SUPPLEMENTAL PERFORMANCE ANALYSES FOR IGNEOUS ACTIVITY AND HUMAN INTRUSION AT THE POTENTIAL HIGH-LEVEL NUCLEAR WASTE REPOSITORY AT YUCCA MOUNTAIN

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ABSTRACT

The U.S. Department of Energy (DOE) is considering the possible recommendation of a site at Yucca Mountain, Nevada, for the potential development of a geologic repository for the disposal of high-level radioactive waste and spent nuclear fuel. Consequences of hypothetical disruption of the Yucca Mountain site by igneous activity or human intrusion have been evaluated in the *Yucca Mountain Science and Engineering Report* (S&ER) (1), which presents technical information supporting the consideration of the possible site recommendation. Since completion of the S&ER, supplemental analyses have examined possible impacts of new information and alternative assumptions on the estimates of the consequences of these events. Specifically, analyses of the consequences of igneous disruption address uncertainty regarding: 1) the impacts of changes in the repository footprint and waste package spacing on the probability of disruption; 2) impacts of alternative assumptions about the appropriate distribution of future wind speeds to use in the analysis; 3) effects of alternative assumptions about waste particle sizes; and 4) alternative assumptions about the number of waste packages damaged by igneous intrusion; and 5) alternative assumptions about the exposure pathways and the biosphere dose conversion factors used in the analysis. Additional supplemental analyses, supporting the Final Environmental Impact Statement (FEIS), have examined the results for both igneous disruption and human intrusion, recalculated for a receptor group located 18 kilometers (km) from the repository (the location specified in 40 CFR 197), rather than at the 20 km distance used in the S&ER analyses.

INTRODUCTION

In May 2001, the DOE released the S&ER (1). This report provided a technical summary of scientific and engineering information supporting the possible recommendation of a site at Yucca Mountain, Nevada for the potential development of a geologic repository for the disposal of high-level radioactive waste and spent nuclear fuel. Included in the information contained in this report was a summary of analyses of the consequences of hypothetical disruptions at the site by igneous activity and human intrusion, as documented in the *Total System Performance Assessment for the Site Recommendation* (TSPA-SR) (2). Additional analyses of the possible consequences of these events have been conducted since completion of the S&ER to examine impacts of new information, including alternative modeling assumptions and modifications in regulatory requirements dictated by the promulgation of final U.S. Environmental Protection Agency (EPA) and U.S. Nuclear Regulatory Commission (NRC) standards for Yucca Mountain. These supplemental analyses are summarized in this paper, and are documented in the *FY01 Supplemental Science and Performance Analysis* (SSPA) report (3,4) and a subsequent letter report supporting the FEIS (5). The supplemental analyses include examination of both a high-temperature operating mode (HTOM) that is similar to the TSPA-SR base case operating mode, and an alternative low-temperature operating mode (LTOM).

SUPPLEMENTAL ANALYSES OF IGNEOUS DISRUPTION

The TSPA-SR model for igneous disruption (2, Section 3.10.2) calculates the combined doses from eruptions that entrain waste in volcanic ash (direct eruptive pathway) and from igneous intrusions that damage waste packages and allow releases of radionuclides into groundwater (indirect groundwater pathway). As described in SSPA Volume 1 (3, Section 13.4), the biosphere dose conversion factors (BDCFs) for eruptive and groundwater pathways were modified to account for new information developed since completion of the TSPA-SR (2). Impacts of these changes on the BDCFs used for the igneous intrusion groundwater pathway are slight. Changes in the volcanic eruptive pathway BDCFs, however, are more extensive and result in a shift of emphasis from ingestion to inhalation as the main contributor to dose from contaminated ash following an eruption. Modifications to the eruptive BDCFs increase the probability-weighted annual dose by a factor of approximately 2.5.

