5.8	103	1.6

- ^{85}Kr accumulation of 4.8E-4 (1.6 particle equivalents) indicative of degraded or defective TRISO.
- Initial ^{134}Cs release of ~one particle equivalent indicates degraded or defective SiC, likely from a single particle given time-dependent rate. Uptick in ^{134}Cs at end of test may be from a second particle and likely related to the observed ^{85}Kr release.
- Cumulative ^{110m}Ag release of 33% was mostly from diffusive release through SiC during the safety test and higher than observed in 1800°C test of Compact 2-3-2 because of higher fractional inventory retained in irradiated particles.
- Uptick in ^{104}Pd release at ~170 hours possibly indicating microstructural evolution at 1800°C. Further PIE necessary.



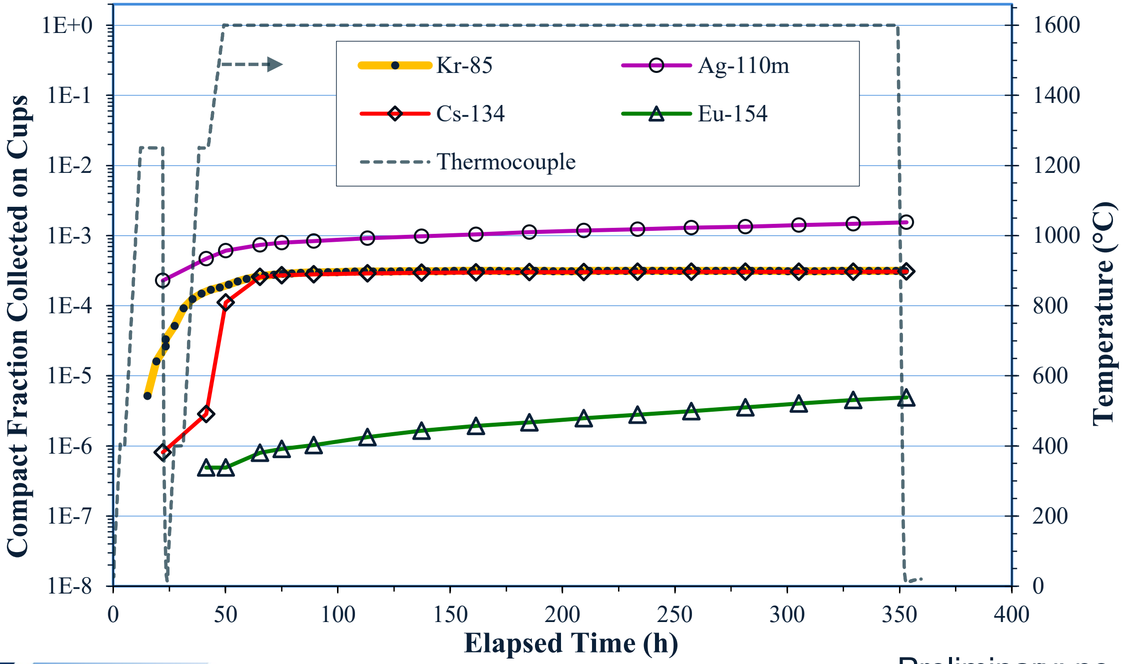


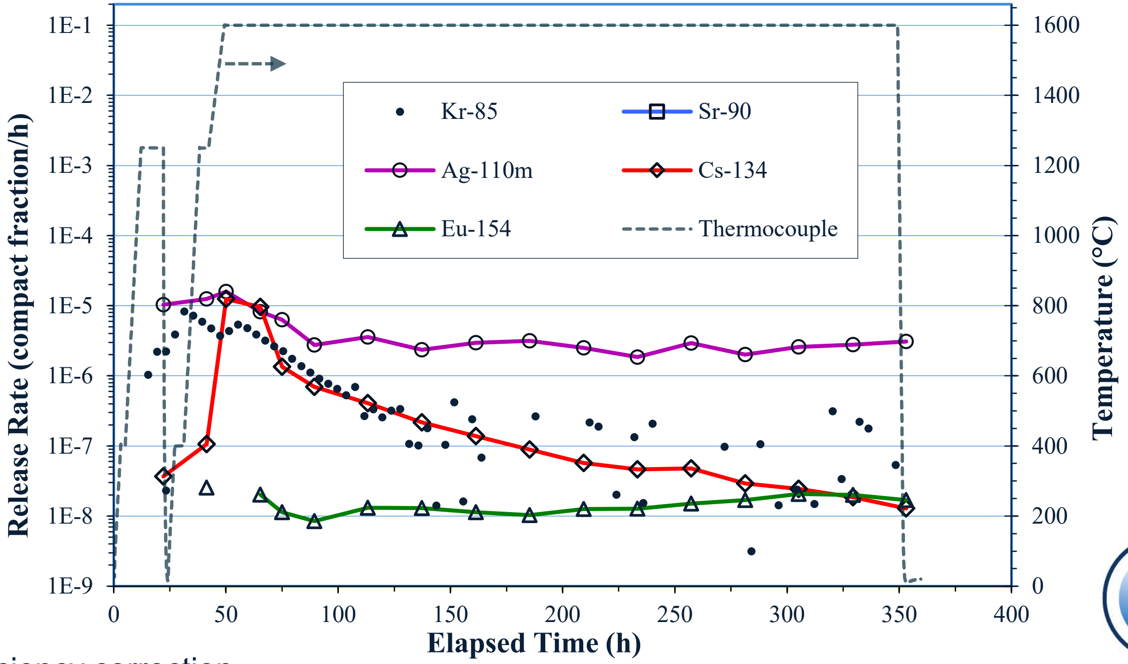
1600°C Simultaneous Safety Test of Compacts 5-2-1, 5-2-4, 5-3-2

