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Microstructure and Property Evolution in Advanced Cladding and Duct Materials Under Long-Term and Elevated Temperature Irradiation: Modeling and Experimental Investigation

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ABSTRACT:

The in-service degradation of reactor core materials is related to underlying changes in the irradiated microstructure. During reactor operation, structural components and cladding experience displacement of atoms by collisions with neutrons at temperatures at which the radiation-induced defects are mobile, leading to microstructure evolution under irradiation that can degrade material properties. At the doses and temperatures relevant to fast reactor operation, the microstructure evolves by dislocation loop formation and growth, microchemistry changes due to radiation-induced segregation, radiation-induced precipitation, destabilization of the existing precipitate structure, and in some cases, void formation and growth. These processes do not occur independently; rather, their evolution is highly interlinked. Radiationinduced segregation of Cr and existing chromium carbide coverage in irradiated alloy T91 track each other closely. The radiation-induced precipitation of Ni-Si precipitates and RIS of Ni and Si in alloys T91 and HCM12A are likely related. Neither the evolution of these processes nor their coupling is understood under the conditions required for materials performance in fast reactors (temperature range 300-600°C and doses beyond 200 dpa). Further, predictive modeling is not yet possible as models for microstructure evolution must be developed along with experiments to characterize these key processes and provide tools for extrapolation. To extend the range of operation of nuclear fuel cladding and structural materials in advanced nuclear energy and transmutation systems to that required for the fast reactor, the irradiation-induced evolution of the microstructure, microchemistry, and the associated mechanical properties at relevant temperatures and doses must be understood. Predictive modeling relies on an understanding of the physical processes and also on the development of microstructure and microchemical models to describe their evolution under irradiation.

This project will focus on modeling microstructural and microchemical evolution of irradiated alloys by performing detailed modeling of such microstructure evolution processes coupled with well-designed in situ experiments that can provide validation and benchmarking to the computer codes. The broad scientific and technical objectives of this proposal are to evaluate the microstructure and microchemical evolution in advanced ferritic/martensitic and oxide dispersion strengthened (ODS) alloys for cladding and duct reactor materials under long-term and elevated temperature irradiation, leading to improved ability to model structural materials performance and lifetime. Specifically, we propose four research thrusts, namely Thrust 1: Identify the formation mechanism and evolution for dislocation loops with Burgers vector of a<100> and determine whether the defect microstructure (predominately dislocation loop/dislocation density) saturates at high dose. Thrust 2: Identify whether a threshold irradiation temperature or dose exists for the nucleation of growing voids that mark the beginning of irradiation-induced swelling, and begin to probe the limits of thermal stability of the tempered Martensitic structure under irradiation. Thrust 3: Evaluate the stability of nanometer sized Y-Ti-O based oxide dispersion strengthened (ODS) particles at high fluence/temperature. Thrust 4: Evaluate the extent to which precipitates form and/or dissolve as a function of irradiation temperature and dose, and how these changes are driven by radiation induced segregation and microchemical evolutions and determined by the initial microstructure.