Development of Barrier Layers for the Protection of Candidate Alloys in the VHTR

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ABSTRACT

This program addresses the demand for advances in materials to accommodate the high He outlet temperatures in the very high-termperature reactor (VHTR). The focus is on the longer-term need for a target temperature capability of 1000°C with superior durability in He environments containing low levels of deleterious impurities (O_2, CO/CO_2, H_2/H_2O, CH_4). The program seeks to retain the viability of the IN617 family of Ni alloys by surface modification, to enable the formation of alpha alumina barriers as an alternative to the chromia scales characteristic of these alloys. The key advantages are the superior stability of α-Al_2O_3 over chromia in carburizing/de-carburizing environments, its slower growth kinetics, and its remarkable effectiveness as a diffusion barrier for O, C, and even H, with ancillary benefits to tritium containment within the primary gas loop. The intellectual challenges are (1) to enable the formation of α-Al_2O_3 at temperatures and environments wherein metastable phases of alumina and other oxides may be kinetically more favorable, (2) to ensure the adherence and self-healing ability of the oxide barrier over the prospective life of the system, especially under thermal cycling and/or creep of the substrate, and (3) to preserve the surface-layer composition needed to sustain α-Al_2O_3 formation as the system undergoes inter-diffusion.

The program builds on preliminary work by the participating institutions under a Nuclear Energy Research Initiative-Consortium (NERI-C) program scheduled to end in September 2010. Two approaches for barrier layer development will be investigated and compared. Both involve aluminizing IN617 specimens, followed in one case by cladding with FeCrAlX foil by diffusion bonding, and then pre-oxidizing under conditions in which a thin, dense, and continuous layer of α-Al_2O_3 forms. Developing the science base needed to assess the potential of these barrier layer concepts, their relative merits, and the path to optimization will be an important goal of the program. The performance and durability of the barrier layers will be assessed by (1) establishing a baseline behavior through fundamental studies of oxidation and interdiffusion at 800–1000°C; (2) investigating the response of the systems to impure He exposure in the same temperature range; and (3) evaluating the sensitivity of the systems to cyclic creep in impure He. Extensive microstructural characterization will be undertaken in conjunction with each of these activities. Emphasis will be placed on developing a mechanistic understanding of the pertinent microstructure evolution and damage phenomena and their dependence on the composition and architecture of the barrier layers. The insight emerging from the assessment activities will guide subsequent modifications of the barrier layers to optimize their attributes and will help identify any hindrances to the implementation of these concepts in the VHTR and directions for future efforts.

The program will yield substantial benefits in the training of human resources. For that purpose, the program is organized to foster interaction among the students across institutional boundaries to enhance their educational experience. It is also intended to interact with relevant groups at the DOE laboratories, providing the students with additional insight into the technology and the role their research plays in advancing its development.