GAS-COOLED REACTOR
ADVANCED REACTOR TECHNOLOGIES PROGRAM

Fission Product Release Data Summary Covering AGR-1 through AGR-3/4

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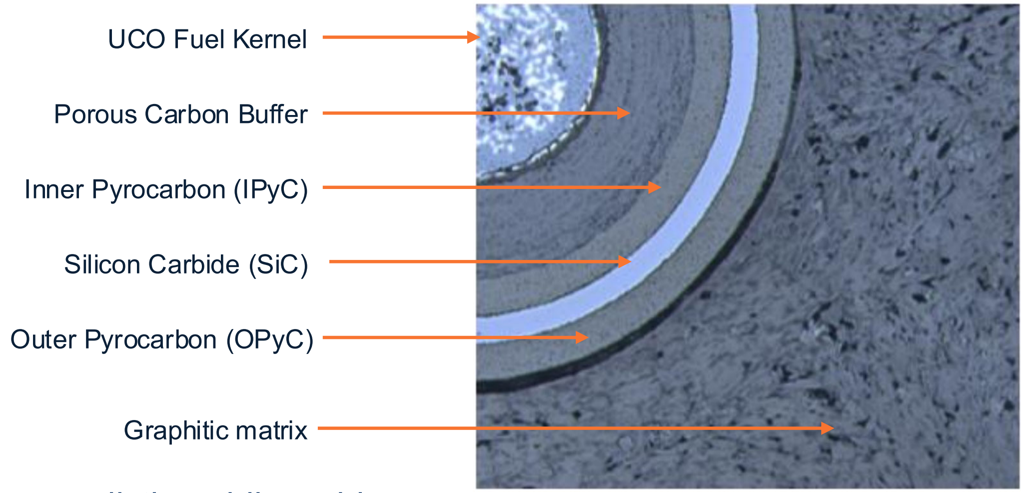
ART AGR TRISO FUEL Post-Irradiation Technical Lead

TRISO Fuels Fission Product Source Term

- Functional containment strategy: fuel is the primary barrier to fission product release. Each material in TRISO fuel retains or attenuates fission products.

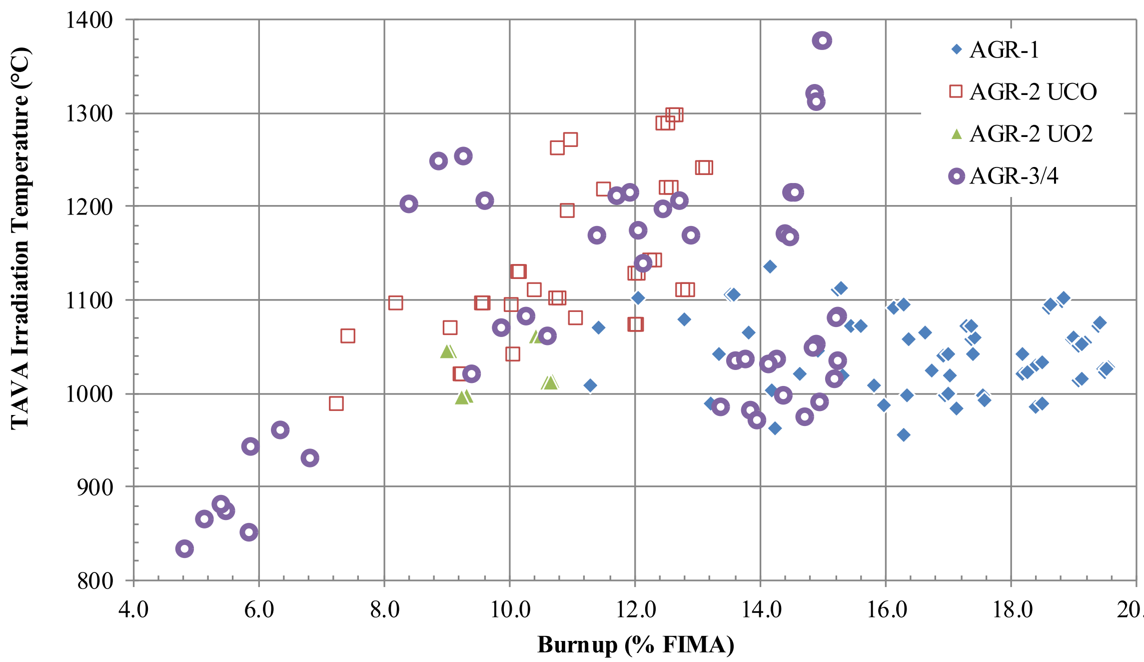


- Source-term prediction philosophies:
  - Integrated mechanistic models: can be very detailed, but fundamental physical constants and validation data are sparse
  - Empirical relationships: grounded in data, but could be harder to justify extension beyond the envelope of data or to modified fuels and conditions
  - Or a combination of the two
- Possible simplification: is source term from fuel elements low enough that taking credit for other phenomena, e.g., holdup in reactor building, is not necessary?

