Unraveling Dynamics of Radiation Damage Formation via Pulsed-Ion-Beam Irradiation

PI: Sergei O. Kucheyev- Lawrence Livermore National laboratory

Collaborators: Swanee J. Shin, Supakit Charnvanichborikarn- Lawrence Livermore National Laboratory

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ABSTRACT:

The primary cause of radiation damage to many nuclear materials is high-energy neutron recoils. Such recoils create collision cascades initially consisting of elementary point defects. The ballistic (collisional) formation and thermalization of cascades are believed to be reasonably well understood. In contrast, our current understanding of the evolution of defects after cascade thermalization is very limited despite the fact that such defect dynamic processes play the dominant role in the formation of stable radiation-induced disorder in most nuclear materials. This is because they are difficult to assess experimentally and challenging to study theoretically. As a result, there remain a number of unanswered questions about very basic radiation defect dynamics. In particular, for how long do defect interaction processes proceed after cascade thermalization? Over what distances do defects migrate after cascade thermalization? What controls defect evolution dynamics and such characteristic time and length constants and how do they depend on material properties and irradiation environment?

Our objective is to develop and demonstrate a novel experimental approach to access the dynamic regime of radiation damage formation processes in nuclear materials. We propose to exploit a pulsed-ion-beam method in order to gain insight into defect interaction dynamics. We will measure (i) defect interaction time constants, (ii) defect diffusion lengths, and (iii) activation energies of defect interaction processes for a prototypical nuclear ceramic material, SiC. The effective time constant of defect interaction will be measured directly by studying the dependence of lattice disorder on the passive part of the beam duty cycle, while the effective defect diffusion length will be estimated from the dependence of damage on the active part of the beam cycle. Ion irradiation will simulate selected parts of the radiation spectrum to which nuclear materials are exposed. The total amount and depth profiles of structural disorder will be measured by channeling-based techniques, and the damage microstructure will be studied by electron microscopy. Electrical transport measurements and x-ray diffraction will be evaluated as additional characterization techniques that can be applied in future studies of more complex nuclear materials whose systematic investigations by ion channeling and electron microscopy are often cost prohibitive.

This proposal is fully supportive of NEET-3 program and offers an excellent opportunity to pioneer a new direction of advanced reactor materials characterization techniques and tools. Experimental data on defect interaction dynamics is essential for building physically sound models to describe the formation of stable radiation defects. This project could establish the pulsed ion beam method as the primary approach to study defect interaction dynamics in nuclear materials.