(8.8% FIMA, 790°C TAVA Temperature)
(9.0% FIMA, 801°C TAVA Temperature)
(8.4% FIMA, 800°C TAVA Temperature)

	^{110m}Ag	^{134}Cs	^{85}Kr
Compact Fraction	1.6E-3	3.1E-4	3.1E-4
Particle Equivalents	16	3.1	3.3

- Cold finger chiller malfunction forced automatic shutdown during 1250°C hold.
- ^{85}Kr release observed during 1250°C hold and accumulated to 3.1E-4 (3.3 particle equivalents) indicative of multiple degraded or defective TRISO.
- ^{134}Cs release of 3.1E-4 (3.1 particle equivalents) indicates particles with degraded or defective SiC.
- ^{110m}Ag showed initial release from matrix plus a steady release throughout test of roughly 16 particle equivalents on par with other Capsule 5 compacts safety-tested at 1600°C.





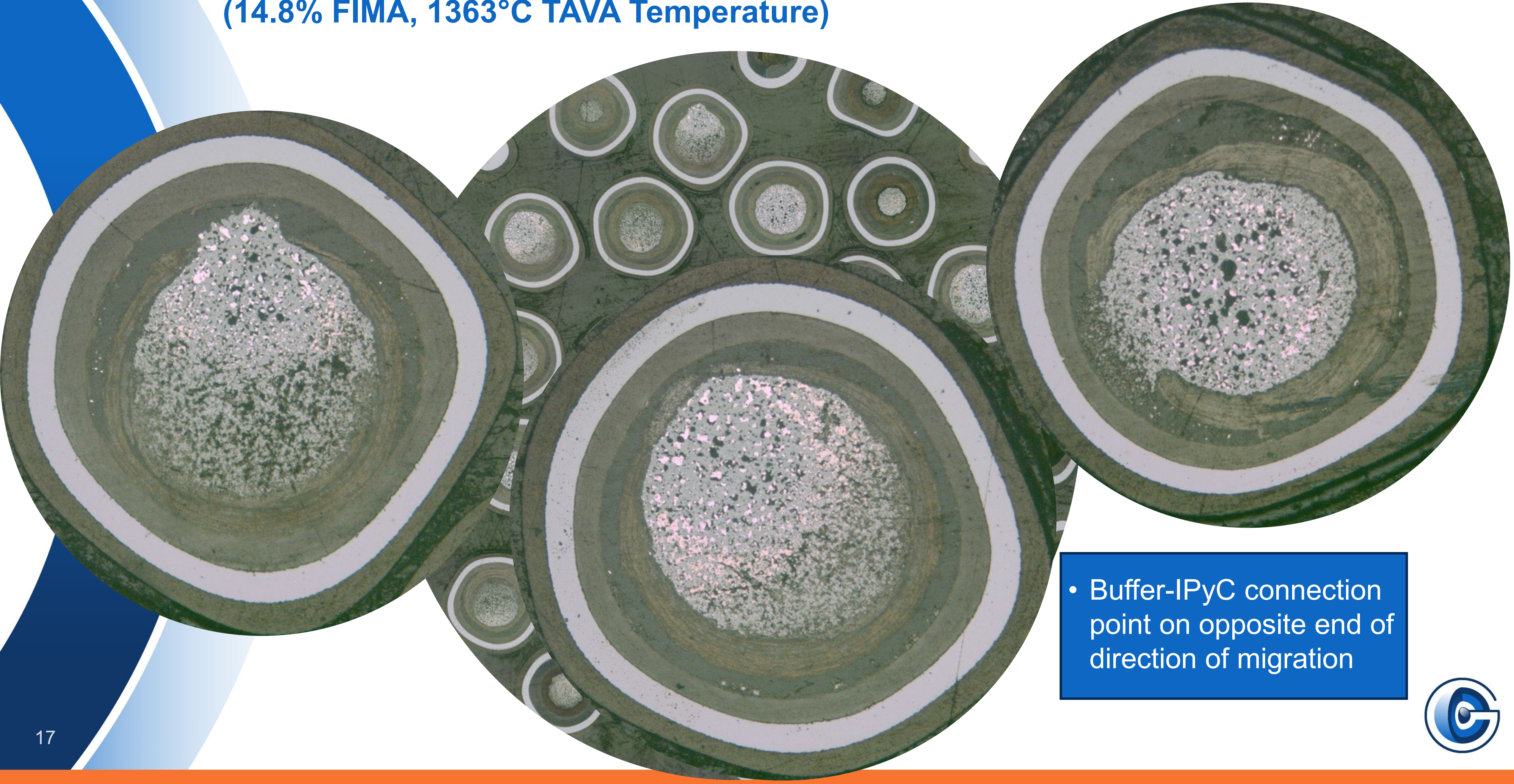
Preliminary: no efficiency correction

Cumulative Safety Test Releases

Compact	^{110m}Ag	^{134}Cs	^{154}Eu	^{90}Sr	^{104}Pd	^{85}Kr
AGR-5/6/7 2-2-2 @1600°C	2.6E-2	8.3E-6	6.5E-3	2.8E-3	1.8E-3	<MDA
(845°C TAVA, 14.0% FIMA)	59	0.019	15	6.3	4.2	--
AGR-5/6/7 2-2-4 @1600°C	2.1E-2	7.2E-6	6.9E-3	3.0E-3	9.4E-4	<MDA
(856°C TAVA, 14.3% FIMA)	48	0.016	16	6.8	2.1	--
AGR-5/6/7 2-3-2 @1800°C	9.9E-3	1.1E-3	1.0E-1	7.1E-2	3.1E-2	2.4E-4
(874°C TAVA, 14.4% FIMA)	22	2.5	232	160	70	0.53
AGR-5/6/7 2-5-1 @1600°C	6.3E-2	9.3E-6	2.7E-3	1.2E-3	3.0E-4	<MDA
(851°C TAVA, 14.8% FIMA)	137	0.02	5.9	2.6	0.66	--
AGR-5/6/7 3-1-2 @1600°C						
(1193°C TAVA, 13.8% FIMA)						
AGR-5/6/7 4-1-2 @1600°C						
(774°C TAVA, 13.7% FIMA)						
AGR-5/6/7 5-2-2 @1800°C	3.3E-1	5.3E-4	4.0E-3	1.7E-3	3.0E-2	4.8E-4
(789°C TAVA, 8.8% FIMA)	1128	1.8	13	5.8	103	1.6
AGR-5/6/7 5-5-3 @1600°C	1.8E-3	1.3E-5	6.6E-5	8.3E-6	4.8E-4	<MDA
(773°C TAVA, 7.6% FIMA)	6.2	0.045	0.22	0.028	1.6	--
AGR-5/6/7 5-6-2 @1600°C	1.7E-2	2.0E-4	1.4E-4	7.0E-5	3.2E-4	5.5E-5
(634°C TAVA, 6.8% FIMA)	56	0.66	0.48	0.24	1.1	0.19

Values are presented as compact fraction and particle-equivalent highlighted
(relative highlight: green – lower release, red – higher release)
Estimated uncertainty in solute analysis is ±10% and less than values for ^{110m}Ag are estimated from first leach.