Report Summarizes AGR TRISO Fuel Fission Product (FP) Release Data

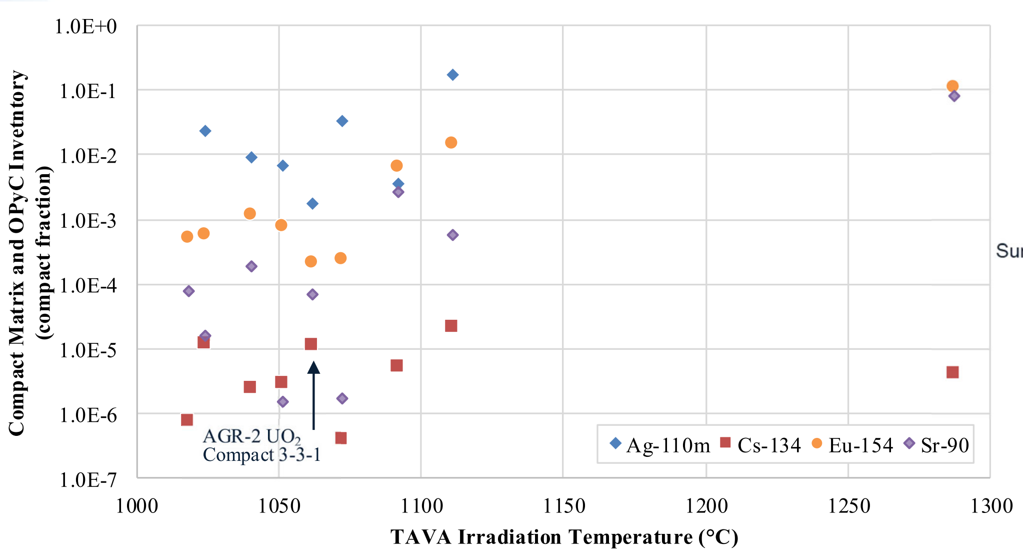
- Summarized data include:
  - Mass balances: FP outside of the fuel after ATR
  - In-pile SiC and TRISO failure rates
  - Compact matrix and OPyC inventory from DLBL
  - Safety test FP release and particle failure rates
- Data used to construct empirical rates of FP release from particles, accumulation in matrix, release from compact in-pile and during safety tests

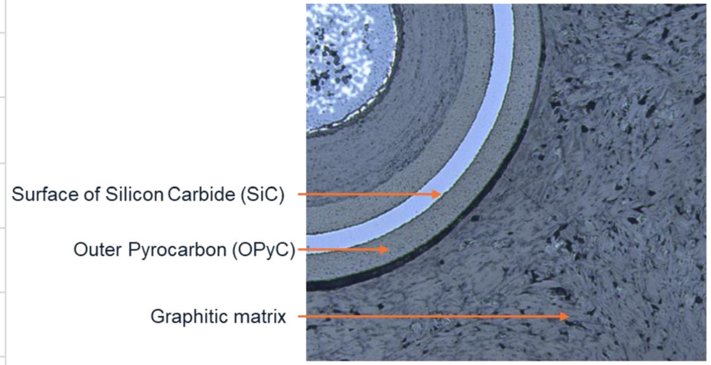
AGR-1, -2, and -3/4 Fuel Compact Irradiation Histories



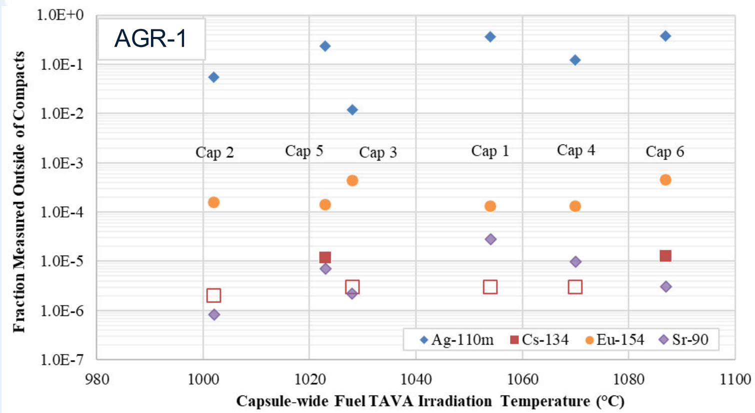
Matrix Inventory from AGR-1 and AGR-2 As-irradiated DLBL

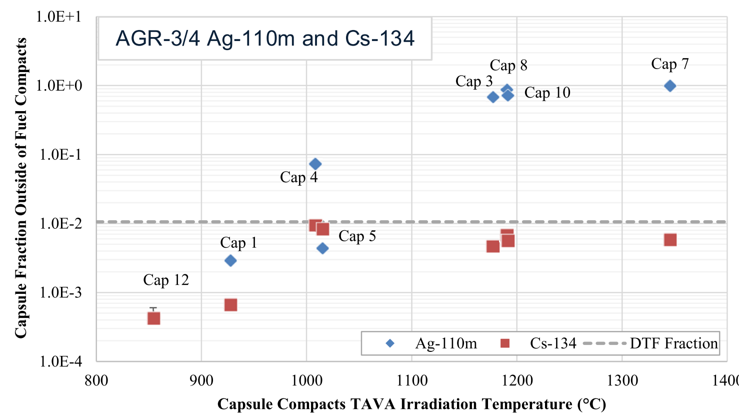
- Only utilized compacts with no apparent SiC or TRISO damage (excludes use of AGR-3/4 compact DLBL)