Several other input parameters to the TSPA-SR models used to calculate the effects of igneous disruption were changed (3, Section 14.3.3.7). Consistent with a re-interpretation of available information regarding the probability of an eruption at the location of the potential repository given an igneous intrusive event, the conditional probability of an eruption at the potential repository was revised from 0.36 (2, Table 3.10-4) to 0.77. Changes also were made in the probability distribution for an intrusive event, consistent with revisions in the potential repository footprint since inputs were compiled for TSPA-SR. New distributions were provided for the number of waste packages affected by eruptive and intrusive events, consistent with the new event probabilities. Changes were made in the input data used to determine the wind speed during an eruption, consistent with the consideration of wind speed data collected from the Desert Rock Airstrip (approximately 40 km southeast of Yucca Mountain) between 1978 and 1995 (6). Additional changes in inputs to the TSPA-SR igneous consequence model are listed in SSPA Volume 1 (3, Section 14.3.3.7, Tables 14.3.3.7-1 and 14.3.3.7-2). Other model inputs and assumptions, including the assumption that wind direction is fixed toward the location of the receptor at all times, are the same as those used in the TSPA-SR (2, Section 3.10).

One-Hundred-Thousand-Year Dose Histories for Igneous Disruption

Figure 1 shows the probability-weighted mean annual dose for igneous disruption (i.e., the combined dose from the eruptive and groundwater pathways) for the supplemental TSPA model for both the HTOM and LTOM cases considered in the SSPA. The 100,000-year supplemental analyses use 5,000 realizations for each case, and are compared to the 5,000-realization, 50,000-year base-case from the TSPA-SR (2, Figure 4.2-1).

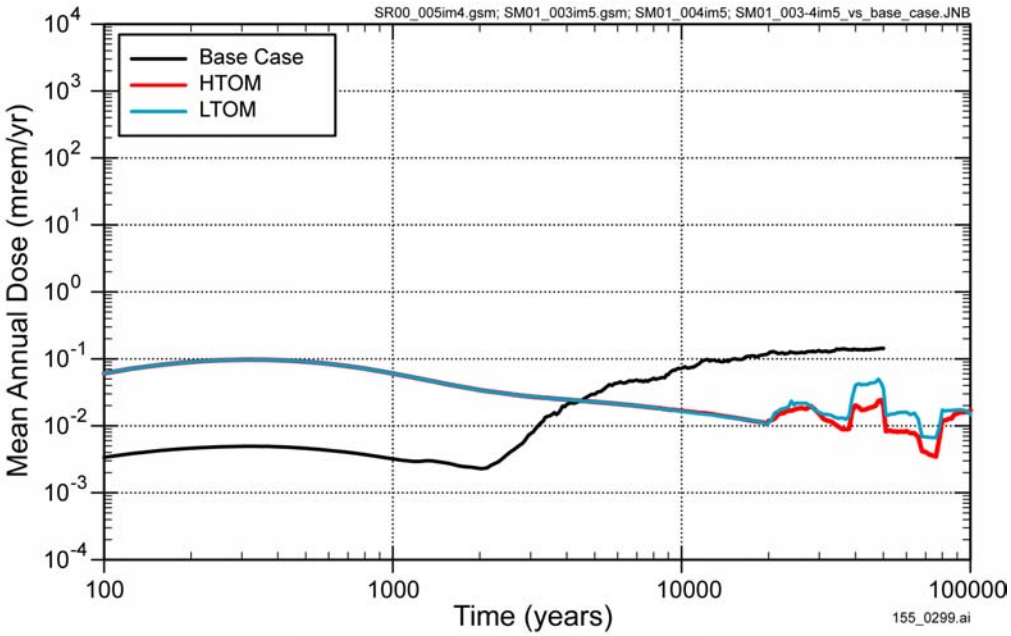

Fig. 1. Probability-Weighted Mean Annual Dose for Igneous Disruption from TSPA-SR (Base Case), Supplemental TSPA Model High-Temperature Operating Mode (HTOM), and Supplemental TSPA Model Low-Temperature Operating Mode (LTOM)

