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IMPLEMENTATION OF LOCALIZED CORROSION IN THE PERFORMANCE ASSESSMENT MODEL FOR YUCCA MOUNTAIN

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A total system performance assessment (TSPA) model has been developed to analyze the ability of the natural and engineered barriers of the Yucca Mountain repository to isolate nuclear waste for the 10,000-year period following repository closure. The principal features of the engineered barrier system (EBS) are emplacement tunnels (or "drifts") containing a two-layer waste package (WP) for waste containment and a titanium drip shield to protect the waste package from seeping water and falling rock. The 20-mm-thick outer shell of the WP is composed of Alloy 22, a highly corrosion-resistant nickel-based alloy, while the 50-mm inner shell is composed of 316 stainless steel (modified with lower carbon and nitrogen compositions), whose primary purpose is to provide structural strength. The barrier function of the EBS is to isolate the waste from the migrating water with its associated chemical conditions that eventually lead to degradation of the waste packages and mobilization of the radionuclides within the packages.

Waste package degradation must be analyzed in response to heat, humidity, seepage, geochemical environment, and moisture changes in the EBS, which can induce five possible degradation modes of the Alloy 22: general corrosion, microbially influenced corrosion, stress corrosion cracking, early failure due to manufacturing defects, and localized corrosion (LC). This paper specifically examines the incorporation of the Alloy-22 localized corrosion model into the Yucca Mountain TSPA model, particularly the abstraction and modeling methodology, as well as issues dealing with scaling, spatial variability, uncertainty, and coupling to other models that are part of the total system model.

Modeling of the localized corrosion degradation process requires characterization of the flow rate and chemistry of the water seeping into the emplacement drifts. Decay heat from the radioactive waste forms will heat the water to temperatures above boiling for close to 1000 years after repository closure. When the water eventually condenses and drips onto the waste packages, there is a potential to cause localized corrosion depending on the chemistry of the heated water, for example, depending on its pH and the concentration of chloride ions (which is a corrosive ion to most metals). The epistemic uncertainty and spatial variability in these environmental parameters must be modeled within the TSPA to give a reasonable representation of the expected evolution of the EBS. The integrated performance assessment is complicated by the uncertainties that arise from the combination of the random nature of some events, incomplete understanding of the underlying processes, and limited data and information. The uncertainties include model uncertainty, parameter uncertainty, including uncertainty in parameter variability, and uncertainty in future events. These are accounted for in the LC initiation model with probabilistic Monte Carlo simulations based on the results of multiple realizations of the probability distributions representing these various forms of uncertainty and variability in key model parameters.

Localized corrosion (like general corrosion) requires the presence of a liquid water film on the waste package surface to initiate and propagate. The dominant form of localized corrosion is assumed to be crevice corrosion, which may occur under a variety of conditions potentially conducive to forming tight crevices, such as (1) mineral deposits on the Alloy 22 surface due to evaporation of the seeping water, (2) contact areas between fallen rock and the Alloy 22 waste package outer surface, and (3) contact areas between the emplacement pallet on which the package rests and the Alloy 22 outer surface. The chemical environment in a creviced region may be more severe than the near field environment due to hydrolysis of dissolved metals in the creviced region. Exposure condition parameters important to corrosion are the temperature and composition of the solution contacting the metal, which include hydrogen ions (pH), halide ions (e.g., chloride ions), and corrosion-inhibiting ions (e.g., nitrate, carbonate, and sulfate ions). Empirical correlations were developed to parameterize the localized corrosion initiation model based on experimental measurements of the long-term corrosion potential (E_{corr}) and the crevice repassivation potential (E_{rcrev}), expressed as functions of temperature, pH, chloride ion concentration, and nitrate ion concentration [1]. In general, localized corrosion of the waste package outer barrier occurs when E_{corr} is equal to or greater than E_{rcrev}.

The TSPA model implementation of LC is done in two sequential parts: (1) the LC initiation analysis that evaluates the chemical conditions for LC initiation on the WP outer surface and (2) the LC submodel within the overall TSPA model, which calculates WP failure histories based on the chemistry evaluation from the LC initiation Analysis. The first part, the LC initiation analysis, includes two computational loops: an outer epistemic uncertainty loop, and an inner spatial variability loop. In the outer loop, Monte Carlo sampling is performed on approximately 24 uncertain parameter distributions, including the LC initiation model regression coefficients, the chemical environment parameters on the WP outer surface (i.e., pH, nitrate concentration, chloride concentration), seepage water flux, and the thermal conductivity of the rubble backfill caused by a seismic event. The inner or spatial variability loop is based on a highly discretized thermal-hydrology model, which divides the repository into thousands of equal-area subdomains and calculates the temperature and relative humidity time histories for several waste packages with different heat outputs within each subdomain, including both hot commercial spent nuclear fuel (CSNF) waste packages and cooler co-disposal waste packages (which contain both defense high-level waste glass and defense spent nuclear fuel). The output of these two loops is a series of time histories that identify the times at which the chemical environment is favorable to localized corrosion for the sampled values of epistemic uncertainty and the particular waste-package temperature and relative humidity.

In the TSPA model the output generated from the LC initiation analysis is used in the LC submodel to determine the number of packages that will experience localized corrosion, based on the timing of a seismic event or other condition that can fail the drip shield and expose the waste package to seeping water. The coupling of the LC submodel within the TSPA model is a complex implementation because of the numerous processes involved, including seepage, thermal-hydrology, thermal-hydrology-chemistry (THC), seismic, drift-degradation, and general corrosion processes.

Based on the current repository design and the evolution of THC processes in the natural barriers, preliminary analyses show a low probability of localized corrosion having a significant impact on EBS performance. For example, the presence of a thermal barrier during the initial years, when the temperature is high, and the presence of the drip shields prevent seepage water from contacting the waste packages, thereby limiting waste package degradation due to localized corrosion. The integrity of the drip shield has a very low probability of being compromised during a fault displacement event (an annual frequency of occurrence of 2×10^{-7} per year or less) but if this does happen it can lead to seepage water contacting waste packages, which can lead to localized corrosion if the WP temperature is above a critical temperature and the composition of the seepage water contacting the waste packages is sufficiently corrosive (i.e. the seepage water contacting the metal contains a high chloride ion concentration and low concentrations of corrosion-inhibiting ions, e.g., nitrate ions).

References:

1. Mon, Kevin G., et. al. "General Corrosion and Localized Corrosion of Waste Package Outer Barrier", DOC.20041004.0001, ANL-EBS-MD-000003 REV 02.