Alloying Agents to Stabilize Lanthanides Against Fuel Cladding Chemical Interaction: Tellurium and Antimony Studies

PI: Jinsuo Zhang-The Ohio State University (OSU)
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Collaborators: Michael Short- Massachusetts Institute of Technology (MIT), Michael Benson, Robert. Mariani, Yongfeng Zhang- Idaho National Laboratory (INL)

ABSTRACT:

The metallic fuel U-Zr has been recognized as a good fuel candidate for fast nuclear reactors because of its high thermal conductivity, potential burn-up, and its natural ability to be recycled. However, fuel-cladding chemical interaction (FCCI) caused by deleterious reactions between lanthanide fission products and cladding material due to the migration of fission products to the fuel periphery during burning has been reported. We propose to develop new minor additives which can form high-temperature stabilizing compounds with lanthanide fission products during operation. The proposed additives are expected to have the capability of immobilizing lanthanide fission products and preventing their transport to the fuel surface. Therefore, FCCI is expected to be significantly reduced or completely eliminated, and fuel performance will be enhanced once the fuel is optimized by alloying with the effective additives. Based on the available binary phase diagrams for the periodic table, Te and Sb are selected as new additives. The proposed research will focus on Te, while keeps Sb as an alternative candidate. The mechanisms of using minor additives to stabilize and immobilize the lanthanide fission products will be investigated. Resulting thermodynamic data obtained by the proposed research will be integrated into MARMOT to enhance its ability to model metallic fuel performance. The proposed research focuses on the optimization of the metallic fuel alloys using an integral approach including an experimental thrust and a theoretical model thrust. For the experimental thrust, the unknown thermodynamic properties of Te-(Pr, Ce, La, Nd) will be measured, the microstructure of the fabricated U-Zr fuel with Te and Nd will be identified, and diffusion couple testing of selected systems (Nd-Te/Fe, U-Zr-Te/ (Fe, HT-9) and U-Zr-Te-Nd/ (Fe, HT-9)) will be conducted. For microstructure characterization and diffusion couple testing, Nd will be first considered, then will move onto Ce, which depends on the success rate with Nd. The selection of Nd and Ce for these experimental tests is because Nd and Ce are two major lanthanide fission products and can represent the chemistries of the rare earth metal generally. The selection one lanthanide for these experiments leads to a right-sized project and makes it to be completed on time. For theoretical modeling thrust, ternary phase diagrams of (U, Zr)/(Pr,Ce, La, Nd)/Te and Fe/(Pr,Ce, La, Nd)/Te will be developed based on the experimental measurements and available data using Calculation of Phase Diagram (CALPHAD) method, and phase field model development with integration with MARMOT will be developed to investigate different alloys and compounds of lanthanide fission products, and to recognize stable alloys, which will significantly enhance the capabilities of MARMOT to accurately predict additive-doped metallic fuel performance and its evolution.

The proposed research directly addresses the Work Scope FC-2.2, which solicits proposals for optimized metallic fuel alloys which could improve the performance of traditional fast reactor fuels.