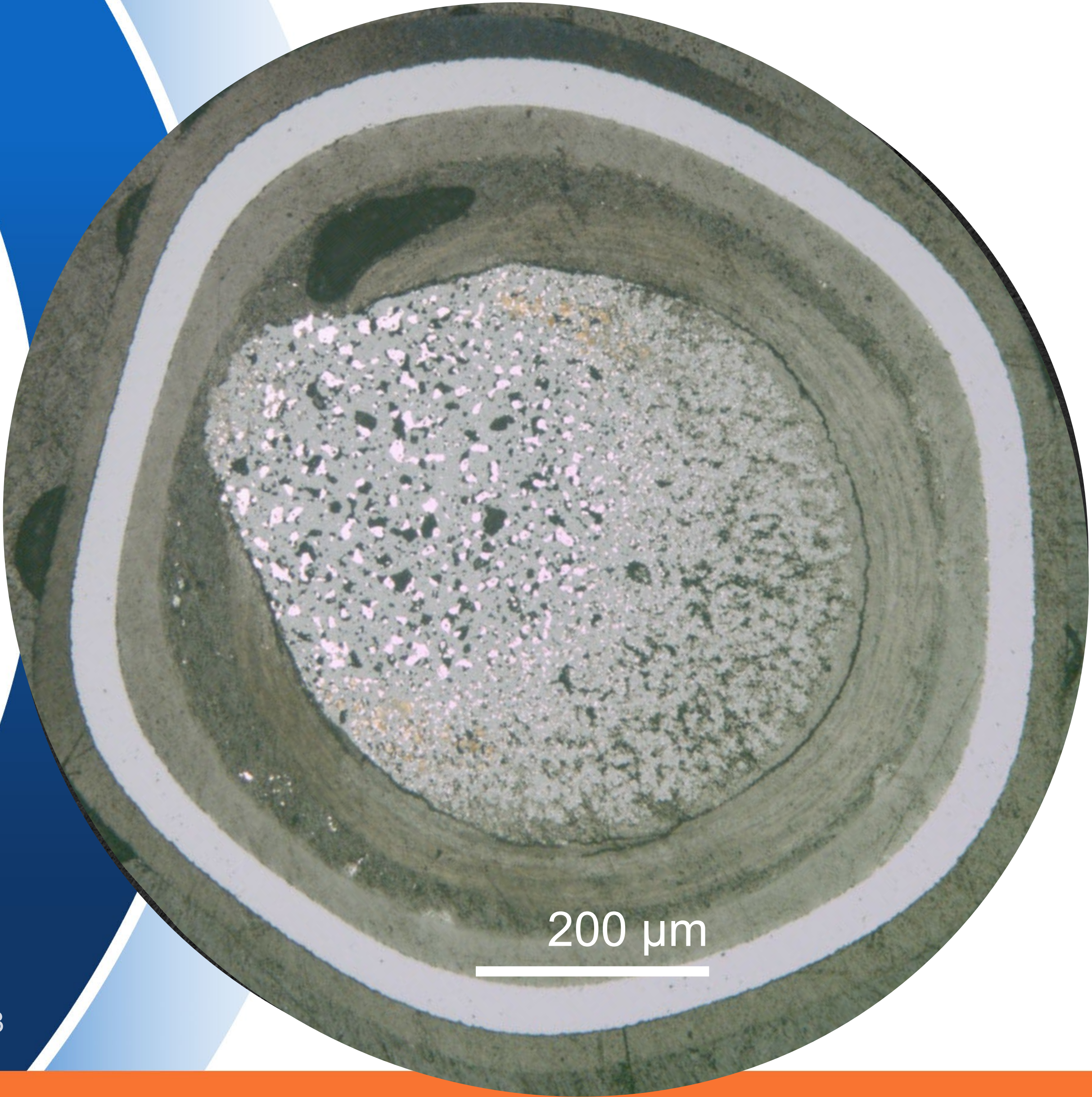
As-Irradiated Compact 3-6-3 Random Samples
(14.8% FIMA, 1363°C TAVA Temperature)

