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Uncertainty and sensitivity analysis for the igneous scenario classes in the 2008 performance assessment for the proposed high-level radioactive waste repository at Yucca Mountain, Nevada

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ABSTRACT

Extensive work has been carried out by the U.S. Department of Energy (DOE) in the development of a proposed geologic repository at Yucca Mountain (YM), Nevada, for the disposal of high-level radioactive waste. In support of this development and an associated license application to the U.S. Nuclear Regulatory Commission (NRC), the DOE completed an extensive performance assessment (PA) for the proposed YM repository in 2008. This presentation describes uncertainty and sensitivity analysis results for the igneous intrusive scenario class and the igneous eruptive scenario class obtained in the 2008 YM PA. The following topics are addressed for the igneous intrusive scenario class: (i) engineered barrier system conditions, (ii) release results for the engineered barrier system, unsaturated zone, and saturated zone, (iii) dose to the reasonably maximally exposed individual (RMEI) specified in the NRC regulations for the YM repository, and (iv) expected dose to the RMEI. In addition, expected dose to the RMEI for the igneous eruptive scenario class is also considered. The present article is part of a special issue of *Reliability Engineering and System Safety* devoted to the 2008 YM PA; additional articles in the issue describe other aspects of the 2008 YM PA.

1. Introduction

Uncertainty and sensitivity analysis are fundamental components of the 2008 performance assessment (PA) conducted by the U.S. Department of Energy (DOE) for the proposed high-level radioactive waste (HLW) repository at Yucca Mountain (YM), Nevada [1,2]. The following presentation describes uncertainty and sensitivity analysis results obtained for the igneous scenario classes [3] in the 2008 YM PA. Additional presentations describe uncertainty and sensitivity analysis results obtained in the 2008 YM PA for the nominal scenario class [4,5], early failure scenario classes [6,7], seismic scenario classes [8,9], and all scenario classes collectively [10].

The uncertainty and sensitivity techniques in use are described in Section 2 of Ref. [5] and involve the use of Latin hypercube sampling, partial rank correlation coefficients (PRCCs) and stepwise rank regression. The presented uncertainty and sensitivity analysis results are obtained with the first of the three replicated Latin hypercube samples (LHSs) described in Sections 11 and 12 of Ref. [2]. This is the same LHS used in the generation of the expected dose results for the igneous scenario classes [3] and also in the generation of results for the other scenario classes under consideration [4–9]. Descriptions of the epistemically uncertain analysis inputs under consideration and references to additional sources of information on these variables are given in Appendix B of Ref. [2]. Further, additional information on the uncertainty and sensitivity techniques in use is available in several reviews [11–14].

The following topics are considered in this presentation for the igneous intrusive scenario class: engineered barrier system (EBS) conditions (Section 2), release from the EBS (Section 3),

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release from the unsaturated zone (UZ) (Section 4), release from the saturated zone (SZ) (Section 5), dose to the reasonably maximally exposed individual (RMEI) (Section 6), and expected dose to the RMEI (Section 7). The movement of three radionuclides (^{239}Pu, ^{237}Np and ^{99}Tc) is described. These radionuclides are broadly representative of the range of radionuclide solubilities, sorption properties and interaction with colloids for all radionuclides considered in the 2008 YM PA; thus, examining results for these three radionuclides provides insights into transport processes. In addition, expected dose to the RMEI for the igneous eruptive scenario class is also considered (Section 8). The presentation then ends with a summary discussion (Section 9).

The primary focus of this presentation is on uncertainty and sensitivity analysis results obtained for the igneous intrusive and igneous eruptive scenario classes. Summary descriptions of the models that underlie these results are given in Ref. [15] and in Section 6 of Ref. [1], and more detailed descriptions are available in the reports cited in Refs. [1,15] and in Appendix B of Ref. [2]. Further, an extensive description of the development process that led to these models is given in Refs. [16–25].

2. Engineered barrier system (EBS) conditions

The EBS comprises the waste disposal drifts, drip shields (DSs), waste packages (WPs), and waste forms (WFs) ([1], Fig. ES-19). This section discusses conditions in the EBS subsequent to an igneous intrusive event that occurs at 250 yr after repository closure and is assumed to damage all WPs in the repository. A summary of the underlying physical models is presented in Ref. [15]; in particular, Section 5 of Ref. [15] describes modifications to the physical models specific to the igneous scenario classes. The indicated intrusion corresponds to a potential basaltic dike intersecting the repository without a surface eruption within the repository boundary ([15], Section 5). After the intrusion, repository conditions are affected by heat from cooling magma, alteration of EBS features, and changes in water chemistry due to reactions with cooled basalt. The flow characteristics of the intruding magma are assumed to be such that magma fills every drift within the repository. As a consequence, all WPs and DSs are assumed to be damaged to the extent that they no longer have water diversion or waste isolation capability. The WPs (including both outer barriers and inner vessel; see [15], Section 2) and the WFs (commercial spent nuclear fuel (CSNF), DOE and naval spent nuclear fuel (DSNF), and HLW; see [15], Section 3.11) are assumed to rapidly and completely degrade subsequent to the event. Because an intruded drift fills with magma within 15 to 25 minutes depending on the width of the dike ([26], Section 6.3.3.5.6), the igneous event is treated as instantaneous in the timescale of the PA model. The magma then cools and solidifies in the emplacement drifts. Radionuclides dissolved in groundwater moving through the basalt will be transported by downward through the waste disposal drifts, and then through the unsaturated and saturated zones to the accessible environment in the same manner as for the nominal scenario class [5]. However, because the drift opening is filled with magma, water flow through the drift is altered from the nominal case. In particular, no capillary barrier is assumed to divert water around the drift openings ([1], Section 6.5.1.1). Similar conditions are assumed to exist after potential igneous intrusive events at other times.

