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ABSTRACT

Nano-Composited Steels for Nuclear Applications

Primary Investigator (U.S.): Roger Stoller, Oak Ridge National Laboratory

Primary Investigator (France): A. Alamo, CEA Saclay

Collaborators: University of California, Santa Barbara

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The successful development of advanced nuclear technologies embodied in the overall concept of Generation IV reactors will provide major challenges to the field of materials science. An underlying theme common to all systems under consideration is the critical importance of developing fuel cladding and structural materials that outperform the best of the materials currently code-qualified for in-core applications. For example, the development of alloys with greatly improved creep strength, fracture resistance, and oxidation resistance combined with a high degree of tolerance for radiation damage would enable systems to be designed with higher operating temperatures and extended component lifetimes.

Alloy development efforts in Japan, Europe, and the U.S. have shown that nano-composited versions of the $Fe^{-8}Cr$ ferritic-martensitic and $Fe^{-13}Cr$ ferritic steels have the potential for developing into a new class of creep and oxidation-resistant steels with outstanding swelling resistance that could be deployed in Generation IV reactor systems. Work is continuing at various institutions to address issues such as anisotropic properties, thermal embrittlement, strength loss associated with microstructural instabilities, and compatibility with liquid and gaseous environments.

This collaborative proposal seeks to develop a scientific knowledge base on the fundamental deformation and fracture characteristics of several carefully selected representative nanocomposited steels strengthened by fine scale oxide particles or atom clusters rich in yttria, titanium, and oxygen. This information will be combined with a study of the effects of neutron irradiation on microstructural stability and mechanical behavior to provide a solid foundation for further development of these innovative materials for nuclear applications.

Miniaturized tensile, creep, and fracture testing techniques will be used, coupled with microstructural characterization to define a limited set of promising composition/microstructures for neutron irradiation studies. Nano-scale structural characterization will be carried out to provide input to microstructure-property modeling activities. Extensive use of Ashby deformation and fracture mapping will be made to characterize the dominant regimes of deformation and fracture processes. A preliminary assessment will be made of the radiation response of a limited number of promising composition/microstructures; irradiations will be carried out using experimental facilities at Phènix, HFIR, or JOYO. The impact of neutron irradiation on the deformation and fracture regimes will be mapped. Relationships between the radiation-modified microstructure and the dominant modes of deformation and fracture will be modeled. This information will be integrated with that obtained from other programs to develop a thorough evaluation of the potential of these materials for expanding the operating temperature limits of fission reactor systems.