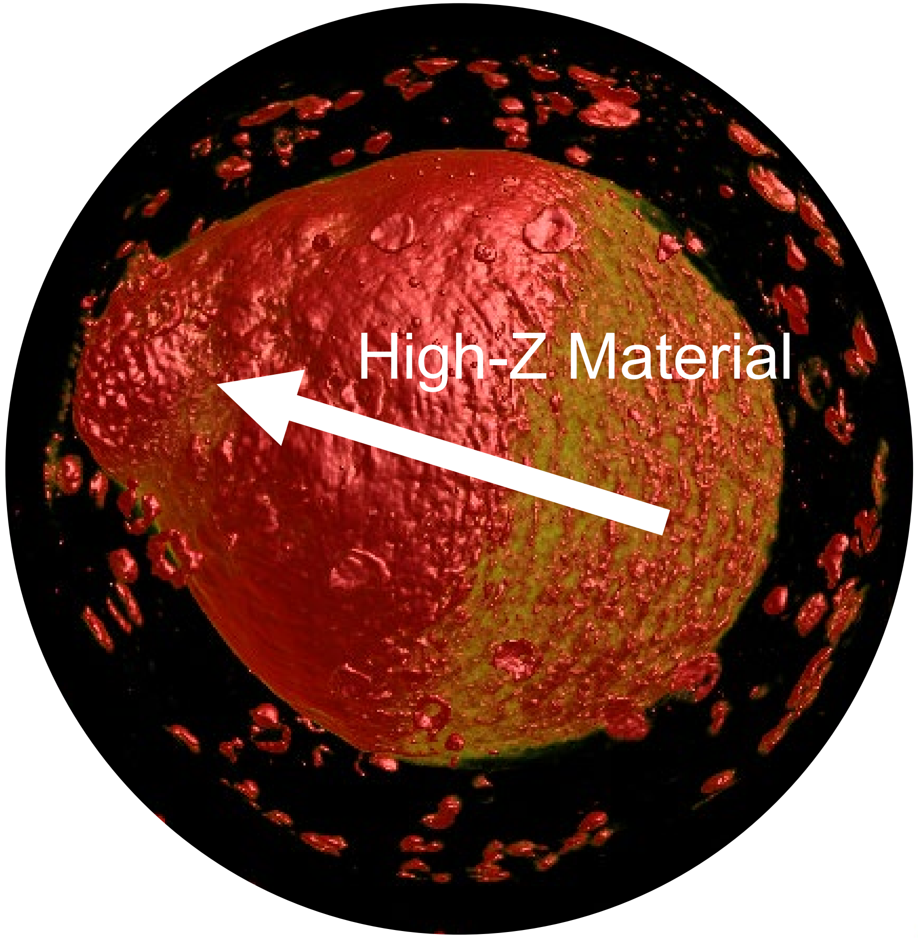


- Buffer-IPyC connection point on opposite end of direction of migration

As-Irradiated Compact 3-6-3 RS-08

(14.8% FIMA, 1363°C TAVA Temperature)