The probability-weighted annual doses for igneous disruption for the supplemental TSPA model HTOM and LTOM cases are similar to each other, but are significantly different from the TSPA-SR base case model results, as shown in Figure 1. Eruptive doses, which dominated in the TSPA-SR base case for only approximately the first 2,000 years, are now the main contributor to both HTOM and LTOM annual dose for more than 10,000 years. Peak mean annual eruptive dose still occurs approximately 300 years after closure, but it is increased by a factor of approximately 25, to approximately 0.1 millirem per year (mrem/yr). Doses from groundwater transport following igneous intrusion are decreased (generally by a factor of 5 or more), and the peak mean intrusive dose (which occurs in the LTOM case between 40,000 and 50,000 years) is approximately 0.05 mrem/yr (for the LTOM case), roughly one-quarter of the comparable peak mean dose in the TSPA-SR. The time of the peak mean annual igneous dose corresponds to the onset of the first full glacial climate at 38,000 years.

The largest single contributor to the 25-fold increase in the probability-weighted mean eruptive dose comes from changes in BDCFs (a factor of approximately 2.5). Other major factors are the change in wind speed (a factor of approximately 2) and the increase in the conditional probability of an eruption at the location of the potential repository (a factor of approximately 2, from 0.36 to 0.77). An increase in the total number of eruptive conduits possible within the potential repository (from 5 to 13) accounts for most of the remainder of the change (parameter values from (2, Table 3.10-4) and (3, Table 14.3.3.7-1)).

Decreases in the probability-weighted annual dose due to igneous intrusion are due to changes in the nominal performance models for radionuclide mobilization and transport. The distributions used to characterize uncertainty in the number of waste packages affected by igneous intrusion were modified, resulting in a larger number of packages damaged for the supplemental analyses (3, Section 14.3.3.7 and Table 14.3.3.7-2). This increase, however, is more than offset by decreases in radionuclide mobilization and transport (7, Section 3.2.7).

As modeled, thermal operating conditions have no effect on the eruptive doses, and the curves for the HTOM and LTOM cases overlie each other until groundwater pathway releases cause minor divergence beginning at about 10,000 years. Differences between LTOM and HTOM performance in the igneous scenario class are negligible until after 20,000 years, when mean annual LTOM doses become up to a factor of 3 greater than HTOM doses (Figure 1). However, the probability of igneous disruption is assumed to be the same for the supplemental LTOM and HTOM cases in these analyses. Increasing the area of the potential repository, as has been proposed for LTOM designs, will proportionally increase the probability of igneous disruption, and associated changes in drift and waste package spacing could affect the number of packages damaged by igneous disruption. Analysis of a LTOM design that increases the length of the potential repository by 3,300 meters (m) shows a 70 percent increase in the probability of igneous intrusion and eruption at the potential repository (3, Section 14.3.3.2.2). Adjusting the probability of igneous disruption for the LTOM case would result in a corresponding increase of 70 percent in the probability-weighted annual dose. Conversely, increasing waste package spacing causes a proportional reduction in the number of packages damaged (3, Section 14.3.3.2.3). Neither correction has been made, and all supplemental LTOM and HTOM results shown here are calculated assuming the same potential repository footprint and emplacement geometry.

An additional supplemental analysis examined the effect of moving the receptor location from 20 km to 18 km as dictated by the final EPA standards at 40 CFR 197. Figure 2, from the FEIS, shows the probability-weighted mean annual dose (from 5,000 realizations) for igneous disruption for the HTOM and LTOM cases, with a receptor located at 18 km (5, Figure 6-10c) and compares them to the TSPA-SR base case that was previously shown in Figure 1.

While there are minor differences between the FEIS model and the SSPA model, the probability-weighted mean annual dose from the FEIS model for igneous disruption (Figure 2) is nearly identical to the probability-weighted mean annual dose from the SSPA model (Figure 1) for both the HTOM and LTOM cases. These results indicate that the effect of moving the receptor location from 20 km to 18 km has a negligible effect on mean annual dose for igneous disruption.