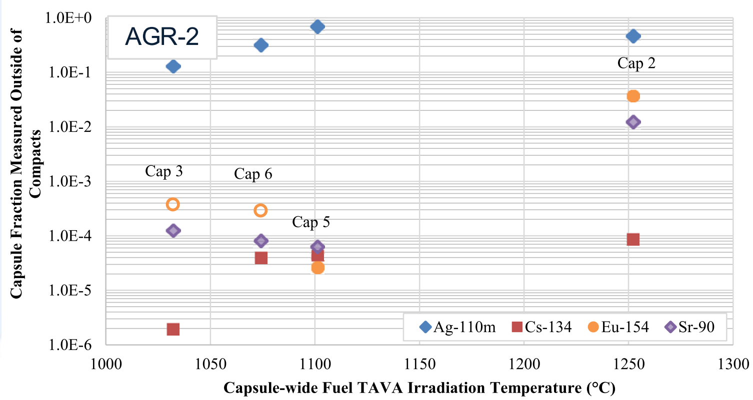


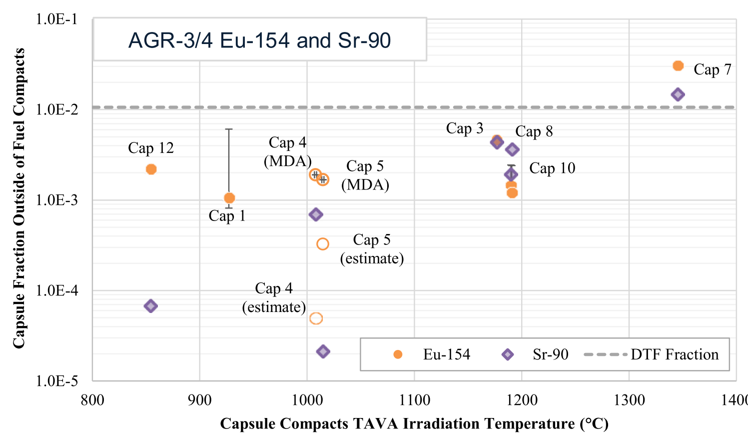


Average In-Pile Release from Compacts per Capsule via Mass Balances



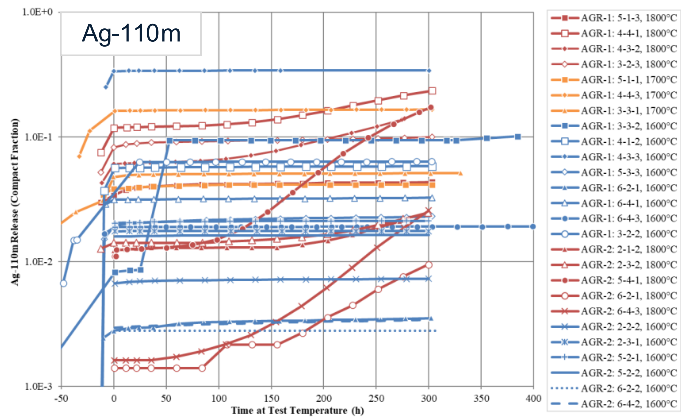


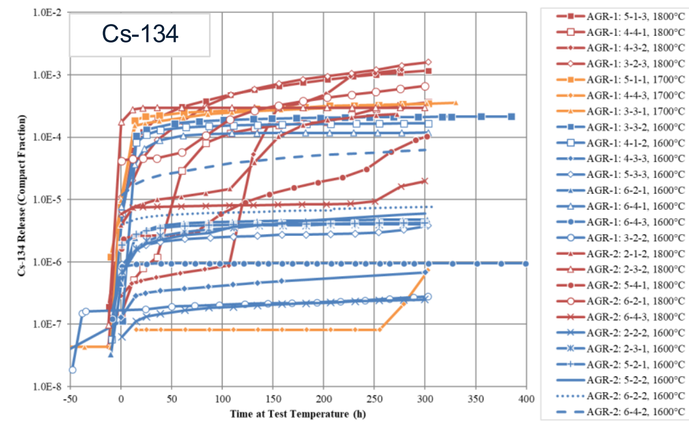


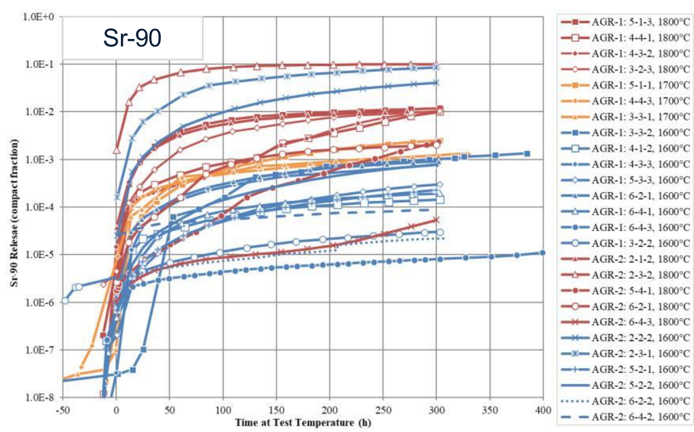


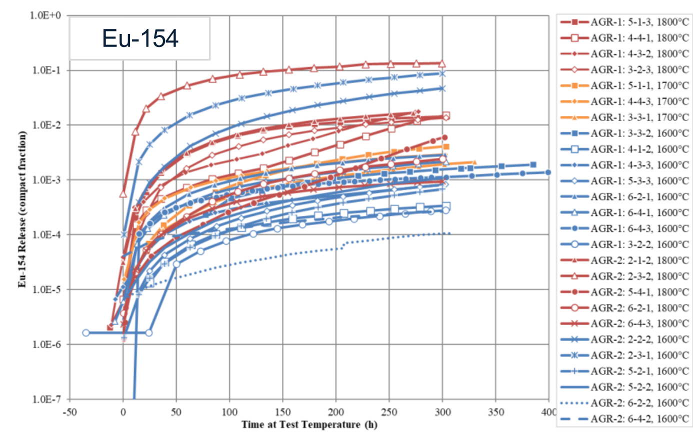
Open symbols derived from minimum detectable activities

