Determining the Stress-strain Response of Irradiated Metallic materials via spherical nanoindentation

PI: Nathan A. Mara- Los Alamos National Laboratory

Program: NEET: Reactor Materials

Collaborators: Andrew T. Nelson- Los Alamos National Laboratory

Siddhartha Pathak- Los Alamos National Laboratory

Surya Kalidindi- Georgia Institute of Technology

Lance Kuhn- Hysitron Inc.

ABSTRACT:

Science Issue: Ion beam irradiation is a novel technique to impart large amounts of irradiation damage (several dpa or more) without activating the material in relatively short time spans of hours or days that would require weeks or months to achieve in reactor conditions. Ion beam irradiation facilities can currently irradiate materials to high dpas at prototypic reactor temperatures to emulate radiation effects in different reactor conditions. However, the volume of irradiated material is limited by the beam energy to depths of fractions of a micron to several microns, making the investigation of bulk mechanical properties very difficult. **The lack of validated methods to characterize the changes in the local anisotropic elastic-plastic properties of the microscale constituents and interfaces in ion-irradiated material volume is a major impediment to attaining a deeper physics-based understanding of the effects of irradiation on the material microstructure and its associated mechanical properties.** We propose to utilize a novel approach for extracting indentation stress-strain curves from spherical nanoindentation datasets in order to study the material behavior at such length scales. Due to their ability of reliably quantifying many of the important aspects of the local mechanical constitutive behavior in the samples – such as the loading and unloading elastic moduli, the indentation yield points, as well as some of the post-yield characteristics from shallow indentation depths of ~50-100 nanometers– these indentation stress-strain curves are far more versatile than other nanomechanical test techniques which only provide data for hardness and modulus values as a function of irradiation depth, or require extensive sample preparation, often using FIB-based techniques. The properties characterized using indentation stress-strain curves (such as the indentation yield from the loading segment) correspond to the intact material at the indentation site, i.e. before the indentation itself imposes additional local plastic deformation and alters the local microstructure and its properties. The measurements obtained from the indentation stress-strain curves along with the local structural information obtained at similar lengths using EBSD, will be matched with predictions from sophisticated crystal plasticity finite element models to arrive at reliable values of the grain-scale properties (averaged over the indentation zones). The novel crystal plasticity simulation tools developed by Kalidindi's group are ideally suited for this task.

Hypothesis: **We hypothesize that through spherical nanoindentation stress-strain analysis, we will be able to determine the elastic response, elasto-plastic transition, and onset of plasticity in ion-irradiated metallic materials, and compare their relative mechanical behavior to the unirradiated state.** Currently, this approach has been used on systems including W, Fe-3%Si, and Al, but has not been applied to irradiated materials, let alone engineering alloys. Work in the third year would extend to testing hot HT-9 or 304, 316 stainless steels in a nanoindenter in a glove box (collaboration with Hysitron, Inc).

R&D Approach: The methods developed here will be critically validated in a series of metallic samples subjected to a broad range of conditions (e.g., annealed, irradiated).

Material Systems and Specific Experiments: We will develop the spherical nanoindentation stress-strain technique to obtain data of the following material systems in the unirradiated/irradiated states (He, heavy ions, ion irradiation carried out at LANL). **The large body of mechanical test data of Zircaloy and 304, 316, and HT-9 steels irradiated under a variety of conditions (ions, neutrons) will provide the ultimate benchmarking of our revolutionary technique. W—** unirradiated data already published. **Fe-3%Si—**unirradiated data already published. **Zircaloy 4,HT-9, 316,304 stainless steel—**Large amount of irradiation data to benchmark this technique.