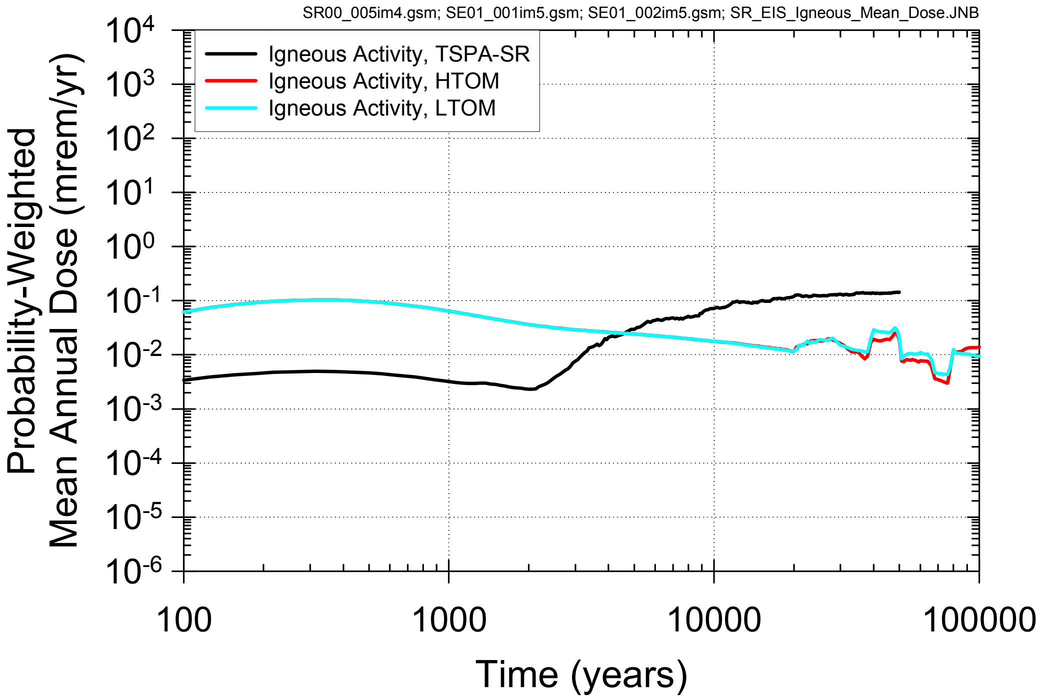

Fig. 2. Probability-Weighted Mean Annual Dose for Igneous Disruption from TSPA-SR (Base Case), FEIS High-Temperature Operating Mode (HTOM), and FEIS Model Low-Temperature Operating Mode (LTOM)

Individual Radionuclides Contributing to Total Probability-Weighted Dose, Igneous Disruption

Figure 3 shows the major radionuclides contributing to the total probability-weighted mean annual dose for the HTOM supplemental analyses. LTOM and TSPA-SR base case results are not shown because of their similarity to HTOM results. Major contributors for eruptive doses are similar for all three cases, and total doses are dominated by americium-241, plutonium-240, plutonium-239, and plutonium-238. At later times, intrusive doses are dominated by plutonium-239 in all three cases. Neptunium-237 is a less important contributor in the supplemental TSPA analyses than in TSPA-SR, primarily due to a decrease in the mean solubility limit of this species in the nominal scenario class (4, Section 3.2.7).

