POTENTIAL MICROBIAL EFFECTS ON NEAR-FIELD CHEMISTRY FOR ALTERNATIVE WASTE MANAGEMENT SCENARIOS

Jude McMurry

Center for Nuclear Waste Regulatory Analyses (CNWRA®), Southwest Research Institute, 6220 Culebra Rd., San Antonio, Texas 78238
Contact jmcmurry@swri.org

Existing assessments of disposal system performance have typically attributed low consequence to microbially influenced corrosion processes because the microbial population in deep geologic formations is generally expected to remain dormant due to constraints on the availability of nutrients. Also, the elevated temperatures and dryout zones that would be associated with spent nuclear fuel waste packages upon emplacement would tend to reduce or eliminate microbial effects in the vicinity of the waste packages for hundreds or thousands of years. However, alternative spent fuel management scenarios may have waste packages or disposal system designs with lower initial thermal outputs. For example, prolonged storage (e.g., 100 years or more) of high-level wastes prior to disposal may result in the emplacement of lower temperature waste packages and, consequently, a wet but warm near-field environment during the early postclosure period. These conditions could maintain or promote microbial activity in the vicinity of the waste packages, potentially providing a corrosion environment that differs from conditions that have been evaluated for existing repository performance assessments.

I. INTRODUCTION

An initial step in assessing a repository system is to identify and evaluate the importance of features, events, and processes that may affect the safety of the system over time.[1,2,3] An understanding of one repository system can be used to identify potential differences in the features, events, and processes for alternate high-level nuclear waste management scenarios. This paper focuses on a particular example, the effects of microbial activity on the near-field chemical environment, using a concept developed for a potential geologic repository at Yucca Mountain, Nevada, as the reference case for comparison.

In the United States, the siting process for a potential deep geologic repository for the nation's commercial used nuclear fuel was limited by federal legislation in 1987 to a single location, at Yucca Mountain in southern Nevada. Accordingly, the U.S. Department of Energy (DOE) focused site characterization and performance assessment activities on the Yucca Mountain area for more than 20 years.[4,5,6] The repository concept DOE developed differed from geologic repositories under consideration in other countries because the proposed Yucca Mountain repository would be located above the water table, in hydrologically unsaturated rock several hundred meters below the crest of the mountain. Waste containers would be placed in long, open drifts excavated in densely welded volcanic tuff. In DOE's nominal scenario for performance assessment, a combination of initially high temperatures from the waste packages and corrosion-resistant drip shields placed over the containers would protect the container surfaces from contact with groundwater seepage or condensation in the drifts, and the waste containers would remain intact, under relatively dry and oxidizing conditions, far into the future. The engineered barrier corrosion processes that were considered in DOE's performance evaluation included general corrosion, localized corrosion, and stress corrosion cracking.[7]

Potential alternate waste management strategies for the back end of the nuclear fuel cycle in the United States include long-term storage of used fuel, reprocessing, and implementation of other geologic settings or engineering designs for waste emplacement. Ultimately, some form of deep geologic disposal is still likely to be necessary to protect public health and safety into the distant future. However, each of these alternate waste management strategies could result in consideration of a different set of features, events, and processes for a deep geologic repository than those that were used to develop the Yucca Mountain reference case example. In particular, alternate disposal concepts could involve different geologic media or a different engineering design, and long-term storage or reprocessing could change the thermal properties of as-emplaced waste forms.

II. MICROBIAL ACTIVITY IN DEEP GEOLOGIC SETTINGS

Given that ambient populations of bacteria and other microbes have been detected in almost every terrestrial environment—in deep crystalline rocks and the ocean depths, beneath the polar ice caps, in fumaroles and hypersaline lakes—a list of features, events, and processes for virtually any alternate disposal concept would consider the presence and potential effects of microbes. Microbially influenced corrosion can occur by direct contact of microbes with the metal surface, as biofilms,[8] or indirectly, by microbial production of potentially corrosive chemical species, such as sulfides.[9] The scarcity of nutrients and slow processing of the available energy resources in deep geologic environments limit the activity of microbes, but the heterogeneity and resilience of lithotropic microbial communities attest to their adaptability to the resources that are available to them.[10]

In DOE's proposed repository for Yucca Mountain, DOE considered that microbial effects on radionuclide transport and on the corrosion of the engineered barrier materials would be of low consequence overall for several reasons.[1] First, compared to conditions in the biosphere, the geosphere's ambient microbial population was expected to be limited by the availability of nutrients in the subsurface. Second, the initially dry, hot conditions generated by the emplaced wastes were expected to create an environment that would sterilize or greatly diminish microbial activity in the repository drifts and near-field rocks, restricting the likelihood of microbially influenced corrosion of metals during the elevated thermal period. Third, the waste container and drip shield metals were selected to be corrosion resistant, including resistance to microbially influenced corrosion, under the expected repository conditions.[11,12]

Other countries evaluating deep geologic disposal of high-level radioactive wastes have characterized container corrosion processes and the effects of microbial activity in various deep geologic media and engineered barrier systems.[9,13,14,15,16] Repository designs that include the emplacement of a compacted buffer material, such as bentonite clay, as an engineered barrier potentially introduce another source of microbes into the repository environment. One function of the compacted bentonite surrounding the container is to limit access of bacteria or their byproducts to the container surface.[17,18,19] For example, heat from the waste packages is expected to dry out and sterilize the bentonite near the container. Expansion of the bentonite upon resaturation would tend to limit the repopulation of the clay by microbes and would slow the diffusion of corrosive chemical species from the geosphere to the container surface.

In alternate waste management strategies, both the reprocessing of used fuel and the prolonged storage of nuclear wastes would involve changes in the thermal properties of emplaced wastes. Repository temperatures are determined by a combination of repository design, including waste package spacing, and the properties of the waste package itself. With regard to microbial activity related to geologic disposal for these alternate strategies, the main effect for reprocessed waste forms could be an initially hotter or more extensive dryout zone in the engineered barrier system and surrounding rock, further inhibiting microbial activity in the near field compared to the reference case.

The prolonged storage of nuclear wastes prior to emplacement is a waste management alternative that has received increased attention in recent years.[20] At the eventual time of disposal, wastes that have been allowed to cool for decades or perhaps hundreds of years before emplacement are different because the cooler wastes may provide a lower thermal impact both spatially and temporally, which would result in a warm (not hot) and wetter near-field environment. If an initial dryout or sterilization zone did not develop in buffer material under those conditions, microbes potentially would have greater opportunity to affect the corrosion of engineered materials in the repository, particularly in a water-saturated geologic environment.

III. CONCLUSIONS

The simulation and evaluation of long-term performance in potential future disposal system designs may need to identify microbially influenced environmental conditions that could significantly affect the corrosion of engineered barriers important to waste isolation. An initial step in this process for a prospective geologic environment and disposal system design would be to compare the expected range of temperature-related corrosion rates for the engineered materials with the expected viability of microbes under the range of thermal conditions in a disposal system. Near-field environments that are not too hot to eliminate microbial activity but are still warm enough to support temperature-enhanced corrosion rates for the engineered barriers may need to be evaluated more carefully for potential risk. Further investigations may be necessary to characterize the expected microbial population of the near-field environment and to assess the likelihood that the microbes would significantly affect the corrosive conditions for engineered materials.

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