Nanoprecipitates-Strengthened Advanced Ferritic-Martensitic Steels and Ferritic Alloys for Advanced Nuclear Reactors

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ABSTRACT:

The overarching goal of this project is to develop advanced Ferritic-Martensitic (FM) steels and ferritic alloys that can be successfully applied to a variety of advanced nuclear reactor concepts. FM and ferritic steels have been considered as candidate materials for core components of fast reactors and life extension of light water reactors due to their superior swelling resistance and low irradiation creep, primarily inherited from their body-centered cubic (bcc) structure. However, their use is rendered difficult due to their poorer creep strengths at temperatures higher than ~873K. Another crucial problem of FM and ferritic steels is pronounced matrix hardening when irradiated at low temperature ($<0.3T_m$), leading to an increase in the ductile to brittle transition temperature and a decrease in the fracture toughness. In a NEET FY 2012 award led by the PI, novel FM and ferritic steels strengthened by a high number density of nanoprecipitates have been developed, resulting in greatly enhanced high-temperature strength and thermal creep resistance. While the NEET FY 2012 award focused on increasing the number density of conventional nanoprecipitates such as MX carbides and Laves phase, **the goal of this proposal is to obtain a high number density of novel nanoprecipitates with a strong tendency for amorphization, thereby achieving significantly enhanced irradiation resistance of FM and ferritic steels**. The alloy design goal is to reduce the irradiation-induced defects in the matrix by trapping them at the amorphous particles and crystalline/amorphous interphase boundaries so that the materials have better irradiation resistance. Computational thermodynamics tools will be used to guide the discovery of nanoprecipitates with a strong tendency for amorphization. The novel FM and ferritic steels are aimed at approaching the performance of ODS steels but with manufacturing advantage of using traditional steelmaking methods. **Relevance:** This project specifically addresses the work scope stipulated in **Reactor Materials (NEET-3)** for developing advanced reactor materials with dramatically improved performance over traditional materials, which can be applied to multiple reactor designs, components, and concepts. The proposed research is directly relevant to DOE NE's mission in light water reactor sustainability (LWRS), advanced reactor technologies (ART), and small modular reactors (SMRs) programs. **Outcome, impact and merit**: The new steels resulted from this project will enable advanced reactors to be operated at higher temperature for longer life, leading to enhanced thermal efficiency, increased reactor economics, safety margins and design flexibility. The knowledge accumulated from the proposed work will advance our understanding on the relationship between the irradiation resistance and the amorphization of nano-size intermetallic precipitates, and provide guidance on the design of future irradiation resistant metal/amorphous composite materials. The methodology and concept of using computational thermodynamics aided alloy design can be extended to the research and development of a broader category of reactor materials. The project will consolidate expertise and resources of the investigators in the areas of computational thermodynamics modeling, alloy design, alloy development, mechanical testing, radiation-resistance evaluation and microstructural characterization, and support education and training of graduate students and postdoctoral scholars.