The igneous intrusion model assumes an initial temperature of the intrusive body of 1150 °C, and uses a cylindrical one-dimensional, transient heat conduction model to describe the cooling of the intrusive body and the surrounding rock mass ([26], Section 6.4.1.1). The effects of latent heat were considered and were found to have no impact on the results ([26], Section 7.3.2.1.1.2). Repository temperatures return to ambient conditions (i.e., temperatures prior to the event, which are controlled by heating from radioactive decay) after approximately 100 yr ([1], Table 6.5-1). Consistent with this, time histories of temperatures in the drift are essentially the same as those for the nominal scenario class ([5], Fig. 13; [1], Fig. K6.2-1). Similarly, the relative humidity conditions and the partial pressures for CO_2 in the EBS are assumed to revert to nominal conditions consistent with heating from radioactive decay at the same time that temperature returns to conditions consistent with heating from radioactive decay. As a result, the relative humidity conditions and the partial pressures for CO_2 in the EBS are the same as those for nominal conditions ([5], Figs. 14 and 15).

As indicated above, the drifts are assumed to be filled with basalt after an igneous intrusion. Further, the resultant basalt is assumed to have hydrologic properties similar to the host rock that surrounds the drifts. Consistent with this assumption, seepage into the EBS (m^3/yr/WP) is determined by multiplying the percolation rate (m^3/m^2/yr) at the base of the Paintbrush nonwelded tuff (an overlying rock formation) by the footprint area (m^2/WP) of the drift segment containing one WP ([1], Section 6.5.1.1). Seepage rates for percolation bins 1 and 5 (i.e., subregions; see [5], Fig. 2) are shown in Fig. 1; the seepage rates for bins 2, 3 and 4 fall between the seepage rates for bins 1 and 5 ([1], Fig. K6.2-2). To facilitate comparison with results for the nominal scenario class, WPs remain partitioned into the percolation bins after the intrusion, and within a percolation bin, all WPs experience the same

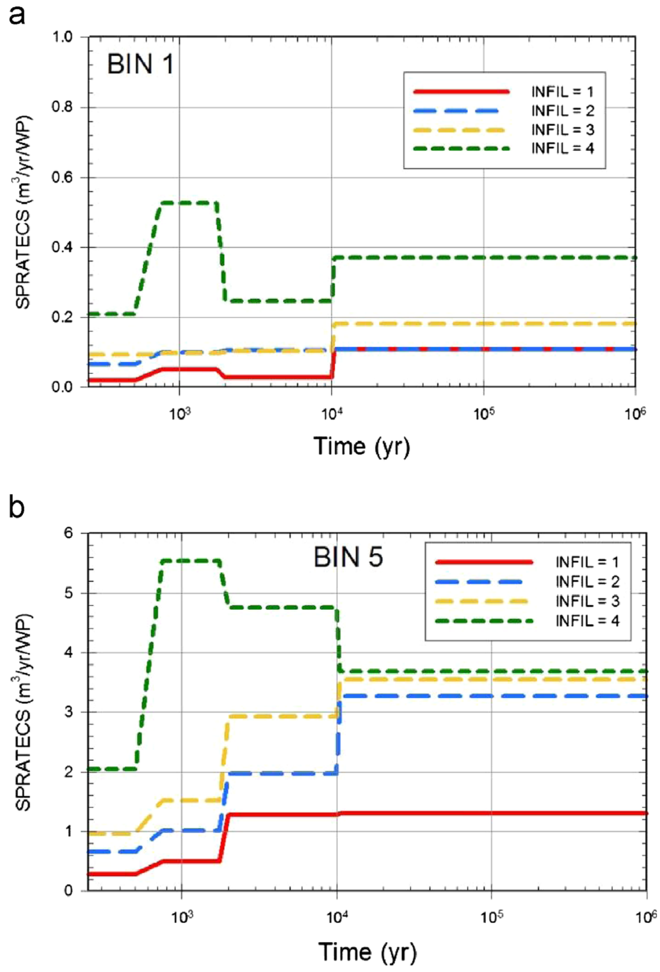

Fig. 1. Time-dependent seepage rates (m^3/yr/WP) into the repository above CSNF WPs (*SPRATECS*) resulting from an igneous intrusive event at 250 yr that destroys all WPs in the repository: (a) Bin 1, and (b) Bin 5 ([1], Fig. K6.2-2).