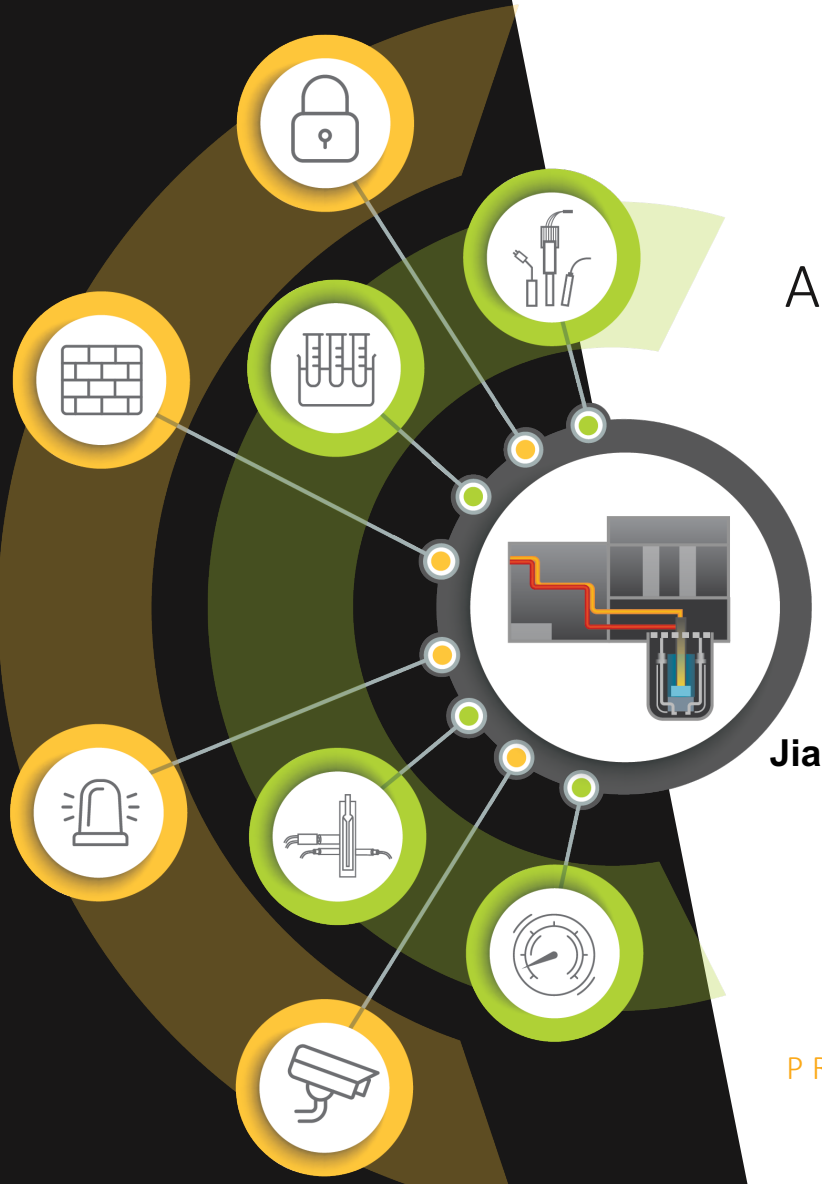


ADVANCED REACTOR SAFEGUARDS

TRISO NDA Measurements for Burnup

Mark Croce, Daniel McNeel, Katherine Schreiber, Rico Schoenemann[1]
Jianwei Hu, Callie Goetz, Jason Harp, Wade Ivey, Tammy Keever, Lisa Duncan, Haley Wightman[2]
Daniel Becker[3]
Ammon Williams, Brian Bucher, Edward Seabury, Maegan Coleman, Brian Storms[4]

[1]Los Alamos National Laboratory
[2]Oak Ridge National Laboratory
[3]University of Colorado
[4]Idaho National Laboratory

