Monitoring of Subsurface Contaminant Remediation at the Former Moab Uranium Mill Site by In Situ Nuclear Magnetic Resonance

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Background/Objectives. The Moab Uranium Mill Tailings Remedial Action (UMTRA) site is a former uranium ore-processing facility adjoining the Colorado River near the town of Moab, Utah (USA). One of the major goals of this facility is to protect the Colorado River ecosystem from the uranium plume. The current remediation approach is based on injection of solutions of calcium-citrate and sodium-phosphate into sediments that leads to citrate biodegradation and formation of hydroxyapatite serving as a permeable reactive barrier that decreases uranium mobility. In this work, we aim to use borehole NMR technology to monitor longitudinal change in water signal associated with progress of hydroxyapatite precipitation at Moab UMTRA.

Approach/Activities. NMR measures the response of hydrogen in groundwater to a magnetic field perturbation, providing information about the quantity of fluid and its pore environment. The NMR measurements are non-destructive, non-radiogenic, and provide high-resolution evaluation and visualization of crucial aquifer properties. To measure the water signal associated with progressive hydroxyapatite formation reaction, we first conducted lab tests on silica sand columns that were saturated with solutions of calcium-citrate and sodium-phosphate. The NMR signal was monitored over 33 days using the Dart bore logging system (Vista Clara Inc). Next, we conducted similar monitoring experiments using core samples extracted from one representative monitoring well at Moab UMTRA. Due to the relatively small size of the samples, the samples were monitored for 29 days using benchtop NMR system (Helios, Vista Clara Inc). Finally, we have conducted initial bore logging NMR (Javelin, Vista Clara Inc) and evaluation of water content at several wells at Moab UMTRA.

Results/Lessons Learned. In silica sand columns, we have observed a significant amount of gas buildup during the first week of the experiment. The gas displaced some water in the pores leading to an elevated water layer above the sand. Not surprisingly, this process was associated with a decrease in total water content measured by NMR. As the experiment proceeded, two distinct water populations associated with long and short T2 distributions were detected in CPMG and Diffusion-CPMG experiments. When NMR experiments were conducted on Moab core samples, a significant decrease in water content and hydraulic conductivity were detected during 29 days in all samples. In these core samples, pronounced gas formation was also observed during the first week of the experiment along with visible, white hydroxyapatite precipitation within pores and coating sediment particle surfaces after two weeks. In parallel to hydroxyapatite precipitation, we have observed a formation of iron sulfide (FeS) minerals. This process is a by-product of microorganisms stimulated by the added citrate that leads to the co-generation of aqueous iron and sulfide resulting in the precipitation of FeS. Interestingly, decreases in water content and hydraulic conductivity was greater in core samples containing gravel and coarse sand (larger pores), than in samples containing silty sand and fine grain (smaller pores) potentially as a result of pore space occlusion in the fine-grained sediment by exceedingly narrow pore throats. Using these controlled lab experiments, we demonstrated the feasibility of NMR to monitor hydroxyapatite precipitation with a level of pore-scale detail not available from other in-situ and non-destructive methods. In May 2022, we have conducted initial NMR bore logging to evaluate the aquifer properties of wells installed at Moab UMTRA for injection of solutions of calcium-citrate and sodium-phosphate and monitoring of hydroxyapatite precipitation. High groundwater table and large fraction of mobile water were detected in most of the wells. We are planning to install several NMR sensors for continuous monitoring of hydroxyapatite precipitation at Moab UMTRA this fall.