

Micro- and Nano- Characterization of Neutron Irradiated TRISO Coated Particles

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Tri-structural-isotropic (TRISO)-coated particles are considered an inherently safe fuel type with potential applications as fuel for various next generation reactor types, such as high-temperature gas reactors, small modular reactors, and micro-reactors. The as-fabricated UCO fuel kernels (composed of a mixture of UO₂ and UC, small quantities of UC₂) [1][2]) are encapsulated by a buffer layer of porous carbon, an inner pyrolytical carbon (IPyC) layer, a silicon carbide (SiC) layer, and an outer pyrolytic carbon (OPyC) layer. Irradiation experiments on TRISO coated particles compacted within a graphite matrix, are in progress at Idaho National Laboratory (INL) followed with a large array of post irradiation examination at INL and Oakridge National Laboratory (ORNL) to determine the performance envelope. In aim to understand the neutron irradiation effects on TRISO coated particles and the fission product mechanisms, micro- and nano- characterization has been performed. This paper provides selected results from an AGR-2 particle (AGR2-223-RS06, irradiated at a time-average volume-average temperature [TAVA] of 1161°C; to burnup of 10.8 % fissions of initial metal atoms [FIMA]) and AGR-1 particles (AGR1-632-035 or AGR1-632-034) with a similar irradiation history (1070°C TAVA; 11.4% FIMA) [3][4].

Transmission electron microscopy (TEM) analyses (FEI Titan Themis 200 scanning/transmission electron microscope [STEM/TEM]) focus on the fuel particle kernel center. The microstructures of irradiated fuel kernel feature as two primary phases: (1) a “high-Z (atomic mass)” UC(O) phase (rock salt; a=0.496 nm); and (2) a “low-Z” UO₂(C) phase (fluorite structure; a = 0.547 nm). UC phases are present as inclusions within the UO₂ grains, or as small submicron particles decorating the UO₂ grain boundaries. Metallic fission products (i.e., Zr, Mo, Ru) have a higher concentration in the UC phase than they do in the UO₂ phase (similar for AGR-1 and AGR-2 particles). Unlike conventional oxide fuels (e.g., UO₂, MOX), the Zr found in TRISO fuel particles remains in a metallic state and resides primarily within the UC phases, which can be attributed to a relatively lower local oxygen potential and a higher solubility of Zr in the UC phase. Multiple submicron-size precipitates were identified in both AGR-1 and AGR-2 kernels (see Figure 1). AGR-1 fuel particle center contains smaller-sized precipitates than the AGR-2 fuel particle center, which is attributed to lower average peak temperatures of the AGR1 particle (1144°C vs 1335°C). Analysis using a Cameca SX 100-R shielded electron probe micro-analyzer (EPMA) performed on Particle AGR2-223-RS06) show vastly different behaviors in the two analyzed traverses. The Sr, Te, Eu, and Sn concentration in the recoil zone (RZ) of the non-gap side is on the order of two-to-four times higher than that observed in the RZ on the gap side. Figure 2 shows the radial traverse and Sr x-ray maps.

SiC grain boundary characteristics are evaluated due to the mobility of specific fission products through grain boundaries. Precession electron diffraction (PED) was performed using STEM (ASTAR system, NanoMegs, Inc., on a Tecnai TF30-FEG STwin; see Ref. [5] for details) and analyzed using EDAX OIM

v7.1.0 software. The AGR-1, high-Ag-retention particle, was found to have statistically more CSL-related grain boundaries, but fewer low-angle grain boundaries as compared to the AGR-2 particle. This implies CSL-related grain boundaries may have a direct influence on Ag retention. High angle grain boundaries were found to be the favored grain boundary type for fission product precipitation. However, precipitates were found on a relatively small fraction of CSL-related grain boundaries in both particles. Only the AGR-1 particle exhibited a very small fraction of fission product precipitates on low angle grain boundaries [6].

References:

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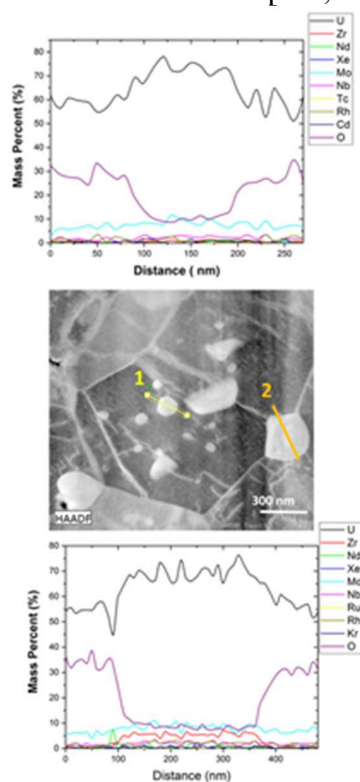


Figure 1. Fine precipitates in AGR2 fuel UC phase.

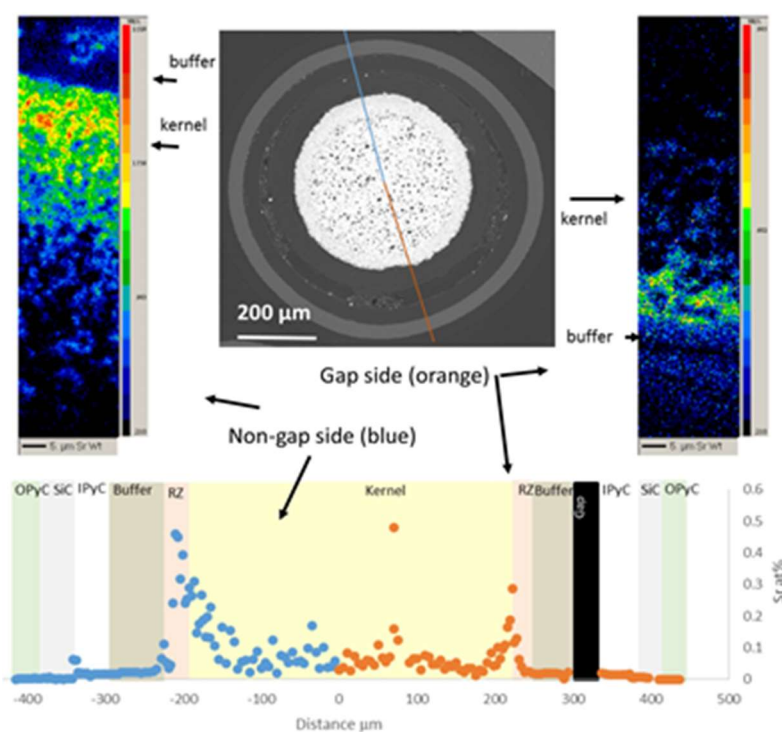


Figure 2. Particle AGR2-223-RS06 EPMA x-ray radial traverses and maps.