PRESENTED BY

Mark Croce, Los Alamos National Laboratory

October 2023

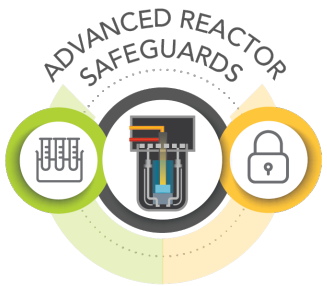
LA-UR-23-32047

U.S. DEPARTMENT OF ENERGY

Project Objectives

- Enable cost-effective safeguards for advanced reactors by understanding exactly how nondestructive analyses can be used
- Directly measure NDA uncertainty to provide a comprehensive set of validated measurement capabilities for safeguards models
- Current focus is burnup measurement of TRISO fuels for pebble bed reactors to support:
  - On-line burnup measurement system
  - Safeguards of used fuel

What signatures of burnup can be observed in TRISO fuels? Measure them!



- Measurements of dissolved AGR2 and AGR5/6/7 TRISO fuels completed at ORNL Analytical Laboratory
- Measurements of AGR2 and AGR5/6/7 intact compacts and subsamples completed at ORNL Irradiated Fuel Examination Laboratory
- Planning completed for additional TRISO particle measurements at INL Analytical Laboratory

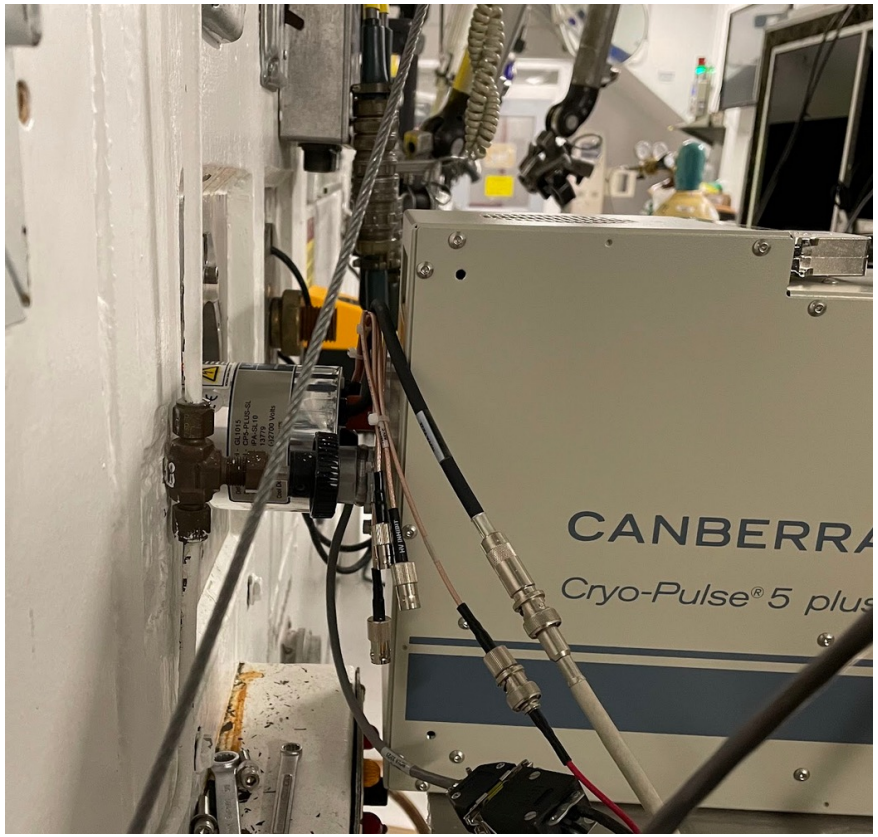
Los Alamos NATIONAL LABORATORY

OAK RIDGE National Laboratory

INL Idaho National Laboratory

University of Colorado

ORNL Hot Cells



Solid TRISO Fuels

ID	Burnup	Notes
AGR5/6/7 Compact 223	14.33%	Intact compact
AGR2 Compact 211	12.5%	Intact compact
AGR2 Compact 542	12.03%	~90% of compact
AGR2 subsamples	7.3-12.7%	11 samples with ~150-235 particles
AGR5/6/7 subsamples	9.3-14.3%	4 samples with ~235 particles

