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Multiphysics degradation processes, and their mitigation, in engineered and geological barriers: experiments and simulation

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ABSTRACT:

The objective of this work is to fill the gaps in understanding of mechanisms of a series of degradation processes potentially affecting geo-materials involved in nuclear waste disposal, including buffers, seals, backfills, as well as host rock intended to isolate the waste. The degradation is due to thermal, hydric, geo-chemical and transport processes phenomena developing in the repository over a long-period of time. The main among such processes is drying-cracking due to forced ventilation, heat and/or mineral chemical reactions. Drying-cracking raises concerns of formation of preferential paths of advection of radionuclides in cracked rock, while their expected healing and sealing are only partial. There is a general gap of knowledge on drying-cracking which consists of multiple, coupled, physical, mechanical and hydraulic processes. Having understood the mechanisms, appropriate mathematical models will be built and implemented into existing codes to predict the material degradation degree and develop strategies to reduce the risk and consequences of it. Given the extended stretch of the required service time over which the nuclear waste disposal facilities are meant to maintain not only their integrity, but also functionality, and perhaps ability to retrieve the waste, it is clear that any potential degradation of the material properties, mechanical, hydraulic or geochemical, must be addressed. A proof of concept for several techniques to mitigate drying-cracking consequences will be presented. The focus is on materials and conditions relevant to Used Nuclear Fuel Disposition program. Clay rocks or volcanic tuff with a zeolitic and clay fractions and bentonite are going to be studied as main options for geologic disposal. Their long-term integrity is of concern in view of higher waste package temperatures and/or of long hot ventilation times currently considered in an open-emplacement mode of disposal. The work includes constitutive, laboratory, and numerical efforts. In the constitutive studies mechanisms of interaction will be investigated between shrinkage of rock, its compressibility, evolution of pores, mineralogy, evaporation rate and cracking. A key questions are physically based criteria of air entry, which is the moment when air during drying penetrates the interior of the material, and of subsequent drying-crack formation. Experiments show that the air entry happens within a fraction of a second, forming flaws, which penetrate deep enough into soil/rock to induce stress concentrations, causing rock to crack. We will verify these hypotheses at three sales: of a few grains, large clusters and larger bodies.

We will furthermore address: (i) effects related to electro-chemistry of clays, including an increasing ionic concentration due to evaporation, enhancing the clay shrinkage and reducing its swelling capacity, and long-term effects of transformations of clays and rocks changing their mechanical strength and permeability; (ii) mechanisms of air entry into micro-, nano-meter pores in silts, clays and zeolites; (iii) superposition of thermal and evaporation effects. We will build reduced scale physical models to test cracking in geomaterials near heated surfaces at up to 200ºC. The deliverable will include a body of the experimental finding and mathematical models describing coupled physical/mechanical/hydraulic processes implemented into numerical codes. Hence a multi-disciplinary team has been formed, including Duke University engineers, Lawrence Berkeley National Laboratory hydrogeologists and geochemists, experimentalists and modelers from the Federal Institute of Technology in Lausanne, Switzerland and physicists from the University of Montpellier in France.