Integrating multi-modal microscopy techniques and the MOSAIC simulation environment to assess changes in the physical properties and chemical durability of concrete following radiation exposure

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ABSTRACT:

Background: Concrete, a mixture of cement, sand, stone and water is used in the construction of critical structural and shielding components in nuclear power plants. However, concrete, and its polycrystalline aggregate (i.e., sand and stone) constituents are affected, and degraded by exposure to radiation, e.g., in the form of neutrons. For example, the disordering of the native (*pristine*) atomic architecture of the mineral constituents that make-up aggregates have been shown to: (a) affect their physical properties such as density, which often decreases, as a result of which aggregates expand; a process known as radiation-induced volumetric expansion (RIVE), and (b) affect their chemical durability, wherein disordered (*irradiated*) minerals dissolve much faster than their pristine counterparts (i.e., resulting in the onset of irradiation-induced alkali silica reaction). These alterations in physical properties and chemical durability – which result in concrete degradation – are problematic as they can compromise concrete's mechanical integrity, and thus its ability to fulfill shielding, safety and structural functions in nuclear power plants (NPPs). However, in spite of the potential for such degradation, presently, we have no ability to assess how / whether exposure to radiation may have affected the concrete or not?

Objectives: To overcome this major knowledge gap, the objectives of this proposal include:

[1] Irradiation: To establish accelerated methods based on proton [H^+] implantation to controllably induce atomic-scale alterations in technical polycrystalline aggregates used in nuclear concretes,

[2] Multi-Modal Imaging: To develop unprecedented multi-modal imaging methodologies that integrate and fuse: VSI (vertical scanning interferometry), μ-XRF (micro-X-ray fluorescence), 2-MGEM (two-modulator generalized ellipsometry microscopy), μ-XRD (micro-X-ray diffraction), EBSD (electron backscatter diffraction), EDS (energy dispersive X-ray spectroscopy) and PLM (polarized light microscopy) to unravel: physical, structural and chemical durability alterations in polycrystalline (concrete) aggregates, prior to and upon their increasing exposure to radiation, and,

[3] Empowering SLRs: To implement the analytical outcomes in MOSAIC: a simulation environment developed by the Light Water Reactor Sustainability Program (LWRS) to predict / assess changes in concrete properties to inform, enable and empower second license renewal (SLR) applications.

Outcomes: This proposal develops presently unavailable capabilities including multi-modal analytical methods, molecular dynamics-based, and micromechanical computational tools, and databases for elucidating structure-reactivity relationships of harvested- and laboratory-created concretes and their aggregate constituents. These activities enable diagnosis, prognosis and forecasting of whether, and to what extent an irradiated concrete is serviceable, durable or damaged: a significant factor to consider in SLR applications. These data are needed by the nuclear industry, and Nuclear Regulatory Commission (NRC) to understand how, and to what extent concrete may be damaged by radiation (or not) over short and longer time scales? For these reasons, the outcomes of this research are well-placed to benefit the U.S. nuclear industry in a timely manner as one-half of the nation's nuclear plants seek SLRs by 2040.