Polymer-Derived C-SiC Coatings on Kernel Particles for Advanced Nuclear Reactors

PI: Kathy Lu, University of Alabama at Birmingham

Collaborators: Co-PI: Eddie Lopez-Honorato, Oak Ridge National Lab; Co-PI: Kaustubh K. Bawane, Idaho National Laboratory; Co-PI: Lin Shao, Texas A&M University

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ABSTRACT:

Motivation: A critical function of the coating layers outside nuclear fuel kernels is to act as a containment shell/diffusion barrier for the fission fragments. A SiC layer is expected to act as a miniature pressure vessel to help contain fission products and must be impenetrable for fission species. Different pyrocarbon layers provide barriers and volume change buffers. The current complex buffer + inner pyrolytic carbon + SiC + outer pyrolytic carbon layer designs, the thick protective coatings, and the requirements for layer interfacial compatibility necessitate new fuel encapsulation considerations. A new concept that has not been tested is creating one integrated kernel coating layer (instead of three or four) using a liquid polymer-derived ceramic approach. C-SiC/ZrC-based composites of varying compositions from the fuel kernel to the outer surface can more effectively retain fission gases, reduce coating layer volume, maintain high strength in oxidizing environments, resist damage under irradiation, act as sinks for migrating defects, and minimize material decay heat. In addition, the liquid polymer crosslinking and pyrolysis approach allows the formation of amorphous matrix coatings with a conformal configuration with the kernel. ZrC at various levels can be incorporated into the C-SiC matrix to increase oxygen mitigation, mechanical integrity, and irradiation resistance.

Scope and objectives: This program aims to use a polymer-derived ceramic approach to develop different C-SiC/ZrC coatings on nuclear fuel kernel particles. The new fuel encapsulation materials will embody a continuously gradient and conformal attribute to accommodate the fuel kernel changes under irradiation along with enhanced strength and irradiation resistance. We will conduct ion irradiation testing of the new materials for nuclear irradiation performance evaluation. We will also carry out detailed mechanical, oxidation, microstructure, and composition characterization to assess the C-SiC/ZrC coated fuel particle behaviors before and after ion irradiation, with the ultimate objective of creating effective fuel kernel coatings with excellent chemical, mechanical, and irradiation properties, and fully advancing this new encapsulation material system for nuclear fuel applications.

Description of the project: **Major tasks:** First, we will use a polymer-derived ceramic approach to create C-SiC materials of different C:Si ratios and C content on fuel kernel substitute particles. We will also in-situ form ZrC in the C-SiC matrix as O getters. Second, we will form different layers of C-SiC/ZrC composites and conduct ion irradiation testing to assess the C-SiC/ZrC coating behaviors and effectiveness in preventing kernel swelling and distortion. Third, we will conduct mechanical, oxidation, chemical, and microstructural characterization of the C-SiC/ZrC coatings to provide a comprehensive understanding of the coating behaviors and evolution mechanisms. **Deliverables:** Because of the gradiently integrated C-SiC/ZrC microstructures with tailoring levels of free carbon and SiC/ZrC nanocrystallites from the kernel particle and outwards, as well as the ability to introduce different levels of irradiation-resistant ZrC additive, the new encapsulant should have much-improved kernel distortion resistance, stress tolerance, and gas management capability. The coating should also have high oxygen-absorbing and irradiation resistance. **Potential impact:** The research efforts come from a strong and collaborative team of two universities and two national labs and have the great potential to create a new class of fuel coating materials for the ultradurable use of advanced nuclear reactor fuels.