Multi-scale Effects of Irradiation Damage on Nuclear Graphite Properties

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ABSTRACT:

Radiation induced damages change dimension and properties such as stiffness, strength and creep. The biggest gap in knowledge remains to be the fundamental deformation mechanisms behind the property changes. We propose to eliminate this gap with a multi-scale experimental framework exploiting in-situ transmission electron microscopy (TEM) and X-ray computed tomography (X-ray CT).

The major deliverables will be (i) Multi-scale deformation mechanisms & properties data, coming from mechanical tests performed inside high resolution analytical microscopes (ii) In-situ TEM self-ion irradiation data with real time visualization of defect generation (iii) Dose and length-scale equivalence connecting ion irradiation to neutron irradiation and (iv) Future workforce training involving graduate and post-doctoral research. The scope of this three-year project will be limited to IG-110, a fine-grained next generation graphite from petroleum coke. However, the methodology will be applicable to other graphite types, e.g., NBG-18. In-situ TEM and X-ray CT microscopy will be performed during properties measurements. X-ray CT data will be used to build a predictive Finite Element Model for mechanical response. The study will involve mostly using self-ion irradiation. Ion and neutron damage equivalence study will be performed. The overarching objective of this research is to elucidate (a) microstructural changes in nuclear grade graphite when exposed to radiation and high temperature and (b) their influence on elastic modulus, strength, toughness and creep.

The project comprises of three tasks, with objectives of discovering the fundamental mechanisms behind (1) Elastic modulus and strength (2) Fracture toughness and irradiation creep and (3) Dimensional changes during radiation. The outcomes of this project will bridge the (a) discontinuity between defects/microstructure and dimensional/property changes and (b) discontinuity between the length-scales (micro/nano mechanics of damage to bulk scale failure). It will advance the state of the knowledge by introducing the concept of heterogeneity or localization as a driver for quasi-brittle properties. It also introduces the concept of building and validating a virtual specimen to study the roles of constituents, interfaces, defects that are not feasible experimentally.

The project is led by the Pennsylvania State University, performing in-situ TEM and X-ray CT experiments and relevant modeling. Sandia National Laboratories is a collaborator, performing self-ion irradiation and creep studies. Idaho National Laboratory is another collaborator, performing bulk scale characterization, neutron irradiation and equivalence of radiation dose and specimen length-scale.