Mechanistic insights into the role Pu plays in properties of U-Pu-Zr fuels

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ABSTRACT:

In this project, we propose to capture phase-dependency of thermo-mechanical properties by conducting a systematic experimental assessment of the microstructure and physical properties of fuel alloys with varying Pu content and developing a mechanistic BISON model for thermal and mechanical properties of U-Pu-Zr fuels that will directly couple to the phase fractions determined by the constituent redistribution model in BISON. Investigation of U-Pu-Zr fuels is critical for several reasons. First, during operation, Pu is generated within the fuel pin by neutron-capture reactions with U. Incorporating Pu into the fuel matrix has been shown to introduce additional complexity in the observed fuel behavior; therefore, the influence of Pu on limiting irradiation behaviors can be utilized to extrapolate robust safety criteria applicable to both U-Pu-Zr and U-Zr fuel systems. Second, as spent fuel reprocessing becomes more attractive, mechanistic comprehension of Pu's impact on fuel performance will be necessary. The proposed research aims two answer two fundamental questions:

- What role does Pu play in constituent redistribution?
- What effect does increasing Pu content have on thermo-mechanical properties of metallic fuels?

We hypothesize that increasing Pu content will accelerate constituent redistribution, thus leading to a substantial microstructural heterogeneity. We further hypothesize that newly formed phases improve thermo-mechanical properties locally, but the microstructural heterogeneity will result in an overall decrease in bulk properties. We will leverage unique NSUF capabilities including electron microscopy, thermal conductivity microscopy (TCM), differential scanning calorimetry (DSC), laser flash analysis (LFA), nanoindentation, and micro-mechanical testing equipment and combine them with multiscale modeling to obtain much needed data and models for thermal and mechanical properties of U-Pu-Zr fuels that will directly couple to the constituent redistribution. Our systematic experimental assessment of the microstructure and phase-dependent thermal and mechanical properties will be performed on several U-Pu-Zr fuels with increasing Pu content: U-0Pu-10Zr, U-8Pu-10Zr, U-22Pu-10Zr, and U-26Pu-10Zr. These alloys were strategically chosen to determine how Pu concentration alters constituent redistribution and the resultant physical properties of metallic fuels. We will conduct characterization of both archived as-fabricated alloys and those irradiated to burnups of ~11 at. % in EBR-II, which will allow us to understand the behavior of the fuel in prototypic irradiation conditions and determine the extent to which properties degrade with irradiation.

The scientific outcome of this project will be to grow the fundamental understanding of the impact Pu has on thermo-mechanical properties of metallic fuels while aiding with modeling properties of other advanced nuclear fuels. Existing BISON fuel performance models assume that U does not transmute during irradiation and establishing correlation between Pu and material properties will advance the development of mechanistic fuel performance models. This will facilitate broader engineering impact of mitigating potentially life-limiting phenomena, establishing metallic fuel safety margins, enhancing fuel efficiency, providing data needed for fuel qualification, and advancing the knowledge needed for advanced reactor designs. This project is synergistic to AFC metallic fuels research program on the PIE of metallic fuels, particularly with involvement from co-PIs Capriotti, Adkins, and Yao. This project is relevant to DOE-NE because establishing a fuel performance basis for metallic fuels has been deemed a number one priority, and this project seeks to fill an important technological gap.