FP Release from Compacts during Safety Tests



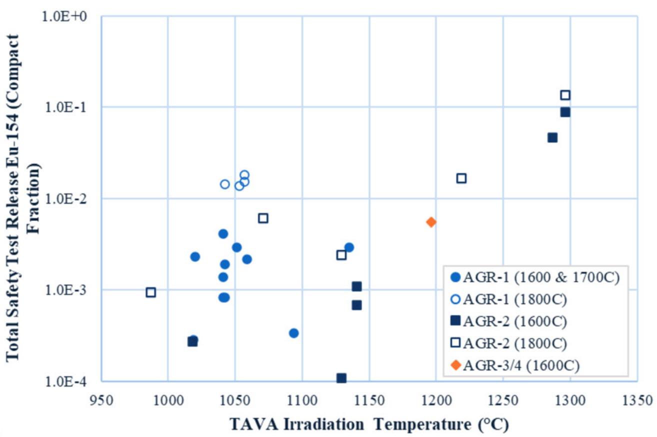




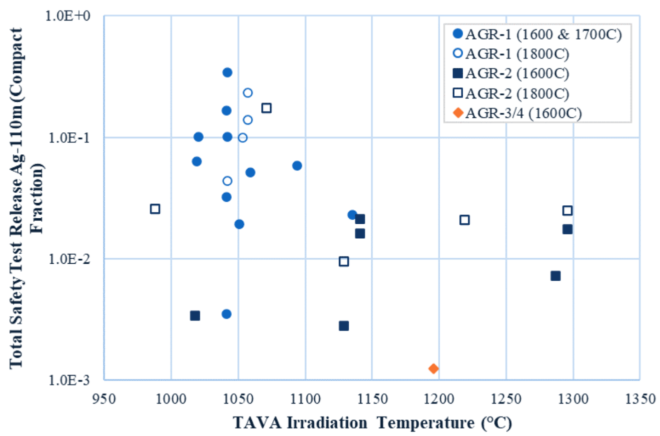


FP Release from Compacts during Safety Tests

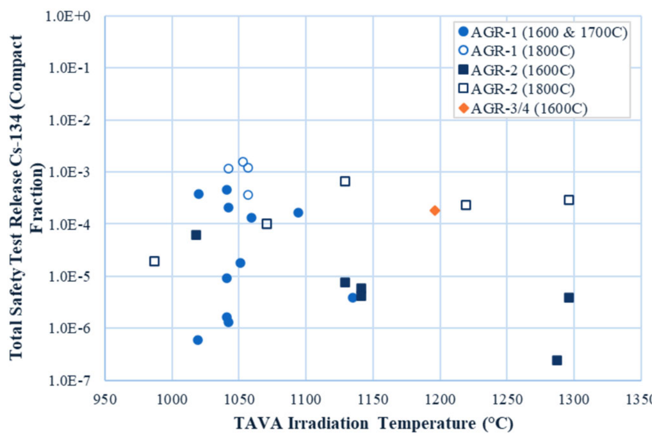
- Eu-154 release increases with safety test temperature and compact irradiation temperature (1200°C+)



- Ag-110m highest for irradiation temperatures ~1050°C



- Safety test Cs-134 release insensitive to irradiation temperature.
- Higher release with higher safety test temperature which also has higher rate of SiC and TRISO failure



TRISO and SiC Failure Rates In-pile and during Safety Tests

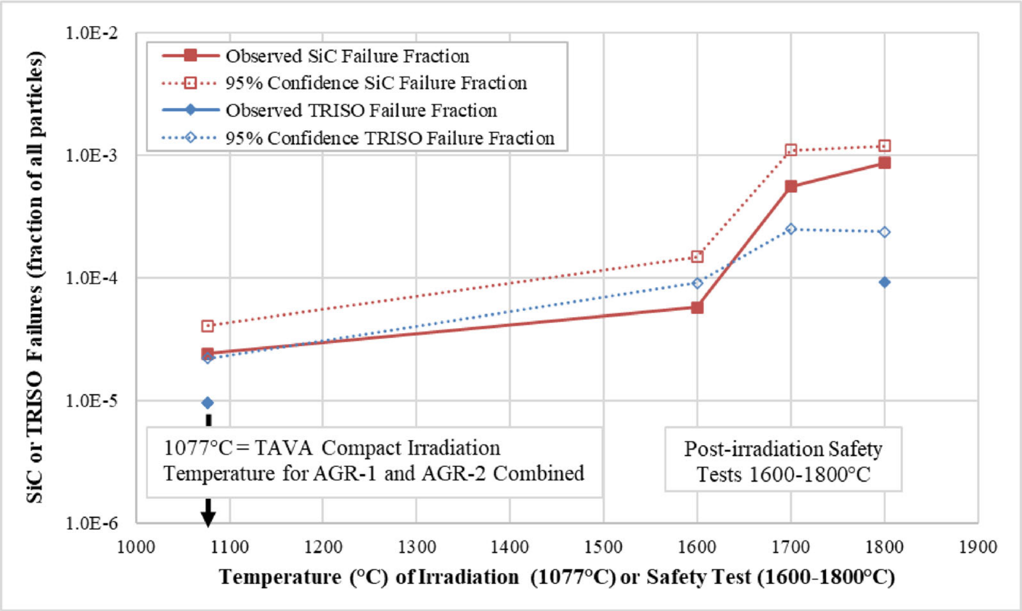


Figure 18. Plot of observed and SiC- and TRISO-failure fraction and the upper 95% confidence limits from the combined results from the AGR-1 and AGR-2 irradiations and safety tests. UCO fuel only.

In-pile Capsule-average Compact Release Rates From Mass Balances

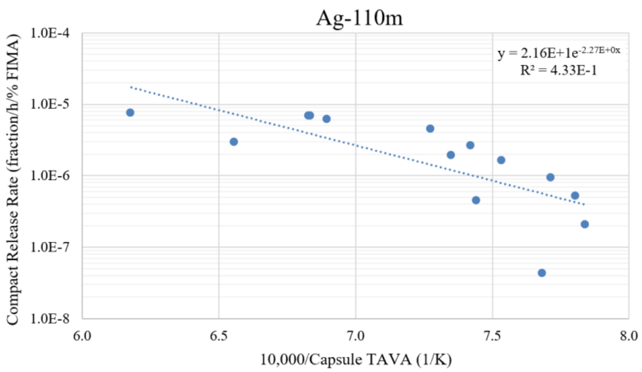


Figure 19. Compact release rates for Ag-110m. Data points come from AGR-1 Capsules 1-6; AGR-2 Capsules 2, 5, and 6; and AGR-3/4 Capsules 3, 4, 7, 8, and 10.

