Microstructure and Property Evolution in Advanced Cladding and Duct Materials Under Long-Term Irradiation at Elevated Temperature: Critical Experiments

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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 microchemistry changes due to radiation-induced segregation, dislocation loop formation and growth, radiation-induced precipitation, destabilization of the existing precipitate structure, as well as the possibility for void formation and growth. These processes do not occur independently; rather, their evolution is highly interlinked. Radiation-induced 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 to 200 dpa and beyond). 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. This project builds upon joint work at the proposing institutions, under a NERI-C program that is scheduled to end in September, to understand the effects of radiation on these important materials.

The objective of this project is to conduct critical experiments to understand the evolution of microstructural and microchemical features (loops, voids, precipitates, and segregation) and mechanical properties (hardening and creep) under high-temperature and full-dose-range radiation, including the effect of differences in the initial material composition and microstructure on the microstructural response, including key questions related to saturation of the microstructure at high doses and temperatures.