Correlating buffer microstructure with failure progression into the SiC layer in TRISO

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ABSTRACT:

The tristructural isotropic (TRISO) particle fuel is being developed as the fuel for Advanced Gas-cooled Reactors (AGRs). The TRISO particle contains a uranium bearing (e.g., UCO or UO_2) kernel, enclosed sequentially by a pyrocarbon buffer layer (buffer), an inner pyrocarbon layer (IPyC), a SiC layer, and an outer pyrocarbon layer (OPyC). While the AGR TRISO particles have demonstrated excellent performance during neutron irradiation with rare instances of failure, a common failure mechanism has been observed that is related to buffer-IPyC debonding (tearing) and subsequent IPyC fracture. The buffer layer is of low density and high porosity, serving the purpose of retaining fission gas. During irradiation, significant densification occurs in buffer, causing buffer fracture and full or partial buffer-IPyC debonding as the enclosed fuel kernel expands outward. In AGR-1 fuel particles, IPyC fracture was over three times more frequently observed in particles with partial buffer-IPyC debonding than with full or no debonding. Such a strong correlation between buffer tearing and IPyC fracture calls for a mechanistic understanding of buffer tearing. In our Phase-I study (CINR 20-19556), a set of novel modeling and experimental tools have been developed to characterize the buffer microstructure, measure buffer mechanical properties, and simulate buffer fracture, which serve as a measure of performance. A microstructure-property-performance (MPP) is established that suggests the promise of tailoring buffer fracture by controlling initial buffer microstructure, including the atomic structure of buffer matrix and the porosity (i.e., pore structure). The findings also call for further studies on the effects of two other critical factors: i) anisotropy in buffer mechanical properties caused by anisotropic porosity distribution and ii) irradiation induced changes in buffer microstructure, including both buffer matrix and porosity.

The Phase-II continuation will harness and extend the success of Phase-I to establish an Irradiation-Microstructure-Property-Performance (IMPP) correlation that links initial buffer microstructure with fracture initiation in buffer and progression to the SiC layer in TRISO particles. The correlation can be turned into design principles to further improve the irradiation performance of TRISO by controlling initial buffer microstructure. Adopting the tools developed, knowledges accumulated, and team assembled in Phase-I, in Phase-II we will characterize the anisotropy in initial buffer porosity distribution, measure mechanical proprieties, and quantify irradiation induced changes. The underlying mechanisms for mechanical deformation and irradiation behavior will be uncovered by combing simulations and experiments at the atomic scale. In addition, we will further develop the BISON model created in Phase-I and carry out statistical BISON simulations to study how initial buffer microstructure and its evolution under irradiation affect buffer fracture and subsequent progression to SiC. The proposed research will correlate irradiation condition, microstructural and property evolution, and fracture behavior as a performance criterion, to establish an IMPP correlation for the purpose of guiding further improvement in TRISO robustness.