Computational and Experimental Studies of Microstructure-Scale Porosity in Metallic Fuels for Improved Gas Swelling Behavior

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ABSTRACT:

Metallic fuels are optimal fuel systems for liquid-metal-cooled fast reactors due to several factors including high thermal conductivity and superior compatibility with liquid sodium. Under irradiation, metallic alloy fuels do have a propensity to undergo rather large volumetric swelling, a characteristic that has traditionally been circumvented by increasing the fuel-cladding radial gap. Studies have shown that this irradiation swelling is due to gas bubble nucleation and growth. Although increasing the fuel-cladding radial gap and plenum-to-fuel volume ratios have proven to be workable solutions, they do not necessarily represent desirable constraints for advanced fuel types for future reactor systems, particularly at ultra-high burnups. Strategies for mitigating metallic fuel swelling and fission gas retention at the microstructural level of the material are highly sought. A potential approach to minimizing in-pile irradiation swelling is to incorporate an *initial porosity* within the fuel that can accommodate fission gases as they are produced. The primary challenge relating to this strategy that needs to be overcome is the in-pile densification due to sintering that occurs by the diffusion-governed shrinkage and elimination of the initial pores before they can effectively retain the fission gases.

Some preliminary studies have shown that a bimodal distribution in pore sizes is significantly more resistant to densification than monomodal pore distributions, although a scientific explanation for this observation has yet to be developed.

The objective of this proposal is to scientifically investigate, using closely-integrated computational simulations and experiments, the underlying microstructural mechanisms that govern the relative resistance to densification exhibited by a *bimodal pore size distribution* in uranium alloy fuels. This research will advance the field in three ways: (*i*) we will confirm that such stability occurs in *metallic* uranium and its alloys (as previously demonstrated in UO_2), (*ii*) we will monitor, in detail, the complex microstructural morphology that occurs in high temperature annealing including the evolution of grain structure and pore distribution using multi-scale simulation and experiments, and (*iii*) we will develop a predictive approach to specifically design metallic fuel microstructures for optimal swelling resistance and fission gas retention. Developing this understanding will potentially lead to a new metallic fuel design paradigm that will enable better management of both swelling and fission gas release. Such knowledge will also be applicable to the design of accident tolerant fuels.

This proposal meets all the requests provided by the Advanced Fuels division of FCRD, which seeks science-based approaches to develop microstructural understanding of nuclear fuels to improve fission gas retention, and reduce pellet-cladding interaction and fracture. Such science-based approaches, as specified in the call, combine theory, experiments, and multi-scale modeling and simulation, which are all proposed by this team of researchers.