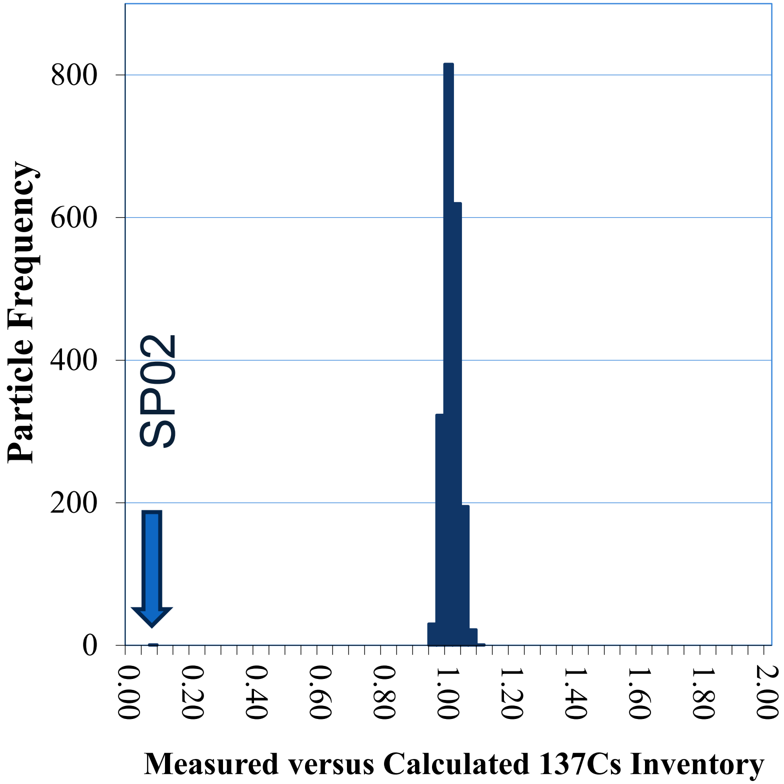


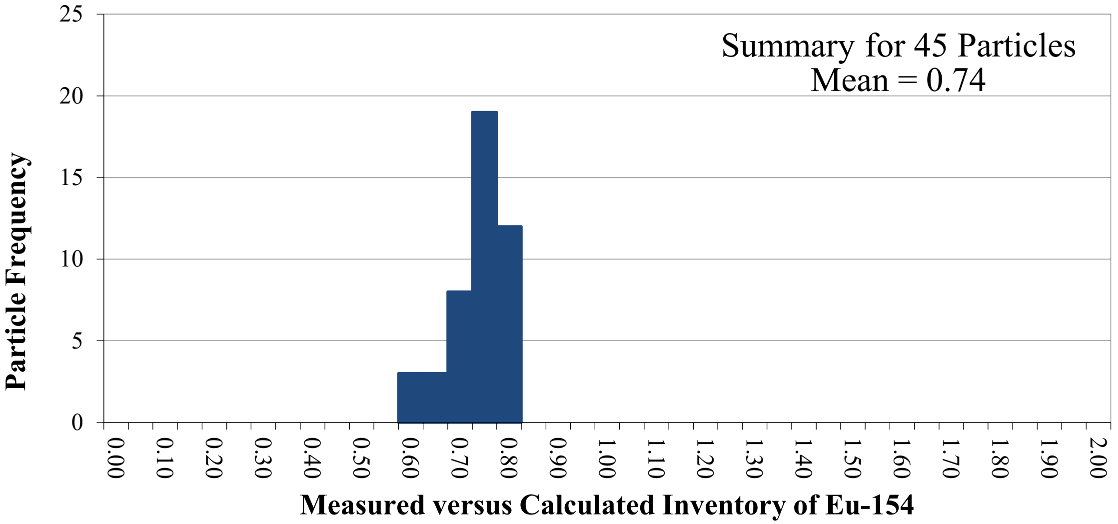


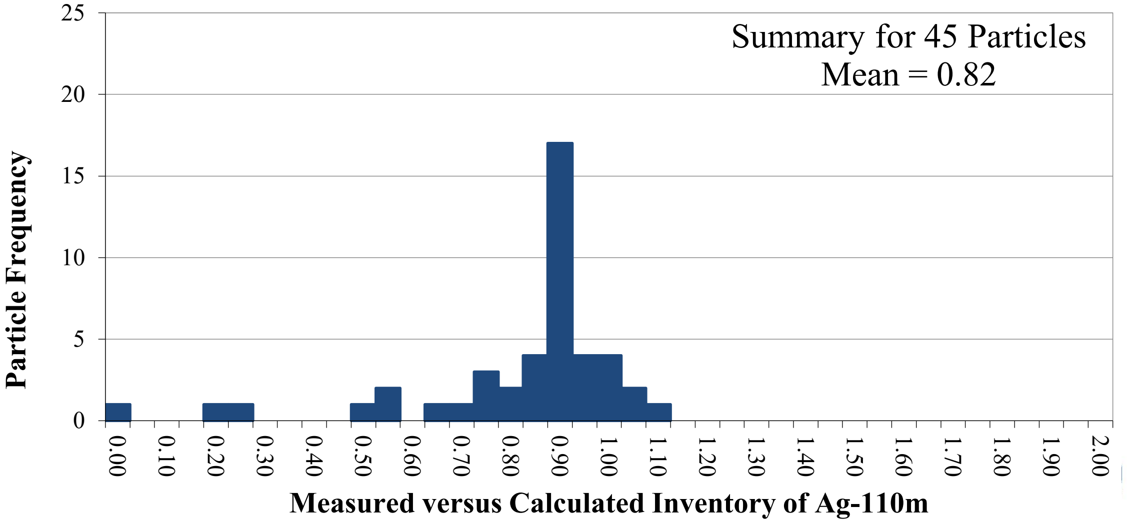
As-Irradiated Compact 3-6-3

(14.8% FIMA, 1363°C TAVA Temperature)

