SUMMARY OF SAFETY TEST ON IRRADIATED AGR-1 COMPACT 3-3-1

Post-irradiation examination (PIE) is in progress on coated particle fuel compacts from the first Advanced Gas Reactor irradiation experiment (AGR-1). The *AGR-1 Post-Irradiation Examination Plan*, INL/PLN-2828/Rev. 1, includes safety testing of the irradiated compacts in the Oak Ridge National Laboratory (ORNL) Core Conduction Cooldown Test Facility (CCCTF) facility and the Idaho National Laboratory Fuel Accident Condition Simulator (FACS) to evaluate the effect of elevated temperature on the fuel microstructure and fission product retention. Safety tests will involve heating compacts for 100–500 hours to maximum temperatures of 1600°C–1800°C, where 1600°C is the expected maximum temperature during a high-temperature gas-cooled reactor depressurization conduction cooldown event, and 1800°C is the expected temperature at which the performance of the SiC layer will begin to degrade.

ORNL completed the first AGR-1 post-irradiation compact safety test in FY2011 on Compact 6-4-3. During the first two quarters of FY2012, three additional safety tests were completed on Compacts 3-3-2, 3-2-2, and 6-2-1. These first four compacts were heated up to a maximum temperature of 1600°C and held at this temperature for a period of 300 hours (400 hours for Compact 6-4-3). In the third quarter of FY2012, an additional safety test was completed on AGR-1 Compact 3-3-1. The heating profile for Compact 3-3-1 was a controlled ramp of the furnace to 1700°C with soaks at 400 and 1250°C, a hold at 1700°C for 300 hours, and then a controlled ramp back down to room temperature. The safety test was initiated in early May, but the overcurrent circuit protection system for the furnace transformer primary coil activated on two occasions, shutting the furnace down while the compact was being heated up. The compact reached a maximum temperature of 1250°C before the first shutdown and 1323°C before the second. After the second interruption, the compact was unloaded to allow for diagnosis and testing of the furnace. Several minor issues were addressed, but no clear source of the overcurrent events was determined at that time. Test runs ramping the empty furnace up to the planned operating temperature of 1700°C were completed without interruption of power. Therefore, the fuel compact was reloaded, the test restarted on June 5, 2012, and run to completion. After completion of the safety test, additional diagnostics on the furnace determined that the cooling-water lines may have been causing some of the supplied current to shunt to ground; the lines were replaced to ensure better reliability for future CCCTF operation.

During the test period, condensable fission products (metals) were collected by the CCCTF in-furnace cold finger and gaseous fission products were collected from the helium sweep gas as it passed through liquid nitrogen-cooled cold traps. Deposition cups attached to the in-furnace cold finger were periodically removed and analyzed by gamma spectrometry and the sweep gas traps were constantly monitored for gamma activity throughout each run. Figure 1 shows the cumulative time-dependent fission product release from the compact. This was determined by adjusting the decay-corrected quantity of each fission product collected on the deposition cups using the estimated efficiency for collection of that fission product, and dividing that adjusted value by the calculated compact inventory for that fission product. Estimated deposition cup collection efficiencies for silver (98.4%) and cesium (95.8%) were taken from the Compact 3-3-2 and Compact 3-2-2 tests. Because most of the silver and cesium is collected on the cups, the uncertainty in these collection efficiencies is low (<7%). The collection efficiencies used for europium and strontium were based on values previously used for the analysis of fission product release from the safety test on Compact 6-4-3, because of the greater uncertainty in the Compact 3-3-2 and Compact 3-2-2 values, which were based on the results of two sequential tests using the same tantalum furnace liner. However, the uncertainty in the europium and strontium collection efficiencies is still relatively high, because the measured values are low compared to the accuracy of the analysis. Additional post-safety test analysis of the furnace internals from the Compact 3-3-1 safety test will be performed to help further refine the europium and strontium collection efficiencies, but the uncertainty is expected to remain high compared to the more volatile fission products.