SUPPLEMENTAL ANALYSES OF HUMAN INTRUSION

The TSPA-SR model for human intrusion (2, Section 4.4) calculates the dose at the receptor location resulting from the penetration of a single waste package by drilling and the subsequent radionuclide mobilization and transport through a groundwater pathway. As described in the letter report supporting the FEIS (5, Section 5.2.7), the following modifications were made to the human intrusion model to account for new information developed since completion of the TSPA-SR (2): 1) errata associated with the treatment of radioactive decay and ingrowth during transport through the saturated zone were corrected (7, Section 6.3.4.1, p. 233); 2) the penetrated waste package was placed randomly in one of several dripping environments depending on the infiltration condition; and 3) colloidal-facilitated transport through the unsaturated zone has been included. The net impact of these changes is to reduce the mean annual dose by a factor of between 2 and 5.

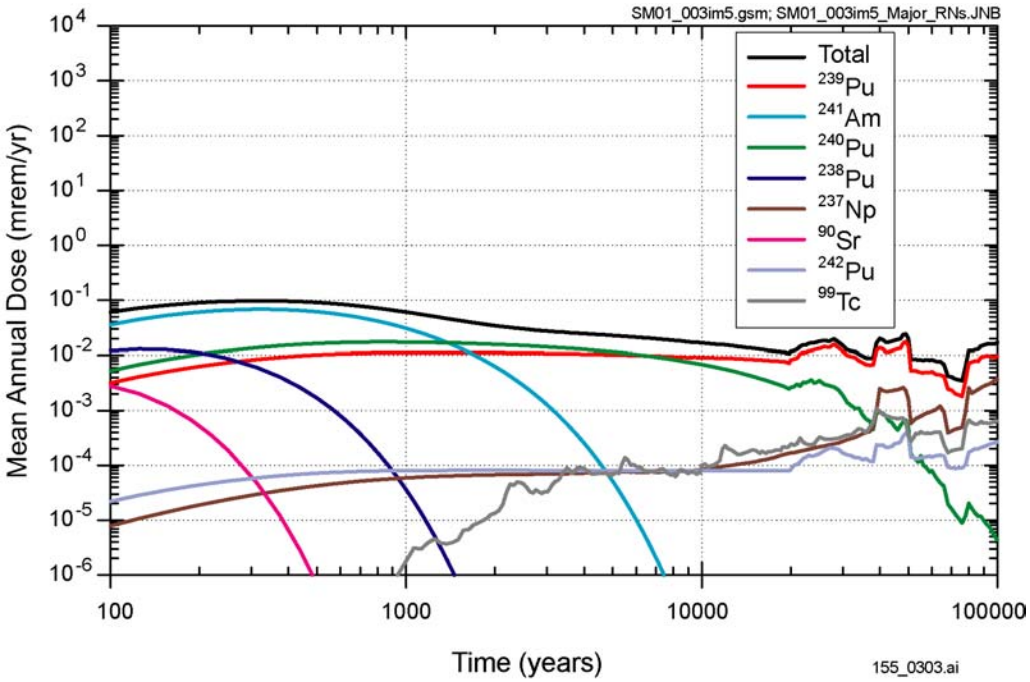

Fig. 3. Probability-Weighted Mean Annual Dose Histories for Radionuclides Contributing to the Total Probability-Weighted Mean Annual Dose for Igneous Disruption from the Supplemental TSPA HTOM Model

Figure 4 displays the probability-weighted mean annual dose (from 300 probabilistic simulations) for a human-intrusion where waste package penetration by drilling occurs 100 years after repository closure from the TSPA-SR (2, Figure 4.4-11) and from the FEIS HTOM case (5, Figure 6-13).

Comparison with the mean annual dose from the TSPA-SR model for human intrusion at 100 years indicates that the mean annual dose from the FEIS HTOM model is lower by about a factor of 2 at 1000 years, a factor of 5 at 10,000 years, and a factor of 5 to 10 at 100,000 years. These lower doses are attributable to the changes for FEIS noted above and also to the decrease in the mean solubility limit of Neptunium-237 (4, Section 3.2.7), which impacts doses after about 10,000 years. As in the igneous disruption analyses discussed earlier, the model changes between TSPA-SR and the FEIS have had some impact on the mean annual dose for human intrusion, but the effect of moving the receptor location from 20 km to 18 km has not had a significant effect on mean annual dose.