AGR2 Irradiations: June 2010 to October 2013

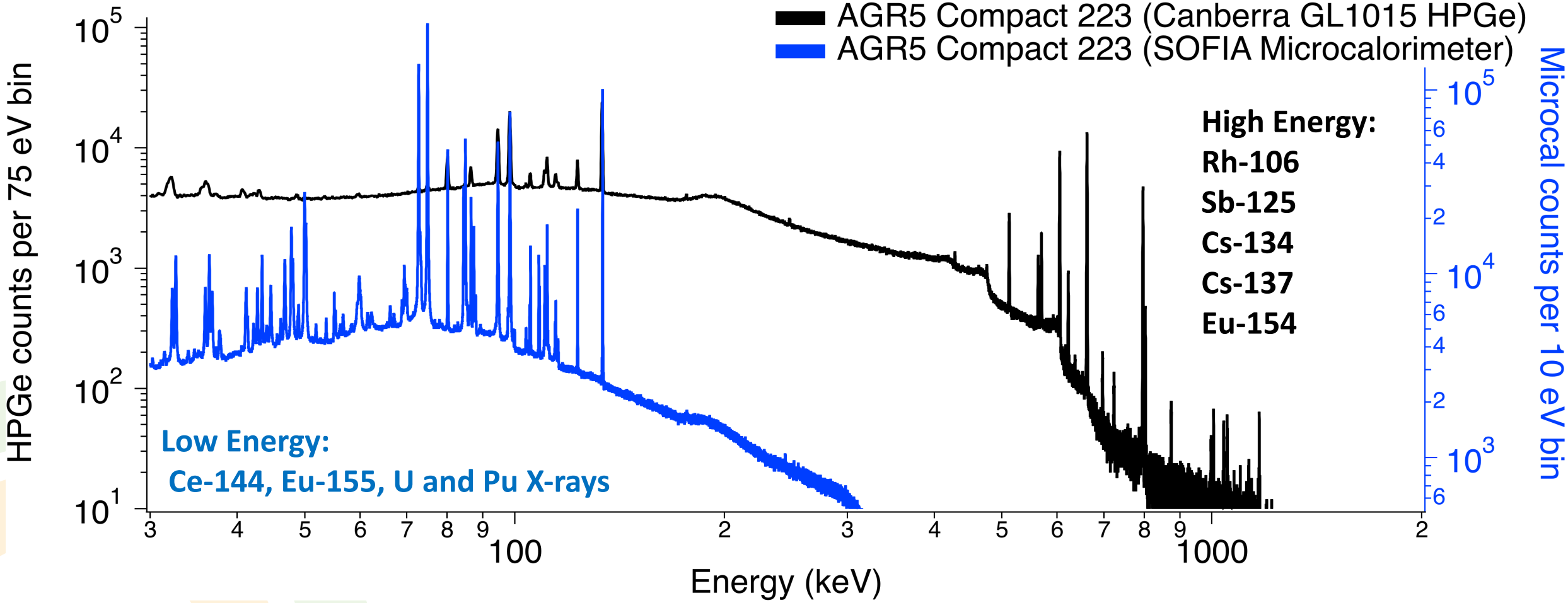
AGR5/6/7 Irradiations: February 2018 to July 2020

Dissolved TRISO Fuels

ID	Burnup	Notes
AGR2 Compact 642	9.26%	3 samples prepared for burnup DA
AGR5/6/7 Compact 232	14.36%	Fuel holder leach solution
AGR5/6/7 Compact 232	14.36%	Deconsolidation acid

