Statistical modeling of the effect of microstructural heterogeneity on the irradiation behavior of TRISO fuel buffer layer

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ABSTRACT:

The objective of this proposed research is to achieve a mechanistic understanding of and to develop a predictive model for the tearing behavior of the buffer layer in TRISO fuel particles. The tristructural isotropic (TRISO) particle fuel is being developed as the fuel for high temperature gas-cooled reactors. 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 Advanced Gas-cooled Reactor (AGR) TRISO fuel has demonstrated excellent performance during neutron irradiation with rare instances of failure, a common failure mechanism has been observed related to buffer-IPyC debonding (tearing), buffer fracture, and subsequent IPyC fracture. The buffer layer is of low density and high porosity, serving the purpose of retaining fission gas. During irradiation, significant inward densification of buffer occurs, causing full or partial buffer-IPyC debonding and buffer fracture as the enclosed fuel kernel swells outward. In AGR-1 fuel particles, buffer fracture was found over three times more frequently in particles with partial buffer-IPyC debonding than with full debonding. When buffers fractured, IPyC fracture were much more likely to occur in particles with partial buffer-IPyC debonding. Such a strong correlation between buffer tearing and buffer and IPyC fracture calls for a mechanistic understanding of buffer tearing under neutron irradiation.

Combining advanced characterization and measurement and multiscale modeling, this project will investigate several critical factors impacting buffer tearing, including the heterogeneity in buffer microstructure and the stochastic differences among particles, buffer-IPyC bonding strength, swelling of fuel kernel, and irradiation temperature. Multiscale modeling and experiments will be carried out to develop microstructure-property correlations, for the use in finite element modeling of in-pile TRISO fuel particle behavior using the BISON code. Statistical simulations considering the heterogeneity in buffer microstructure and the stochastic differences between particles will be performed to understand and predict the probability of buffer tearing in AGR-1 and GAR-2 particles. The research outcomes are expected to **i**) provide accurate data on buffer microstructure and mechanical properties, **ii**) advance the fundamental understanding on microstructure-property correlation of buffer, **iii**) provide a modeling tool for predicting the in-pile buffer tearing behavior, and **iv**) assess the stress state and the probability of fracture in IPyC. The simulation results will be validated using the results from TRISO fuel irradiation tests being carried out by the AGR program. Targeting both a fundamental understanding and a predictive modeling tool, the proposed research will provide critical feedbacks for future design of AGR particles with improved performance.