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Optimized Compositional Design and Processing-Fabrication Paths for Larger Heats of Nanostructured Ferritic Alloys

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ABSTRACT

This proposal addresses the goal of “major increases in fuel burn-up than yet achieved” in the FC-2 scope area that will require new improved cladding materials. The research will advance the development of nanostructured ferritic alloys to achieve this grand challenge. **Nanostructured ferritic alloys (NFAs) have the potential to make transformational (game changing) contributions to developing advanced fission energy.** NFAs are Fe-Cr based ferritic stainless steels that contain an ultrahigh density of Y-Ti-O nanofeatures (NFs). NFAs manifest high tensile, creep and fatigue strengths, unique thermal stability and remarkable irradiation tolerance. The multifunctional NFs impede dislocation climb and glide, resulting in high tensile and creep strength, enhance SIA-vacancy recombination and trap helium in small, high-pressure gas bubbles, that mitigate helium embrittlement and many other manifestations of irradiation effects, including void swelling. Indeed, there is evidence that NFs can be tailored to effectively transform gas bubbles from a liability to an asset, in a way that might provide near immunity to various manifestation of radiation damage. Success in this effort would be a key element in a new path to enable high burn-up fuel cladding to reach 400 or more dpa.

However, NFAs are in the very early stages of development. Important challenges they face include: a) determining the structures and compositions of the NFs; b) identifying composition-synthesis designs that can systematically manipulate the NFs so as to to optimize their sustained high temperature strength and irradiation tolerance; c) demonstrating and understanding the thermal and irradiation stability of far-from-equilibrium NFs and NFA microstructures; d) identifying alloy and thermal mechanical processing paths to optimize the balance of NFA microstructures, so as to provide a suite of outstanding and isotropic properties; e) developing practical fabrication and joining methods that preserve optimal NFA microstructures and yield defect free components; f) improving alloy homogeneity and reproducibility; g) providing a balanced set of performance sustaining mechanical properties, especially including adequate low and high temperature toughness; h) establishing a sequenced path to achieve industrial scale sources of larger NFA heats, while reducing costs; and, i) qualifying new alloys for nuclear service at high dpa. As enabled by extensive collaborations, the proposed research will address most of these issues, at least to some extent. Work on items a) to d) will primarily build on the success of our previous NERI’s (end dates in 2009 for the first and just ended for the second) as well as earlier, and other ongoing related, programs. Items d) to h) will build on a very successful collaboration that we are currently participating in (by subcontract from National Laboratory A to develop improved processing, fabrication and joining “best practice” paths for larger heats of high strength, radiation tolerant NFAs. The first phase of this effort has been completed.