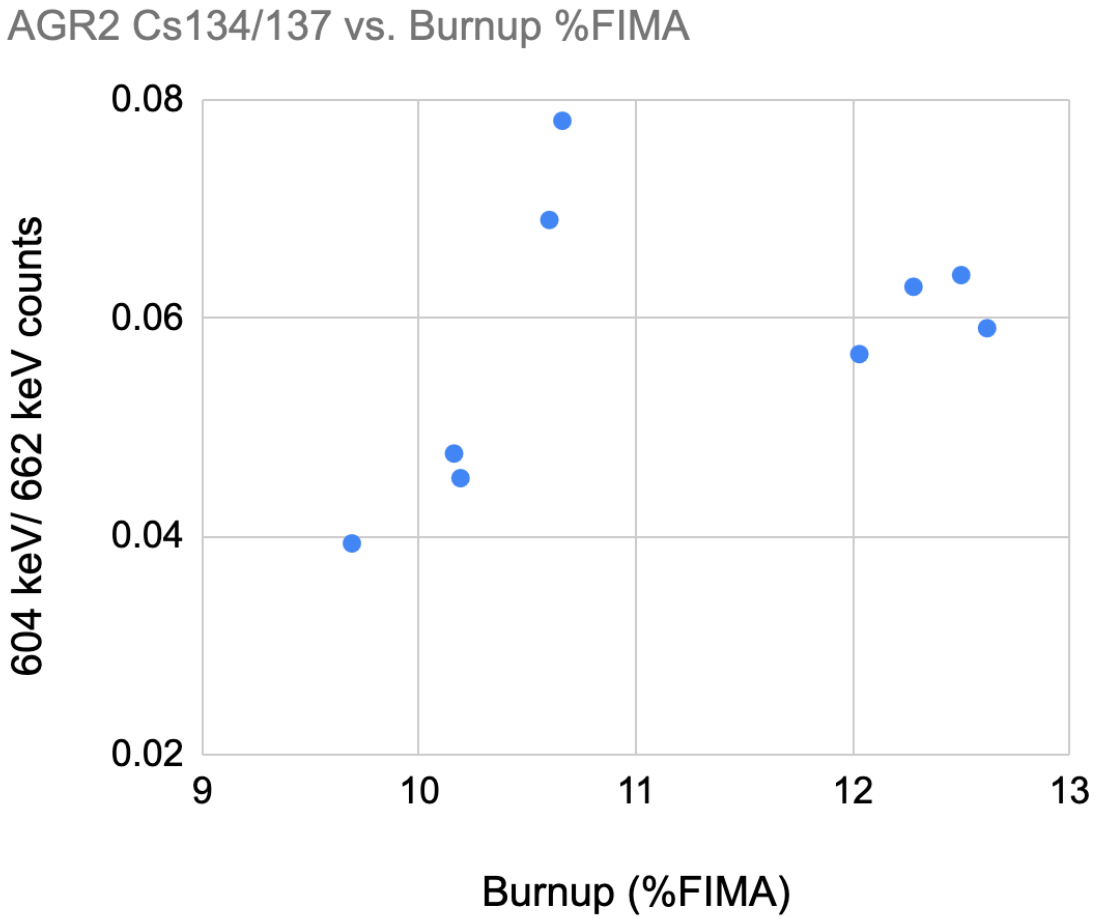
AGR2 Irradiations: June 2010 to October 2013
AGR5/6/7 Irradiations: February 2018 to July 2020