- IMGA data shows acceptable fission product retention despite of kernel migration
- One low-^{137}Cs particle identified







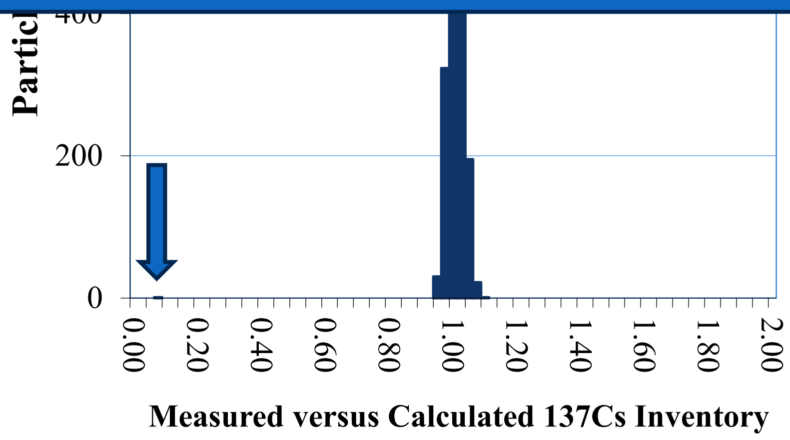
As-Irradiated Compact 3-6-3 Special Particle