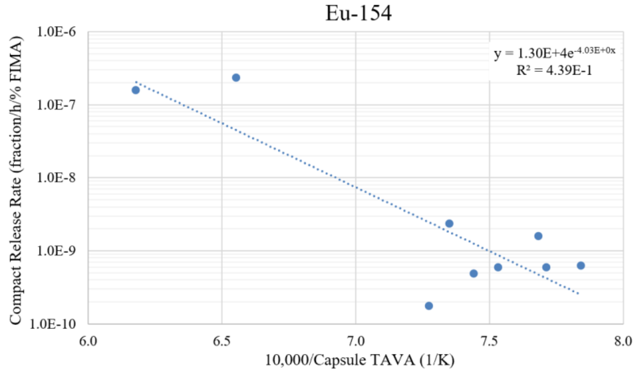


Figure 21. Compact release rates for Eu-154. Data points come from AGR-1 Capsules 1-6; AGR-2 Capsules 2 and 5; and AGR-3/4 Capsule 7.

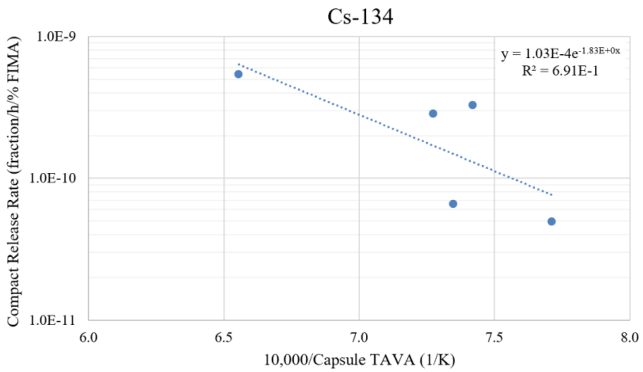


Figure 20. Compact release rates for Cs-134. Data points come from AGR-1 Capsules 5 and 6 and AGR-2 Capsules 2, 5, and 6.

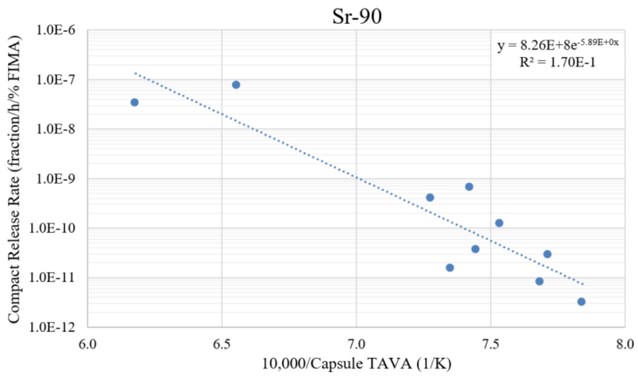


Figure 22. Compact release rates for Sr-90. Data points come from AGR-1 Capsules 1-6; AGR-2 Capsules 2, 5, and 6; and AGR-3/4 Capsule 7.

In-pile Rate of FP Accumulation in Matrix and OPyC from Compact DLBL

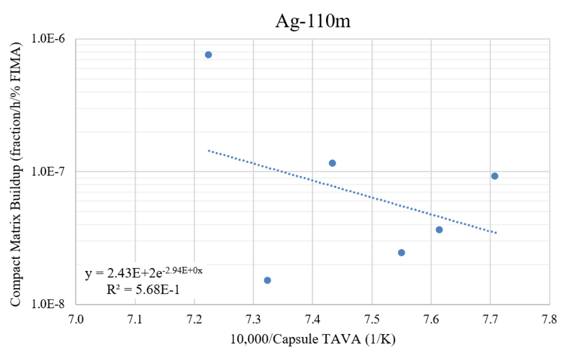


Figure 23. Rate of Ag-110m buildup in the fuel-compact matrix and OPyC from AGR-1 compacts subjected to as-irradiated DLBL that did not have any SiC or TRISO failures. The AGR-2 compacts with no SiC or TRISO failure did not have measurable Ag-110m in the matrix and OPyC.

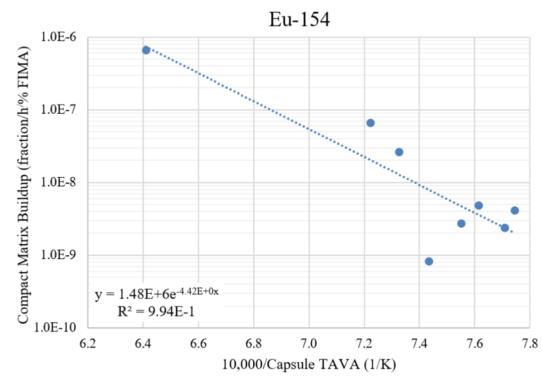


Figure 25. Rate of Eu-154 buildup in the fuel-compact matrix and OPyC from AGR-1 and 2 compacts subjected to as-irradiated DLBL.

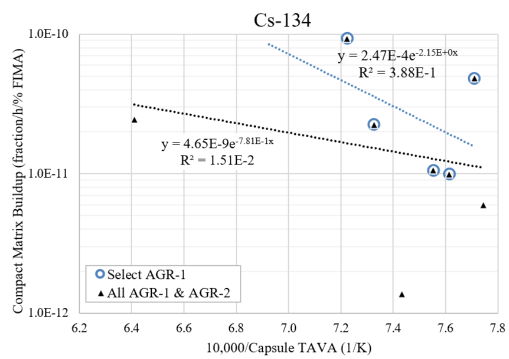


Figure 24. Rate of Cs-134 buildup in the fuel-compact matrix and OPyC from AGR-1 and 2 compacts subjected to as-irradiated DLBL. The data series "Select AGR-1" contains only data points where the Cs-134 content was in excess of what would be expected from dispersed uranium.