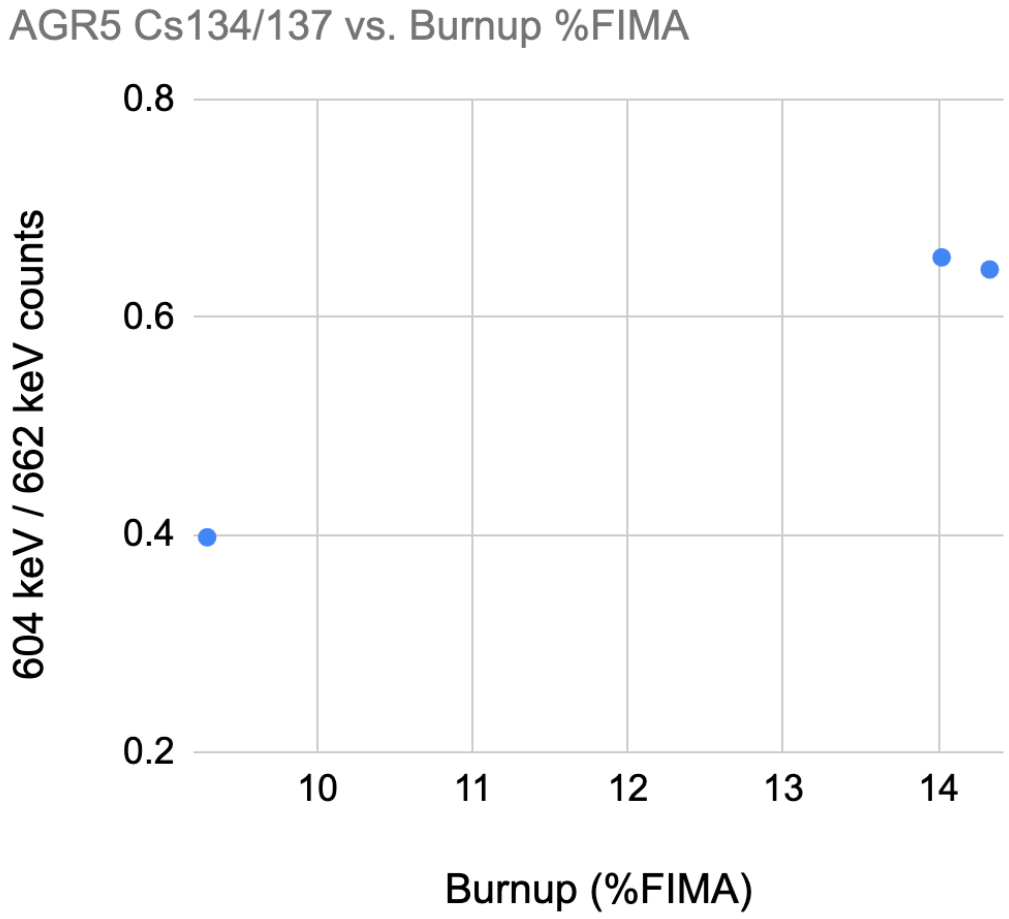
Initial Observations



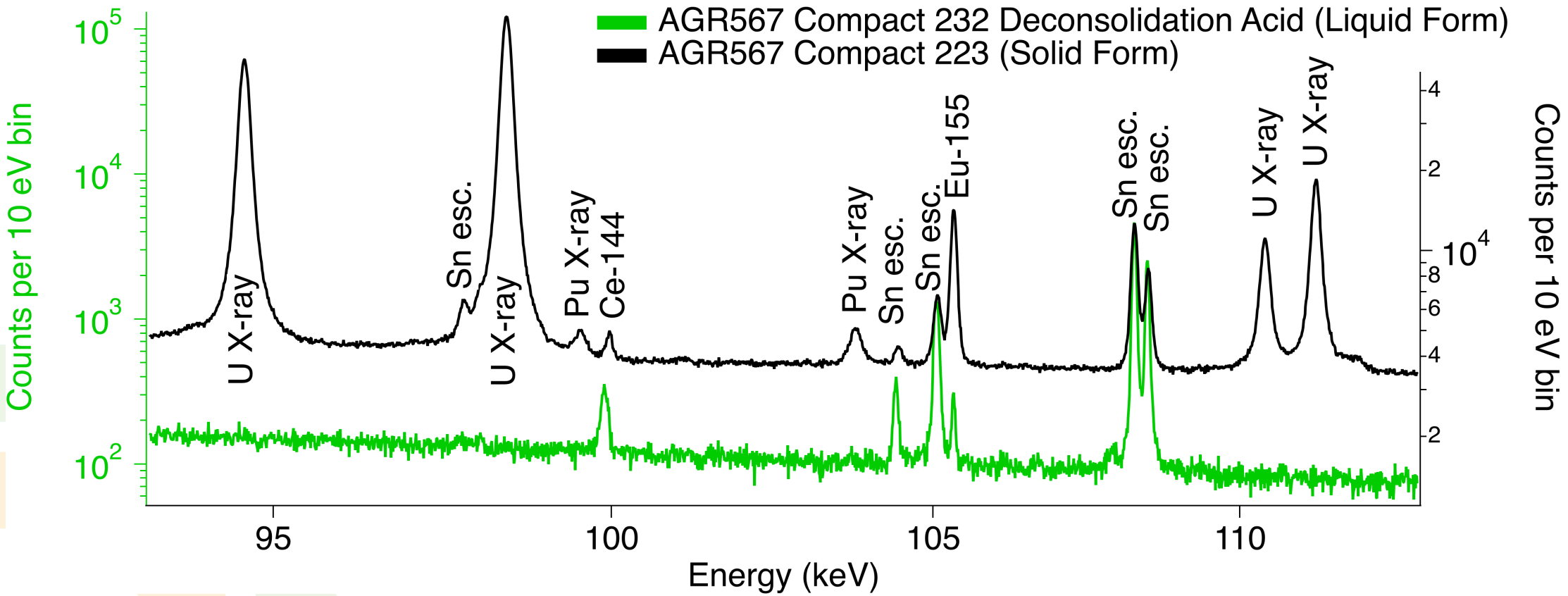
Cs-134/137 Ratios with HPGe

possible issues: changing background, may need correction for irradiation timeline

