A Science Based Approach for Selecting Dopants in FCCI-Resistant Metallic Fuel Systems

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Program: Fuel Cycle Research and Development

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ABSTRACT:

The goal of this project is to identify alloying dopants for minimizing or eliminating the effect of fuel-cladding chemical interactions (FCCI) in fast reactor metallic fuels. Various types of lanthanides are created as a product of fission reactions in the fuel, and among them neodymium, praseodymium, lanthanum and cerium are the most significant ones. They eventually migrate to the fuel-cladding interface gap forming intermetallic compounds, which leads to thinning of the fuel cladding, cladding breach and limited fuel burnup. One key performance requirement is that all nuclear fuel systems must be resistant to such event resulting in release of the fission products and fuel constituents into the reactor primary coolant system. Furthermore, recycled fuel contains significant amounts of rare earth fission products, thus, leading to FCCI from the outset. Over several years, researchers have been working on this problem. Empirical relationships of FCCI have been developed from a large amount of data collected from in-pile and out-of-pile experiments. The alloying approach has been based on adding dopant(s) to the fuel to immobilize the harmful lanthanides by forming compound phases within the fuel meat itself. Researchers have proposed addition of dopants such as palladium (Pd), thallium (Tl), gallium (Ga), tin (Sn), and tellurium (Te). However, the selection approach has so far been largely empirical depending on melting point or certain thermal characteristics. In this project, a *robust science-based* methodology (i.e. 'Design' approach rather than 'Discovery' approach) will be implemented. It aims to develop a suit of fuel alloy compositions resistant to FCCI. Current advances in computational materials can serve as a basis of selection of dopants for immobilizing the lanthanides inside the fuel guided by computational predictive approach. The first task of the project will consider dopant such as Pd and establish the scientific principles that make it the most successful dopant. This will guide our understanding going forward. The proposed program combines the following research tasks: i) Selection of dopant elements based on using electronic structure calculated thermokinetic and bonding parameters of dopant-lanthanide, dopant-matrix and dopant-lanthanide-point defect systems; ii) fuel-dopant-lanthanide fabrication casting; iii) perform diffusion-couple experiments; iv) microstructure and compositional characterization of the annealed diffusion couple experiments; v) incorporation of computational code in results in NEAMS-based fuel performance code. The outcome of the project is likely to be significant in that it can provide science-based guidelines to select dopants for fast reactor fuel compositions. The project team consists of university and national laboratory researchers. Two graduate students will be trained during the course of the project.