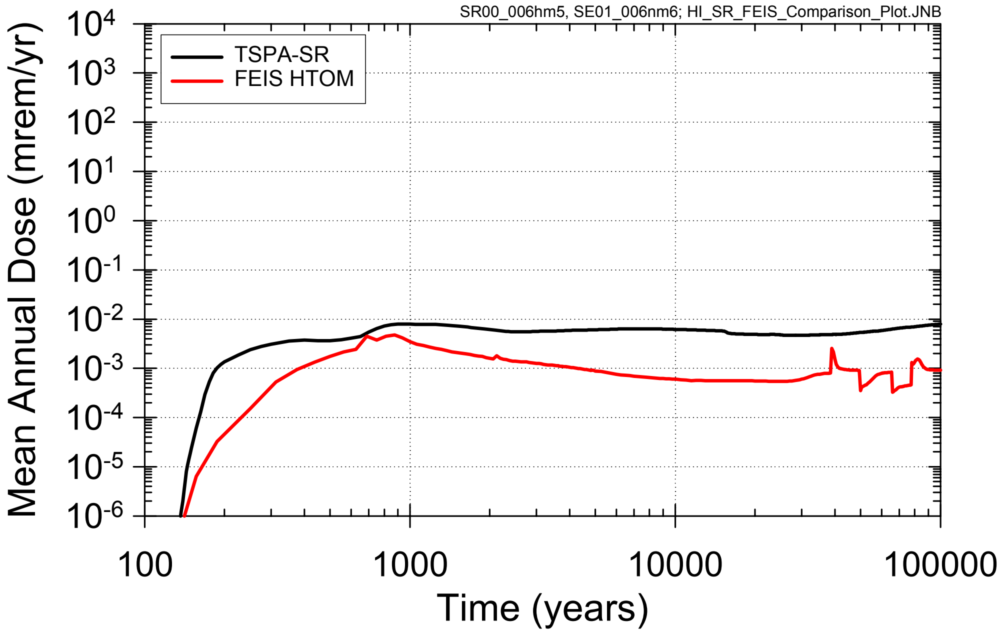

Fig. 4. Probability-Weighted Mean Annual Dose for a Human Intrusion 100 Years After Repository Closure from TSPA-SR and FEIS High-Temperature Operating Mode (HTOM) Models

CONCLUSIONS

Figure 1 compares the igneous disruption probability-weighted mean annual dose results for the supplemental TSPA analyses with those of the TSPA-SR. Overall, the peak probability-weighted mean annual dose during the first 100,000 years is lower by a factor of approximately 2 for the supplemental TSPA analyses than for the TSPA-SR. However, changes in several key input parameters have raised the annual dose during the first several thousand years by a factor of up to 25, and the peak mean annual dose of approximately 0.1 mrem/yr now occurs before 10,000 years. This increase is due to modifications in the input parameters for the volcanic eruption model, consistent with new scientific information developed since the completion of the TSPA-SR. Annual doses at later times are lower for the supplemental TSPA model. These analyses do not include the effects of possible changes in the area of the potential repository or waste emplacement geometry associated with alternative low-temperature operating modes that could increase the length of the potential repository, increase the probability of igneous disruption, and correspondingly increase the probability-weighted annual dose from igneous disruption by 70 percent.

Figure 4 compares the human intrusion mean annual dose results for the supplemental FEIS analyses with those of TSPA-SR. The peak mean annual dose during the first 100,000 years is lower by a factor of approximately 2 for the supplemental FEIS analyses than for the TSPA-SR, due to modifications in the human intrusion model consistent with new scientific information developed since the completion of the TSPA-SR.

For both igneous disruption and human intrusion, the effect on mean annual dose of moving the receptor location from 20 km to 18 km for the FEIS analyses was negligible.

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