Mechanical Response and Chemical Effects at the Fuel-cladding Interface of HT-9 and Metallic Fuel

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ABSTRACT:

Uranium-zirconium (U-Zr) alloys are candidate fuels for fast reactor designs under development by private industry and the U.S. Department of Energy. However, U-Zr fuels are not currently qualified for use within these reactors. Fuel qualification is a costly process that typically takes over 20 years from the conceptualization of the fuel type followed by prolific neutron irradiations and extensive post-irradiation examinations (PIE). Recently, co-PI Beausoleil et al. [1] proposed a new paradigm to dramatically reduce the time required for the fuel qualification process using accelerated neutron irradiations and integrated advanced modeling. An example of the accelerated fuel testing proposed is the Fission Accelerated Steady-state Test (FAST), an integral effects experiment, which can reach higher burnups at reduced times compared to traditional in-pile testing. The basis of this concept is that the FAST irradiation maintains an equivalent linear heat generation rate compared to prototypic fuel (e.g., EBR-II pins) while radially scaling the dimensions to obtain a target burnup more rapidly.

Historically, a major limiting factor for the burnup of U-Zr alloys is fuel-cladding chemical interaction (FCCI), in which fission products and U have deleterious interactions with the cladding alloy constituents (e.g., U-Fe eutectics or an Fe-Nd intermetallic). FCCI is a critical area of research for sodium fast reactors since it is a primary contributor to cladding wastage and eventual cladding failure. For U-10Zr (10 weight percent Zr) alloy fuel, the onset of lanthanide-based FCCI is typically observed at ~10% FIMA (fissions of initial metal atoms) burnup. Therefore, cladding failure in EBR-II fuel was typically observed at burnups of 15-20% FIMA with very few experiments reaching 20% FIMA. To address this early failure, cladding liners, serving as a diffusion barrier between the fuel and cladding, have recently been proposed to mitigate FCCI.

By combining the PIE of the FAST experiments using advanced characterization techniques and modern modeling tools, we will test the following hypotheses:

(1) ***Are the FAST integral experiments suitable for accelerating neutron irradiations to replicate similar irradiation-induced phenomena observed in historical, prototypical in-pile irradiations?***
(2) ***Do Zr liners effectively mitigate FCCI for U-Zr fuels?***
(3) ***Can the diffusion of lanthanides be modeled within the fuel, Zr liner, and FCCI regions to improve the predictions of FCCI evolution as a function of burnup?***

The multi-dimensional datasets generated from the testing of the hypotheses, including diffusion kinetics, microstructure, thermal conductivity, and mechanical properties, will be incorporated into the physics-based model development of MARMOT and BISON.

[1] Beausoleil, et al., *Nuclear Tech*. 207 (2021) 1491.