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Irradiation impact in concrete: Gamma effects on cement paste constituents (calcium silicate hydrates) and neutron effects on minerals present in aggregates

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With subsequent license renewals being granted to part of the Light Water Reactor fleet in the US, several questions regarding the effects of long-term exposure of concrete structures to both gamma and neutrons were raised. Specially, the impact of irradiation on the concrete biological shield around reactor pressure vessels is of importance. Gamma rays affect the hydrates in cement paste components via radiolysis of water and heating, causing water loss of both free and chemically bound water. On the contrary, neutrons have larger impact on minerals present in aggregates, causing amorphization and expansion; what is known as radiation induced volumetric expansion (RIVE). The combination of both detrimental effects in nuclear concrete structures needs to be accounted for in the prediction of damage at long term exposure, to ensure viable operation of this important plant component.

A compilation of literature data on expansion of minerals with neutrons has concluded that the expansion rate and magnitude is mineral dependent, specifically dependent on silica and covalent bond content, making silicates with covalent bonds more susceptible. This implies aggregates comprising different minerals will be subjected to mismatch strains. The strains can be accommodated by crack opening or by relaxation effects in the cement paste. The exact location of cracks in aggregates after irradiation and the decay in viscoelastic properties of cement paste with radyolysis are not well understood and require further investigation.

Japanese aggregates of different nature (sandstones, tuff, and limestone) were irradiated to 4 neutron doses and are being analyzed for changes in density by He pycnometry, crack opening by XCT and SEM, and porosity from the nano to the micro scale via (U)SAXS. Preliminary results indicate porosity is unaltered for limestone, while it increases for tuff and sandstones. Cracks are located both within grains and at grain boundaries, which is relevant information to develop realistic damage models. The effects of large doses of gamma irradiation on calcium silicate hydrates show a clear increase in stiffening, which will impact the ability of the paste to relax stresses due to aggregate expansion with neutrons.