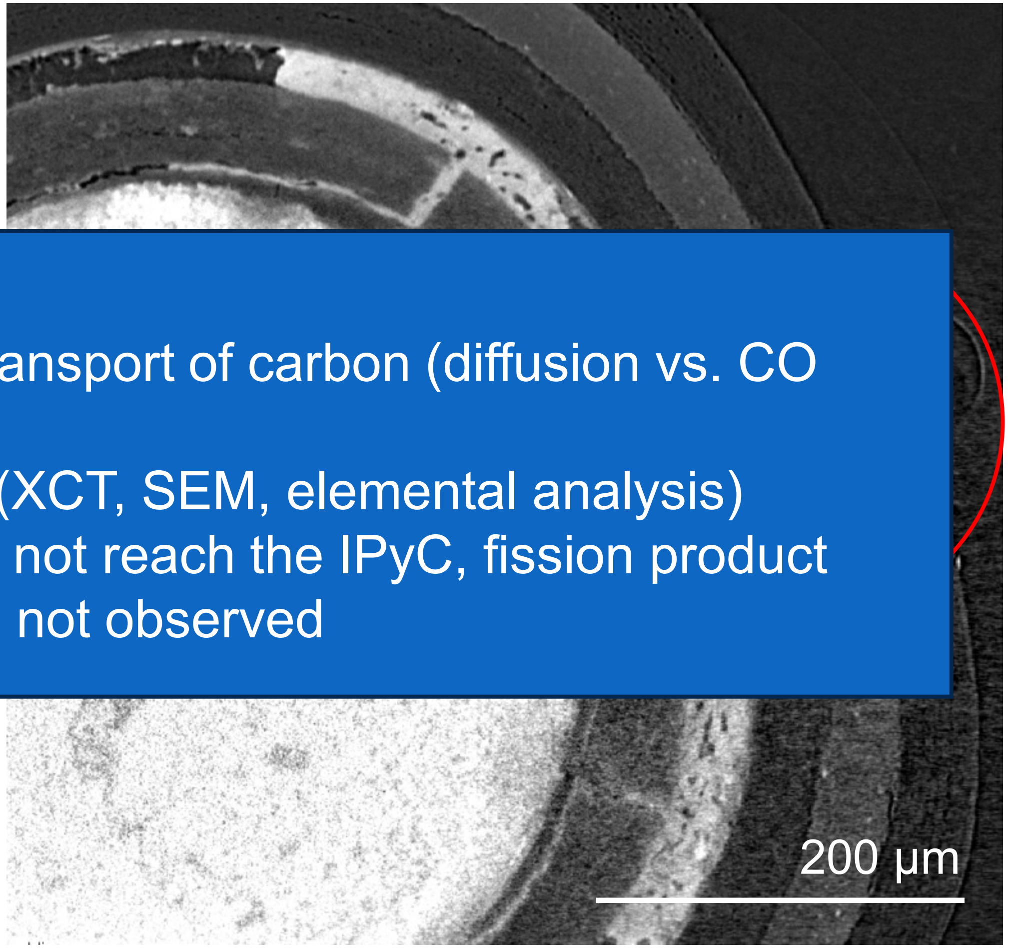
(14.8% FIMA, 1363°C TAVA Temperature)

- Potential IPyC crack and SiC degradation
- More PIE needed to investigate

Key take aways from Compact 3-6-3

- Unclear what mechanism dominates transport of carbon (diffusion vs. CO dissociation and carbon deposition)
- Further tests could elucidate behavior (XCT, SEM, elemental analysis)
- In Compact 3-6-3, migrated kernels do not reach the IPyC, fission product retention is not impacted. Gross failure not observed





XCT image of potential SiC degradation

Summary of ~2 Years of AGR-5/6/7 PIE at ORNL

- AGR-5/6/7 PIE at ORNL has been in progress since April 2022.
  - Seven as-irradiated compacts are in various stages of destructive PIE.
  - Twelve compacts have been safety-tested and are in various stages of post-safety test destructive PIE.
- Similarities and some differences compared with AGR-1 and AGR-2 UCO compact safety testing and PIE are noted and will be studied further.
  - We will soon have more results from the later steps in the destructive PIE to help evaluate results from safety testing and DLBL.
  - We need to build a broader database by examining more AGR-5/6/7 compacts to get sufficient statistics to verify trends in behavior before drawing any broad conclusions.

GAS-COOLED REACTOR

ADVANCED REACTOR TECHNOLOGIES PROGRAM

Thank you for your attention

William F. Cureton

curetonwf@ornl.gov

This work was sponsored by US Department of Energy Office of Nuclear Energy Advanced Reactors Technologies Advanced Gas Reactor Fuel Development and Qualification Program

