Challenging Radionuclides in Environment at the Atomic Scale: Issues in Waste Disposal and Fukushima

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Radionuclides are beneficial in many instances such as power generation, industrial, medical, and geochronological applications. Conversely, some fission products and actinides produced in nuclear reactors are radiotoxic and have long half-lives. These radionuclides need to be isolated and safely stored for geological periods; however, there have been instances where the release of these radionuclides has caused serious environmental issues. In such instances, the release of these radionuclides is governed by their interaction with inorganic, organic, and biological substances at the molecular scale in the Earth's surface and sub-surface. Naturally-occurring nano-particles and microorganisms also play an important role in facilitating or retarding the migration of low-solubility radionuclides. The migration processes at the nano- and atomic-scales have been illustrated by atomic-resolution transmission electron microscopy (TEM). TEM is a powerful technique that enables us to investigate the structural and chemical properties of these particles at scales ranging from micron to sub-angstrom. This talk will address some of the observable microscopic phenomena that can impact the migration of radionuclides in surface and subsurface environments; physical and chemical alteration of nuclear waste and UO_{2+x}, colloid-facilitated transport, microbial nanocrystallization of rare earth elements that are used as surrogate of trivalent actinides, the interaction between nanoparticles and microorganisms, and most recently contamination at Fukushima. At the present, ^{134}Cs and ^{137}Cs are important dose contributors, and their radioactivity will remain in soils, mainly fixed in the form of submicron-sized clay minerals. Some of the particles associated with Cs are transported while surface soils are run off. On the other hand, at the initial stage of Cs release from Fukushima Daiichi Nuclear Power Plant, low-solubility Cs-rich micro-particles, which contain up to ~36 wt% of Cs as Cs_2O, are responsible for ~90% of the radioactivity (rather than soluble forms of Cs such as CsOH). The interior of these particles exhibit evidence of various nanoscale processes in the molten core-concrete interaction (MCCI) that occurred subsequent to melt down in the primary containment vessel. Still, these particles play an important role in the dispersion of low-volatile radionuclides into the surrounding environment. The latter half of the talk will highlight various microscopic but critical phenomena in Fukushima as unveiled by state-of-the-art TEM investigations.