Use of Micro- and Meso-scale Magnetic Characterization Methods to Study Degradation of Reactor Structural Material

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ABSTRACT:
The objective of this proposal is to integrate microstructural metrology, micro-magnetic measurements, andmeso-scale phase field modeling to develop advanced tools and techniques that can extract semi-quantitative diagnostic and interpretive information about the state of microstructural damage in a material based on magnetic signature data alone. Improved diagnostic information about materials degradation will greatly enhance reactor safety by reducing uncertainty in assigning safety margins for materials currently in service and for new materials currently in development. This technology has potential for maturation into real-time, in-situ monitoring capability.

Reactor structural properties degrade due to exposure to extreme environments (e.g. temperature, pressure, irradiation, fatigue, etc.). This degradation results from microstructural changes that affect both mechanical and bulk magnetic properties. We propose that computational modeling can be used to derive correlations from micro- magnetic signatures to provide information about mechanical properties. State-of-the-art materials science characterization techniques will be used to measure structure, chemistry, hardness and crystallography on nanometer to micron length scales. Meso-scale magnetic imaging techniques will be used to measure magnetic properties and correlate them to microstructural features. Physics-based meso-scale models will be developed to integrate and simulate the experimental data with the result being computational models that can perform structure-property (magnetic, mechanical) correlations at the meso-scale. These models can then be used to interpret micro-magnetic property data, to predict the state of microstructural damage, and to provide an estimate of material properties as a function of degradation.

The expected outcomes of this project include development of an integrated methodology to coordinate meso-scale modeling, traditional materials characterization science, microproperty imaging, and scalable signatures for non-destructive evaluation application. We apply these methods to gain insight into material degradation such as volumetric damage in nuclear steels, void formation, swelling, precipitation, and defect cluster formation. Specifically, meso-scale models of steels with martensitic structure and different types of defects will be developed and tied to damage models. New characterization techniques will provide increased insight into microstructural evolution and the sources of magnetic signature change during damage accumulation such as is found in nuclear materials. Our results will be summarized and disseminated in journals and technical conferences. This project consists of collaboration between researchers at the Pacific Northwest National Laboratory (PNNL) in Richland, WA, and Washington State University (WSU), in Pullman, WA. The team consists of a PNNL principal investigator (PI) with expertise in non-destructive evaluation of nuclear structural materials (Dr. Pradeep Ramuhalli), and a WSU co-PI with expertise in magnetic measurements of materials (Prof. John McCloy, WSU).

Additional PNNL key personnel necessary for this project include those with expertise in ion irradiation of solids (Dr. Weilin Jiang), meso-scale modeling and simulation of irradiation damage in steels (Dr. Shenyang Hu), meso- scale modeling of electromagnetic phenomena in materials (Dr. Yulan Li), advanced diagnostic and prognostic technologies for nuclear power facilities (Dr. Ryan Meyer), and management of multi-disciplinary material research programs (Dr. Bradley Johnson). PNNL will lead the tasks on microstructure metrology and computational modeling, WSU will lead the tasks on magnetic and mechanical metrology, and the team will jointly lead the task on specimen fabrication.