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Laboratory-based 3D X-ray microscopy of unirradiated U-10Zr fuel

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Three dimensional (3D) X-ray microscopy, also referred to as X-ray computed tomography, is a data-rich characterization technique that can provide surface and subsurface spatial information in a non-destructive manner.[1-3] However, 3D X-ray imaging of nuclear fuel is a challenging endeavor.[4] X-ray attenuation of high-Z materials, such as uranium, can be significant. This limits the practical maximum X-ray path length (i.e., sample size) to a few millimeters at most. This physical limitation impedes the nondestructive microstructural imaging of real-world samples, such as fuel rods. However, scaling nuclear fuel samples to the appropriate size allows for X-ray path lengths that are suitable for high resolution, laboratory-based 3D X-ray microscopy.

Another challenge of 3D X-ray imaging highly attenuating samples is the presence of cupping artifacts in the resultant 3D tomogram, which is caused by X-ray beam hardening. This occurs from the use of a polychromatic X-ray beam in which a significant portion of the emitted low X-ray energy photons are attenuated by the sample. High energy X-ray photons pass through the sample to the detector, thus providing a radiographic image. The reconstructed tomogram, however, may present this cupping artifact and prevent facile image segmentation based on grayscale intensity. Beam hardening can be reduced during image acquisition by using a physical X-ray filter to adjust the X-ray energy range or the cupping artifact can be corrected during either reconstruction or post-reconstruction using digital image processing. The combination of these methods is typically sufficient for a large number of sample types, but can be ineffective for samples with very low X-ray transmissions.

This presentation will give an overview of laboratory-based 3D X-ray microscopy of appropriately sized, unirradiated U-10Zr fuel cylinders as part of a Nuclear Science User Facility-funded collaborative project to validate Idaho National Laboratory's MARMOT mesoscale fuel performance code. The challenges of imaging these samples, and their solutions, will be addressed. These include the development of a novel, GPU-accelerated post-reconstruction cupping artifact correction method and the implementation of pattern recognition-based segmentation methods[5, 6] using open-source image processing software[7, 8].

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