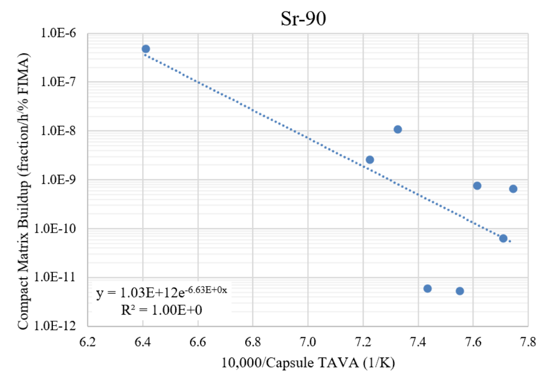
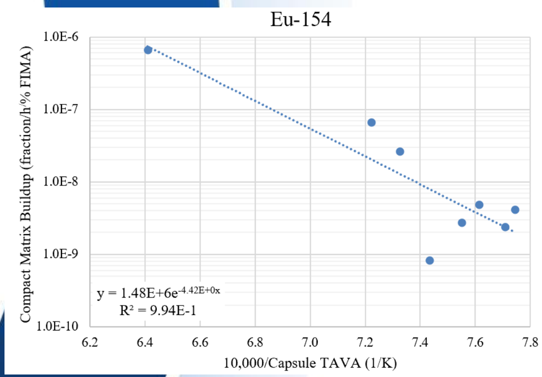
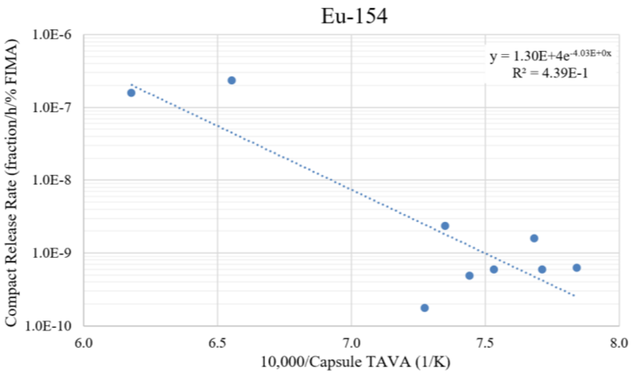


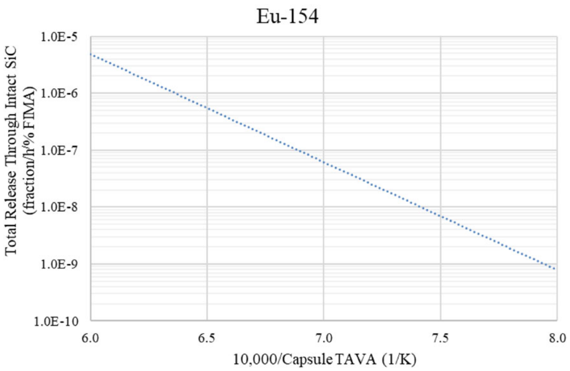
Figure 26. Rate of Sr-90 buildup in the fuel-compact matrix and OPyC from AGR-1 and 2 compacts subjected to as-irradiated DLBL.

Estimated Rate of Total FP Release through Intact SiC Coatings

- The mass balance dictates that the rate of release from compacts is equal to the rate of release from the particles, minus the rate of accumulation in the compact matrix and particle OPyC. Thus, the release rate through intact SiC can be estimated by adding the matrix accumulation rates to the compact release rates.







Safety Test Cs-134 Release Rates

- With no SiC or TRISO failure, pseudo-steady state Cs release rates generally <1E-8 compact fraction/h and increase a little with increasing safety test temperature
- SiC and TRISO failure more likely at higher temperature. Cs rates increase in proportion.

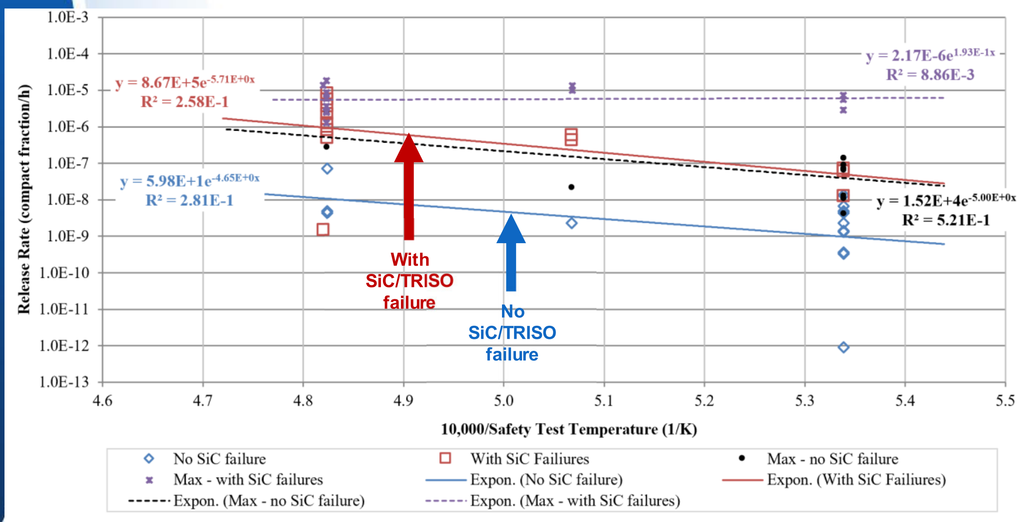
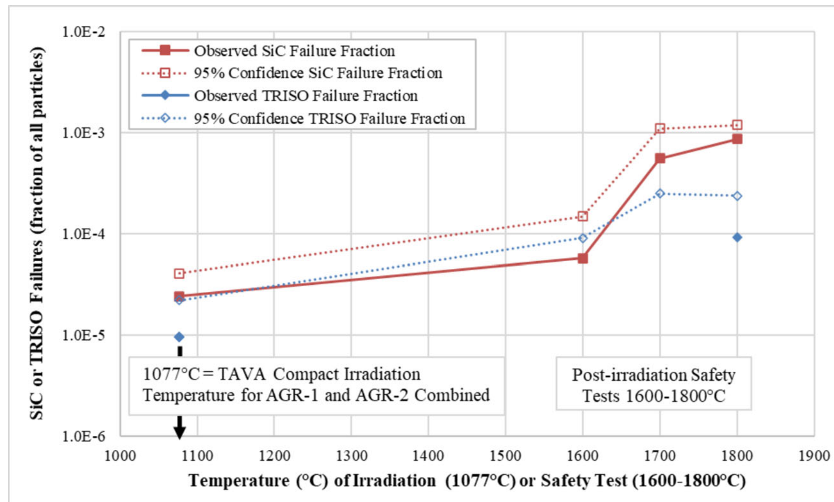


Figure 32. Average pseudo-steady-state release rates of Cs-134 from AGR-2 and 1 fuel compacts subjected to safety testing at temperatures of 1600, 1700, and 1800°C at INL and ORNL. The maximum release rate from the entirety of each test is also plotted.



