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Better Radiation Response and Accident Tolerance of Nanostructured Ceramic Fuel Materials?

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ABSTRACT

Ever increasing energy needs and the recent disaster at Fukushima nuclear power plants have raised the demands for novel and creative solutions to the research challenges, including advanced fuels and cladding materials that withstand irradiation for long periods of time with improved accident tolerance. Nuclear fuels must be highly durable with good chemical and microstructural stability, as well as extreme tolerance to radiation damage. Nanostructured materials with a grain size well below 100 nm are attracting interests for a wide variety of applications due to their ability to alter chemical, physical, and mechanical properties. Nanostructured ceramic materials may provide improved operational fuel and cladding performance and better response in loss of coolant accidents in terms of enhanced radiation resistance, improved mechanical strength, reduced cracking and higher thermal conductivity due to the high density of interfaces and grain boundaries. As a fuel matrix, improved fuel performance and fuel safety due to nanostructure and interfacial effects, as well as diffusion mechanisms of fission products, need to be evaluated.

Structural stability and fission product migration will be studied in nanostructured oxide fuel materials at temperatures and irradiation conditions relevant to operation and accidental scenarios. Specifically, the proposed work will employ novel ion irradiation approaches, complementary characterization techniques, and advanced simulation methods to perform separate and integrated effect studies that will expand the fundamental understanding of 1) damage evolution in ceramic fuel materials in a controlled irradiation environment; 2) phase and structural stability in nanostructured fuel materials to high-temperature high-dose irradiation; and 3) role of the grain boundaries, surface/interface properties on migration and segregation of fission products. The integration of experiments and models aspects to investigate and predict the effects of irradiation at multiple energy levels and rates on the microstructural features and stability of the nanostructured fuels will provide an improved basis for understanding fission product behavior in oxide fuel materials. The proposed work will contribute to the fundamental understanding of the broad category of nanostructured fuel forms, as well as cladding materials, for LWR applications. This study should also provide useful insight on the behavior of the high dose rim effect nanostructured regions of UO_2 during prolonged irradiation.