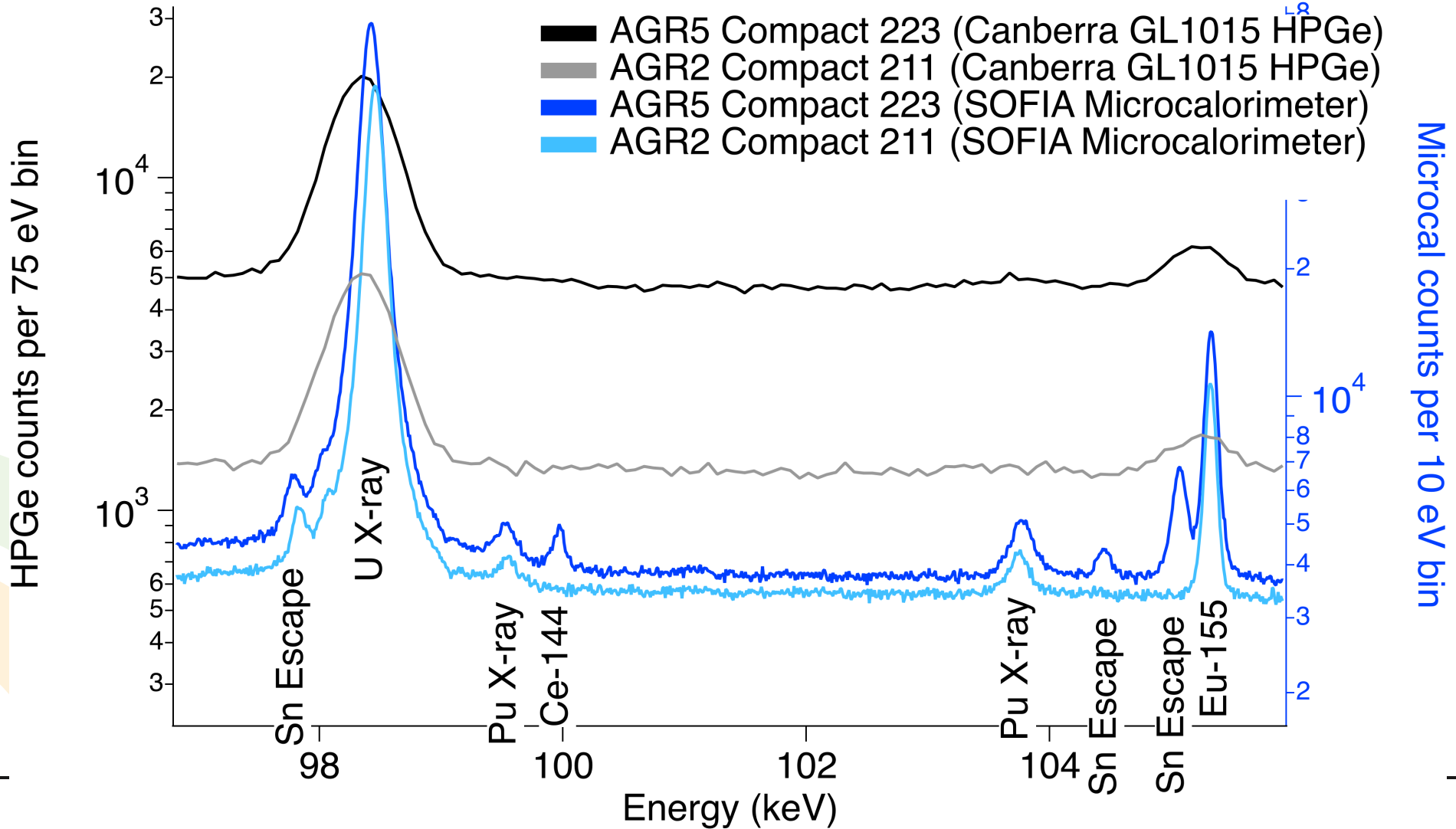




Solid vs. Liquid Fuels: Fluorescence X-rays

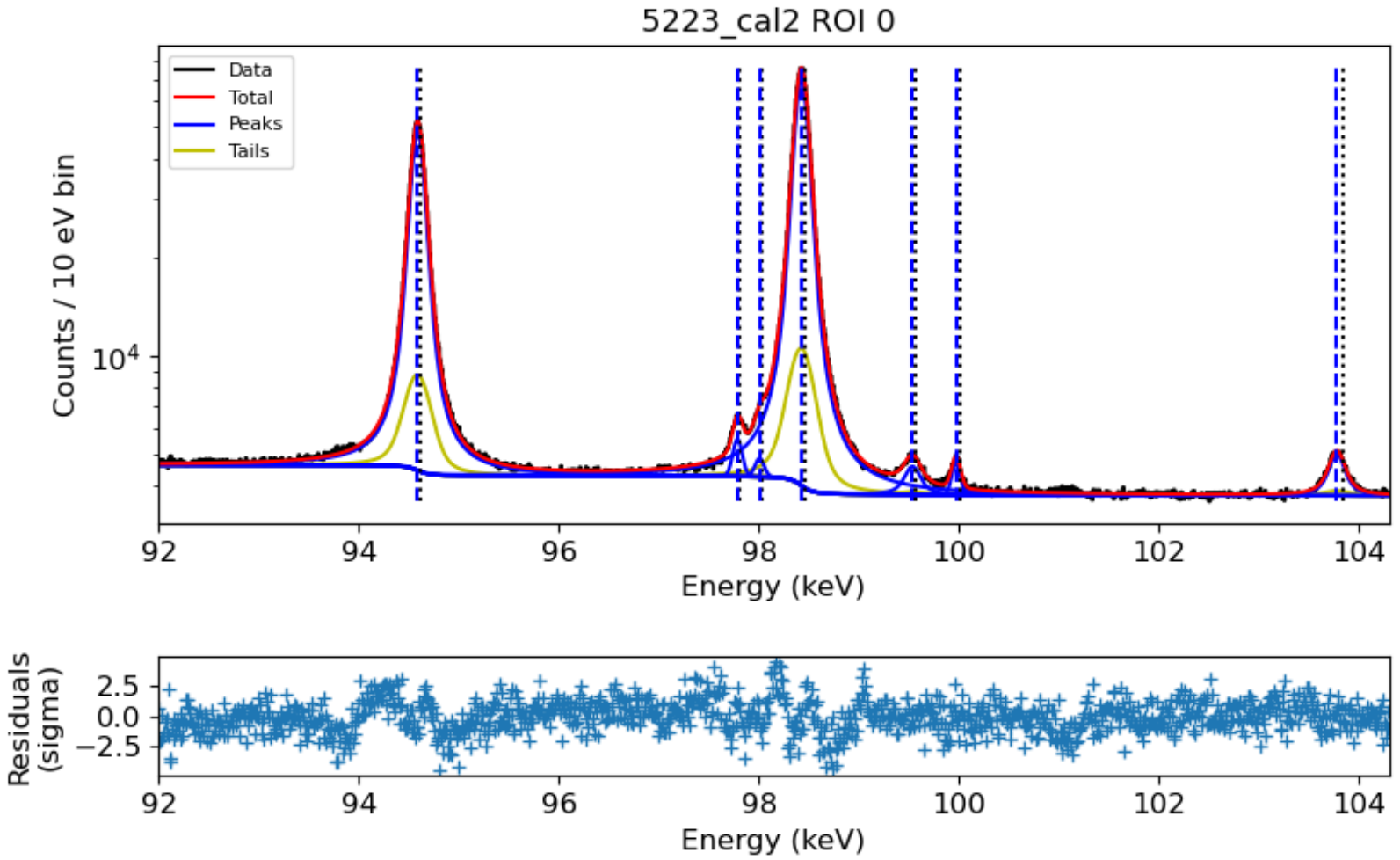


Pu/U Element Ratio Quantification with Microcal



Pu/U Element Ratio

Item	Measured N_Pu / N_U (%)	Calculated N_Pu/N_U (%)
5-223	2.40 +/- 0.07	2.53
2-542	1.46 +/- 0.16	???
2-211	1.96 +/- 0.10	1.732



χ^2_{red} = 1.78 | Main FWHM = 99.9 eV | Tail FWHM = 235.5 eV

Line Centroid (keV) Ref. / fit		Source	Area (uncert)	Lorentzian FWHM (eV)
94.626 /	-0.001	UKa2	1234436.7 (0.143 %)	118.4 (0.8 %)
97.805 /	+0.017	Sn esc	17327.7 (2.256 %)	11.1 (fixed)
98.032 /	+0.010	Sn esc	8050.9 (5.232 %)	11.1 (fixed)
98.461 /	98.428	UKa1	1899621.0 (0.116 %)	122.3 (0.8 %)
99.565 /	+0.006	PuKa2	26018.1 (3.029 %)	136.9 (5.7 %)
100.007 /	-0.000	Ce144	11383.0 (2.593 %)	
103.834 /	-0.021	PuKa1	39097.8 (2.015 %)	136.5 (3.9 %)

Dotted Lines above indicate tabulated peak locations

Dashed lines above indicate best-fit locations

* and red indicate peak used in efficiency curve fit

Next Steps

- INL Measurement Campaign
  - Emphasis is on freshly irradiated TRISO fuels
  - Use HPGe and HERMES-400 microcalorimeter spectrometers
- ORNL Measurement Campaign
  - Additional solid-form subsamples of AGR2 and AGR5/6/7 measured in lower-background location for better quantitative analysis
- Dedicated Irradiation Planning
  - Priority is measuring effect of extremely short-lived fission products
  - Expect much lower burnup than from AGR irradiations