Safety Test Ag-110m Release Rates

- Rates Insensitive to SiC/TRISO failure
- Rapid early upon rise to isothermal hold
- AGR-1 Variant 3 (fine, equiaxed SiC grains) generally highest pseudo-steady state rate

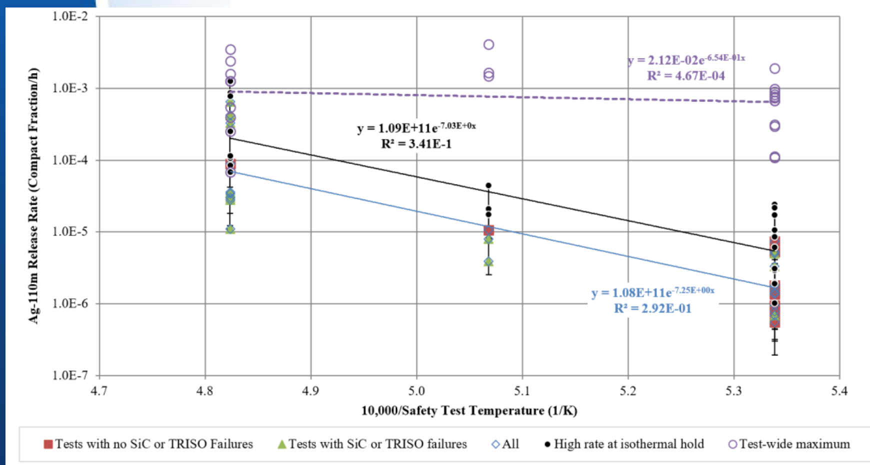


Figure 34. Pseudo-steady-state release rates of Ag-110m from AGR-2 and AGR-1 fuel compacts subjected to safety testing at temperatures of 1600, 1700, and 1800°C at INL and ORNL. Error bars represent the maximum and minimum release rates over the safety-test time interval used to generate the average rate from each test. Local maxima from the time interval used to generate the pseudo-steady-state averages are plotted. The global maximum from each test is also plotted.

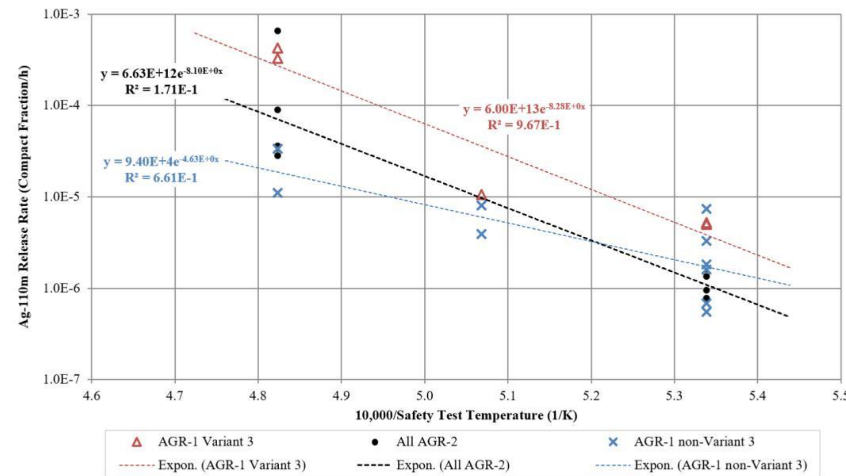


Figure 35. Pseudo-steady-state release rate of Ag-110m from AGR-2 and AGR-1 fuel compacts subjected to safety testing at temperatures of 1600, 1700, and 1800°C at INL and ORNL. Data are grouped for AGR-1 Variant 3 only, all AGR-2, and all non-Variant 3 AGR-1 fuel.

Safety Test Eu-154 Release Rates

- Eu safety test rates are more directly dependent on prior irradiation temperature than Ag or Cs for example.
- SiC failure gives no more than a slight rate increase in fuel with lower irradiation temperatures

