Enhanced Characterization of Concrete Mineralogy using Multi-Modal Tools

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ABSTRACT:

Concrete in structural elements of a nuclear power plant is subject to neutron radiation during the entire service life of the plant. In order to ensure long term operation, especially in the context of 2^{nd} term license renewals, it is important to estimate what physical changes (if any) the concrete will undergo because of irradiation. It has been reported that neutron radiation exposure induces residual stresses and cracking damage in concrete that is driven by volumetric expansion of the component mineral aggregates. In order to address this issue, the DOE Light Water Reactor Sustainability (LWRS) program is using concrete aggregate mineralogy to predict stress fields and cracking in concrete, guided by 2-D mineralogical phase maps of the aggregate minerals. This approach involves implementation of a micro-mechanical modeling software package developed by LWRS called "MOSAIC" (Microstructure Oriented Scientific Analysis of Irradiated Concrete). While considerable progress toward estimating concrete's resistance to radiation-induced degradation has been achieved through MOSAIC, there is room for significant improvement.

We propose to improve the function and utility of MOSAIC and thereby develop a more complete understanding of radiation effects on concrete. Our approach to achieve this objective is structured through three tasks: 1) improve the quality of input data to MOSAIC; 2) validate the outputs from MOSAIC against experimental data; and 3) study the effects of wide-energy spectrum radiation on siliceous minerals. The first task is achieved by: a) obtaining ten-fold improvements in spatial resolution of mineralogical maps using Raman imaging; b) increasing the reliability/accuracy of mineral identification by providing chemical phase data (from Raman and EBSD) to complement chemical composition data (from SEM-EDS and µXRF); and c) enriching the chemical data set by adding mechanical data from spatial nanoindentation measurements. The second task is achieved by comparing the output of MOSAIC (2-D maps overlaid with cracks) against images of experimentally obtained ion-irradiated samples of the same minerals. The predictive capabilities of MOSAIC will be improved by minimizing discrepancies between the cracking patterns of predicted output and actual data through an iterative optimization effort. The third task is achieved by determining optimal ion species/energy combinations that serve to mimic neutron radiation exposure of concrete in a nuclear power plant, but in a robust, safe, and economical manner. This ion irradiation work involves experiments where synthetic siliceous minerals are exposed to a wide spectrum of ion energies, in an effort to invoke both radiolytic and ballistic effects. Successful completion of our project is assured by a diverse and well-balanced investigating team, and will result in significant improvements both to our understanding and to the prediction of concrete's tolerance to radiation induced degradation.