U.S. DEPARTMENT OF ENERGY

Extra Slides

FY22Q3–FY24Q3 AGR-5/6/7 Progress at ORNL

363 DLBL Results

		Total Inventory, uCi	ICP-MS Analyses						
		Sample OD	^{234}U	^{235}U	^{236}U	^{238}U	^{237}Np	^{239}Pu	^{240}Pu
		Post-burn additional matrix ash leach #2							
0	0	Post-burn matrix leach #3							
Max Total of deconsolidation acid and preburn leach #1 and #2			< 2.82E-01	3.05E-01	2.38E-01	2.71E-01	4.30E-01	3.92E-01	6.50E-01
Min Total of deconsolidation acid and preburn leach #1 and #2			2.77E-01	3.05E-01	2.38E-01	2.71E-01	4.30E-01	3.92E-01	6.50E-01
		max preburn compact totals with water rinse	< 2.82E-01	3.05E-01	2.38E-01	2.71E-01	4.30E-01	3.92E-01	6.50E-01
		min preburn compact totals with water rinse	2.77E-01	3.05E-01	2.38E-01	2.71E-01	4.30E-01	3.92E-01	6.50E-01
	max Post-burn Particle totals leach #1 and #2		2.75E+00	2.86E+00	2.60E+00	2.69E+00	2.74E+00	2.40E+00	3.04E+00
	min Post-burn Particle totals leach #1 and #2		2.75E+00	2.86E+00	2.60E+00	2.69E+00	2.74E+00	2.40E+00	3.04E+00
	max Post-burn Matrix totals leach #1 and #2		< 9.10E-02	9.45E-02	7.93E-02	1.81E-01	2.61E-01	2.72E-01	4.70E-01
	min Post-burn Matrix totals leach #1 and #2		8.82E-02	9.45E-02	7.93E-02	1.81E-01	2.61E-01	2.72E-01	4.70E-01
	max postburn compact totals leach #1 and #2		< 2.84E+00	2.96E+00	2.68E+00	2.87E+00	3.00E+00	2.68E+00	3.51E+00
	min postburn compact totals leach #1 and #2		2.84E+00	2.96E+00	2.68E+00	2.87E+00	3.00E+00	2.68E+00	3.51E+00
		maximum grand total leach #1 and #2	< 3.12E+00	3.26E+00	2.92E+00	3.14E+00	3.43E+00	3.07E+00	4.16E+00
		minimum grand total leach #1 and #2	3.11E+00	3.26E+00	2.92E+00	3.14E+00	3.43E+00	3.07E+00	4.16E+00

Cumulative Safety Test Releases from Nine AGR-5/6/7 Compacts

Compact	^{90}Sr	^{104}Pd	^{110m}Ag	^{134}Cs	^{154}Eu	^{85}Kr
AGR-5/6/7 2-2-2 (1600°C) (845°C TAVA, 14.0% FIMA)	2.8E-3 (6.3)	1.8E-3 (4.2)	2.6E-2 (59)	8.3E-6 (0.019)	6.5E-3 (15)	
AGR-5/6/7 2-2-4 (1600°C) (856°C TAVA, 14.3% FIMA)	3.0E-3 (6.8)	9.4E-4 (2.1)	2.1E-2 (48)	7.2E-6 (0.016)	6.9E-3 (16)	
AGR-5/6/7 5-5-3 (1600°C) (773°C TAVA, 7.6% FIMA)	8.3E-6 (0.028)	4.8E-4 (1.6)	1.8E-3 (6.2)	1.3E-5 (0.045)	6.6E-5 (0.22)	
AGR-5/6/7 2-3-2 (1800°C) (874°C TAVA, 14.4% FIMA)	7.1E-2 ~(160)	3.1E-2 (70)	~9.6E-3 ~(22)	~1.0E-3 ~(2.3)	>8.8E-2 >(199)	2.4E-4 (0.53)
AGR-5/6/7 3-1-2 (1600°C) (1193°C TAVA, 13.8% FIMA)	1.3E-2 ~(30)	9.1E-4 (2.1)	~5.1E-3 ~(12)	~4.4E-4 ~(1.0)	9.5E-3 (21)	3.4E-5 (0.076)
AGR-5/6/7 5-2-2 (1800°C) (789°C TAVA, 8.8% FIMA)	1.7E-3 (5.8)	3.0E-2 (103)	~3.5E-1 ~(1180)	~4.8E-4 ~(1.6)	4.0E-3 (13)	4.8E-4 (1.6)
AGR-5/6/7 5-6-2 (1600°C) (634°C TAVA, 6.8% FIMA)	6.9E-5 (0.24)	3.2E-4 (1.1)	1.7E-2 56.068	2.0E-4 (0.66)	1.4E-4 (0.48)	5.5E-5 (0.19)
AGR-5/6/7 4-1-2 (1600°C) (774°C TAVA, 13.7% FIMA)	1.4E-3 (3.0)	4.5E-4 ~(1)	2.0E-1 (444)	3.9E-5 (0.085)	2.0E-3 (4.5)	
AGR-5/6/7 2-5-1 (1600°C) (851°C TAVA, 14.8% FIMA)	1.2E-3 (2.6)	3.0E-4 (0.66)	6.3E-2 (137)	9.3E-6 (0.02)	2.7E-3 (5.9)	

Values are presented as compact fraction and particle-equivalent (in parentheses)
Estimated uncertainty in solute analysis is ±10% and less than values for ^{110m}Ag are estimated from first leach.

GAS-COOLED REACTOR

ADVANCED REACTOR TECHNOLOGIES PROGRAM

U.S. DEPARTMENT OF ENERGY