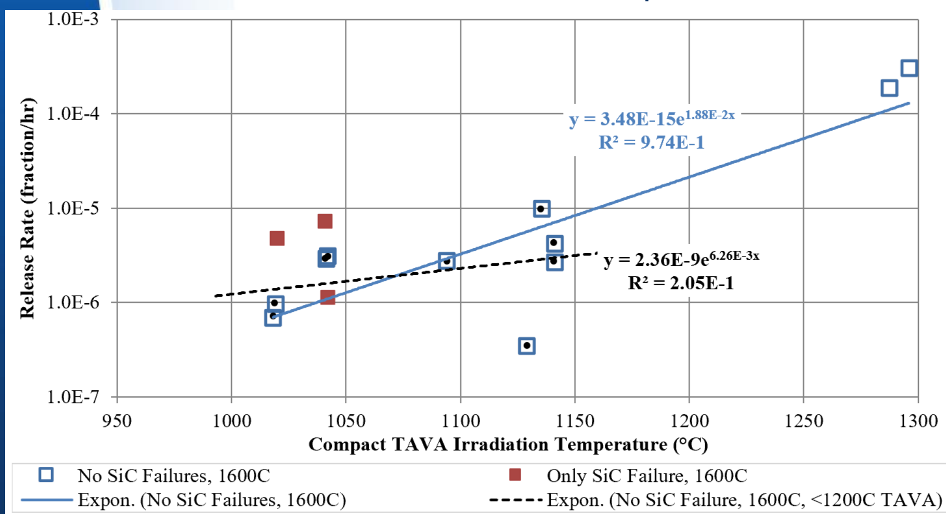
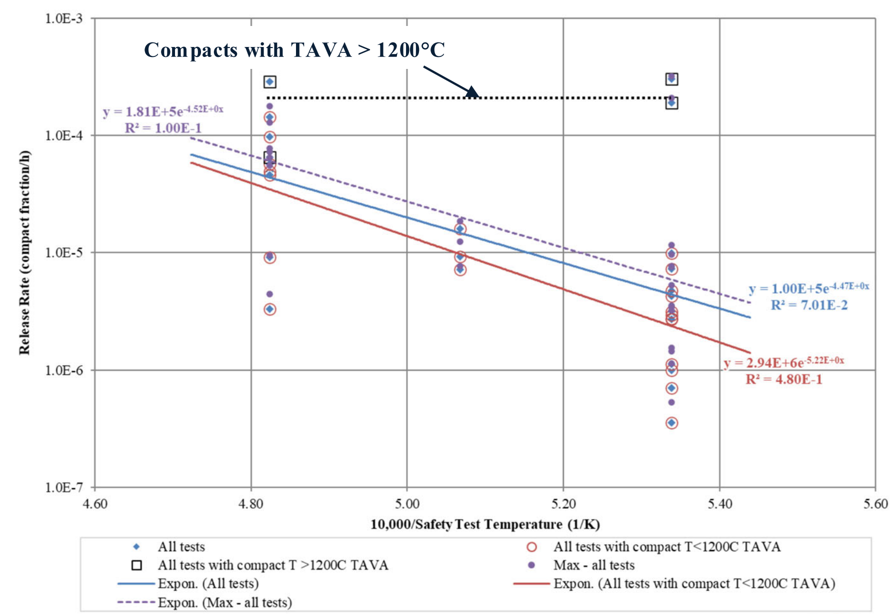


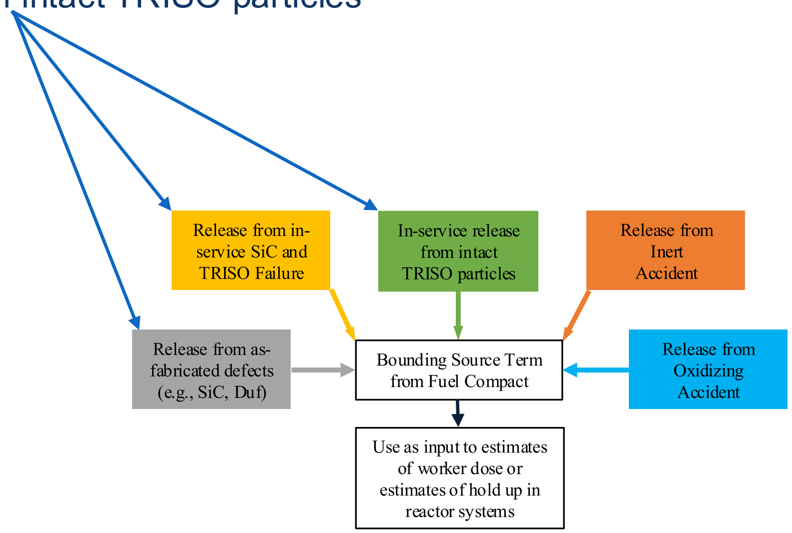
Figure 37. Eu-154 pseudo-steady-state release rates from 1600°C AGR-1 and AGR-2 safety tests versus compact TAVA irradiation temperature. Note that here any kind of failure that involves SiC failure is called "SiC" failure. A particle with a TRISO failure would be included as one with a SiC failure here. The exponential fit shown in black is the fit if fuel with TAVA > 1200°C is neglected.

- Rates increase with safety test temperature
- Highest for compacts with TAVA > 1200°C, ESPECIALLY among 1600°C safety tests
- Sr-90 results are similar to Eu-154



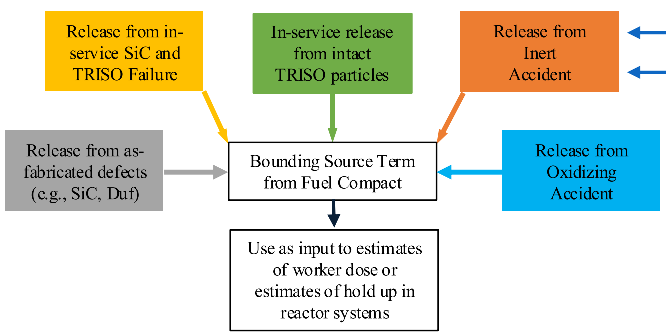
Usage

- In-pile FP compact release rates that account for:
  - As-fabricated defects
  - In-service TRISO/SiC failure
  - Release from intact TRISO particles



Usage

- In-pile rate of FP accumulation in compact matrix
  - This inventory represents and enables estimates of potential for early release during an accident
  - Includes contribution from dispersed uranium
- Inert safety test FP release rates
  - Includes rates with and without TRISO/SiC failure
  - Includes pseudo-steady state and instantaneous and maximum release rates
  - Accounts for effects of as-fabricated dispersed uranium



Future work

- Need to acquire data on oxidation effects

- Develop framework for use of rates and statistics in source term estimates (build on groundwork by Petti et al.)

  D. A. Petti, R. R. Hobbins, P. Lowry & H. Gougar (2013) Representative Source Terms and the Influence of Reactor Attributes on Functional Containment in Modular High-Temperature Gas-Cooled Reactors, Nuclear Technology, 184:2, 181-197, DOI: 10.13182/NT184-181

- Add AGR-5/6/7 data

- Test framework against experiments

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Thank you for your attention

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