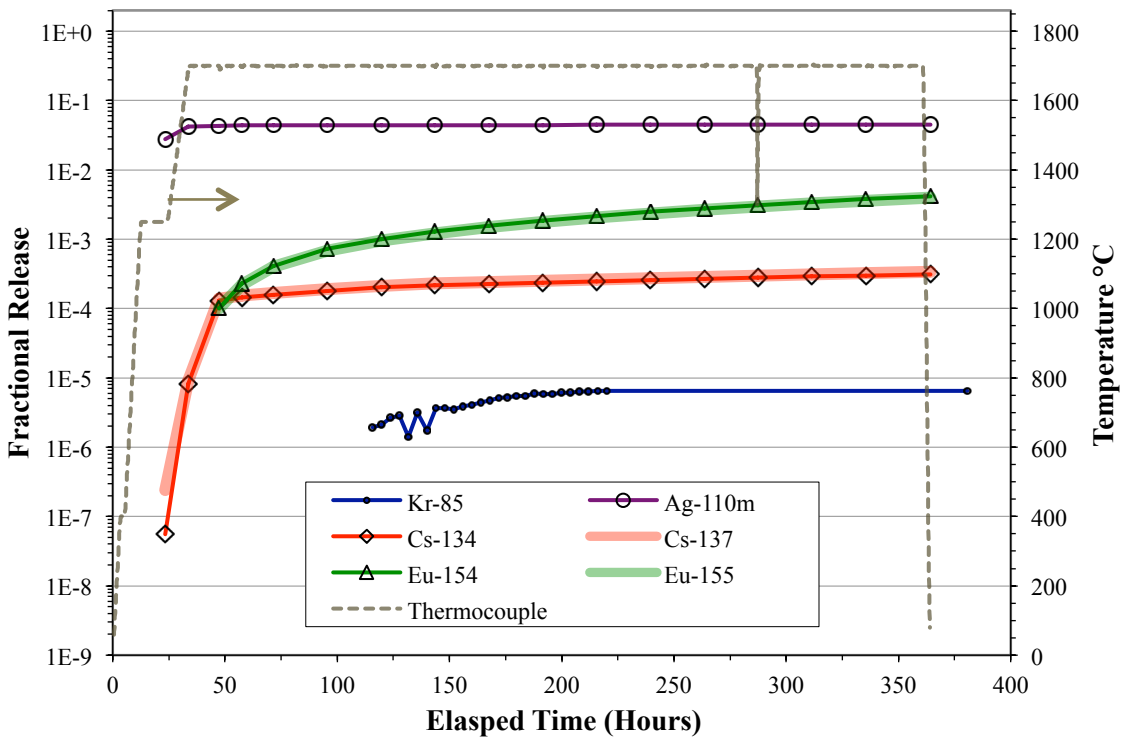

Figure 1. Release of fission products from Compact 3-3-1 during safety testing to 1700°C.

Table 1 lists the total releases for each detected fission product. In Figure 1, the first data points at the end of the 1250°C soak include fission products collected during the interrupted temperature ramps to 1250 and 1323°C; the momentary dip in temperature at 280 hours into the run occurred during a reboot of the control system that occurred after a software conflict. A trace amount of Kr-85 was detected during the run. The amount of Kr-85 detected was near the limit of detection for the sweep gas trap system, and well below a level that would indicate failure of all three outer layers of the tristructural isotropic (TRISO) coating. About 220 hours into the test, background gamma radiation from an unrelated sample in an adjacent test facility made quantitative detection of the very low Kr-85 release impossible. However, post-analysis of the sweep gas traps determined that negligible Kr-85 was released during this period.

Table 1. Cumulative fission product release from Compact 3-3-1 safety test

Isotope	Fraction of Calculated Compact Inventory Released	Equivalent Particle Inventory
^{85}Kr	6.50×10^{-6}	0.03
^{110m}Ag	4.50×10^{-2}	184
^{134}Cs	3.13×10^{-4}	1.30
^{137}Cs	3.36×10^{-4}	1.39
^{154}Eu	4.14×10^{-3}	17.2
^{155}Eu	3.95×10^{-3}	16.4

Note: One particle is equivalent to a compact inventory fraction of 2.4×10^{-4}.

Cesium was released at a level equivalent to the calculated inventory for between one and two particles. The fact that this cesium release was accompanied by only a small amount of Kr-85, indicates that the cesium release was probably from one or two particles with as-fabricated SiC defects but intact pyrocarbon layers. Similar cesium release was observed during the Compact 3-3-2 furnace test, and determined to be related to an as-fabricated soot inclusion defect in the SiC. Europium release was a little

higher than has been observed in compacts heated to 1600°C. Silver release was similar to that observed at 1600°C, with an initial release early in the test, followed by little detectable release while the compact was held at temperature. This release behavior for silver is thought to be an indication that only silver already outside of the SiC is being released during the safety test.

Conclusion

Overall, the CCCTF performed well except for the power supply overcurrent problem that has now been addressed. As originally designed, the cooled-deposition cups have a high efficiency for collection of silver and cesium, and the sweep gas trap system has a good sensitivity to release of Kr-85. Time-dependent monitoring of europium and strontium (not originally part of the CCCTF design) is difficult due to the fact that these elements do not readily release from the graphite and tantalum furnace internals. Analysis of the CCCTF furnace internals at the end of each test will be required for accurate assessment of the total cumulative release of these elements.

Post-safety test analysis is underway. The compact will be deconsolidated, and the particles will be surveyed using the Irradiated Microsphere Gamma Analyzer (IMGA) to detect particles with below average cesium content. IMGA was used successfully to detect the one particle that released cesium from Compact 3-3-2. Based on the amount of cesium released during the safety test, one or two particles from Compact 3-3-1 are expected to have defective SiC.

The negligible Kr-85 release in the sweep gas indicates that the TRISO coatings remained intact when the compact was heated to 1700°C. Significant quantities of silver and europium were released from the compacts during the safety test. Silver appeared to come out of the compact immediately upon heating, but then no further release occurred while the temperature was held at 1700°C. Collection of europium on the deposition cups occurred over a longer time period. It is possible that the silver detected at the beginning of each run, and the europium collected on the deposition cups throughout the safety test, were coming from the compact matrix, as opposed to transport through intact SiC layers. Silver and europium are known to escape through intact SiC during irradiation, and the quantities being detected during the safety tests are in the range of what has been detected in the matrix of as-irradiated compacts. Further PIE of compacts before and after safety testing will help to further investigate this possibility.

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