Comparative study of three-dimensional microstructural imaging and thermal conductivity evolution of irradiated solid and annular U-10Zr fuels

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ABSTRACT:

Uranium-zirconium (U-10Zr) annular metallic fuel promises to simultaneously increase sodium fast reactor core uranium loading and reduce peak cladding temperatures, thus significantly improving fuel performance. However, fuel degradation mechanisms driven by Fuel Cladding Chemical Interaction (FCCI) during irradiation at high temperatures threaten its real-world applicability, requiring a more detailed understanding to predict U-10Zr fuel performance and support fuel design, qualification, and licensing. The complexities of the FCCI require the separation of the phenomena into four main domains: lanthanide transport, fuel-cladding interdiffusion and constituent redistribution, phase transformation, and fuel pore formation, which can result in the interconnection of pores. Ultimately, these degradation mechanisms can lead to lower fuel thermal conductivity and a higher propensity for cracking.

To mitigate FCCI and accommodate fission gas release during reactor operation, annular U-10Zr fuel is being investigated due to its back-end fuel cycle benefits. The annular fuel design comprises a small gap between the fuel and the cladding, filled with helium gas as the bonding material, thereby removing the extra step of sodium disposal, which is associated with the solid U-10Zr fuels. Due to the differences in bonding material and fuel design, the lanthanide fission products diffusion and constituent elements redistribution of the annular U-10Zr fuel could differ significantly from historical solid U-10Zr fuels.

In this project, we propose to combine electron microscopy and transient grating spectroscopy (TGS) with two- and three-dimensional synchrotron-based X-ray imaging techniques to characterize radiation-induced porosity, FCCI in solid and annular U-10Zr metallic fuels with ferritic/martensitic HT-9 steel cladding. We specifically propose to: (I) Study porosity and Ln distribution in irradiated solid and annular U-10Zr using high-resolution synchrotron-based XRD-CT, XANES, and XRF for 2/3D imaging techniques, (II) Resolve the temperature-burnup dependent phase transformation in specific regions of the solid and annular U-10Zr using high-resolution synchrotron XRD, (III) Measure site-specific thermal diffusivity of irradiated annular and solid fuels at different burnups using TGS to correlate with microstructures obtained by techniques mentioned above, (IV) Provide an experimental data pipeline for the BISON/MARMOT team at INL to build mesoscale models for solid and annular U-10Zr fuel performance for various burnup and temperature conditions. This project will use the updated model to develop a correlation between microstructures and their underlying mechanisms of change under irradiation.