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U.S. Nuclear Regulatory Commission
ATTN: Ms. Deborah A. DeMarco
Office of Nuclear Materials Safety and Safeguards
Program Management, Policy Development and Analysis Staff
Office of the Director
Mail Stop T8-A23
Washington, DC 20555

Subject: Transmittal of Abstract for 2001 International High-Level Radioactive Waste Management Conference

Dear Ms. DeMarco:

The purpose of this letter is to transmit for your programmatic review an abstract proposed for presentation at the 2001 International High-Level Radioactive Waste Management Conference to be held in Las Vegas, NV from April 29–May 3, 2001. The abstract by Mohanty, Codell, and Wittmeyer is entitled "Use of Sensitivity Analysis Methods for Identifying Key Technical Issues in Repository Performance." This abstract has already been submitted to the American Nuclear Society for review by the organizing committee; however, official notice of acceptance/rejection will not be provided to the authors until December 12, 2000. If this abstract is found to be programmatically unacceptable, it will be withdrawn from the conference. If you have any questions regarding the technical content of the report please contact Dr. Mohanty at (210) 522-5185.

Sincerely yours,

Budhi Sagar, Ph.D.
Technical Director

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Use of Sensitivity Analysis Methods for Identifying Key Technical Issues in Repository Performance

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INTRODUCTION

To review and quantitatively evaluate the safety case in a potential license application by the U.S. Department of Energy (DOE) for the proposed Yucca Mountain (YM) repository, the Nuclear Regulatory Commission (NRC) with technical assistance from the Center for Nuclear Waste Regulatory Analyses (CNWRA) have developed a Total-system Performance Assessment (TPA) Code (Mohanty and McCartin, 1998). NRC will use the TPA code to focus on those physical aspects of the repository system that are significant to radiological safety. The results from analysis will, in part, be used to focus and direct the review strategy outlined by NRC in its Yucca Mountain Review Plan (YMRP).

The TPA code embodies several conceptual models implemented as abstracted mathematical models. These conceptual models, which describe physical and chemical processes believed to be operative in the proposed repository, can be grouped in the following categories: (1) Infiltration and deep percolation; (2) Near-field environment; (3) Radionuclide releases from the engineered barrier system (EBS); (4) Aqueous-phase radionuclide transport (RT) through the unsaturated and saturated zones; (5) Airborne transport from direct radionuclide releases; and (6) Exposure of critical group to radionuclides. While these conceptual models contained in the TPA Version 3.2 code pertain to a specific DOE repository design and specific site characteristics, yet the code is designed to provide flexibility for examining alternative designs, effects of uncertainties in site and engineered material performance, alternative conceptual models, and the consequences of disruptive events (e.g., seismicity, fault displacement, and igneous activity).

We present an overview of the NRC's system-level sensitivity analyses for determining influential parameters and the effect of model uncertainties. Results of such analyses were used to identify the most important issues related to acceptance and licensing of this site.

WORK DESCRIPTION

The analyses used TPA Version 3.2, and a waste package (WP) design using an inner corrosion-resistant layer of nickel-based alloy 22 as presented in the DOE Viability Assessment[1] (DOE, 1998). Other stipulations about the base case were (1) no backfilling of the repository drifts, (2) no matrix diffusion, (3) no credit for cladding of fuel, (4) uniform-distribution of infiltrating water reaching the WPs, and (5) water accumulation in the WP (i.e, formation of a bathtub) for fuel wetting. These basecase analyses considered seismically induced rock fall and climate change, but not the effects of fault displacement or igneous activity on repository performance. Separate analyses were conducted for the faulting and igneous activity disruptive scenarios. Alternative conceptual models considered in this study

[1]DOE's new design (i.e., EDA II) has been incorporated in the TPA Version 4.0 code.

were (1) matrix diffusion in SZ; (2) credit for cladding; (3) focusing of flow to a smaller number of WPs; (4) flowthrough model with no pooling of water in the WP; (5) flowthrough model, but with faster fuel dissolution; (6) release rate based on a natural analog to spent fuel (SF); (7) release based on the solubility of the uranium mineral schoepite; (8) release based on a fuel grain size rather than particle size; and (9) no retardation of Pu, Th and Am.

Seven different sensitivity analyses methods were used to determine the most sensitive parameters; (1) regression on raw variables, (2) regression with log-normalized variables, (3) differential analysis, (4) the Morris method (Morris, 1991) , (5) FAST method (Cukier et al., 1973, Lu and Mohanty, 2000), (6) t-test on means, and (7) the parameter tree method (Jarzemba and Sagar, 2000). The seven methods have different approaches to determining sensitivity. For example, log-transformed variables often provided a better regression fit than untransformed variables, but distorted the results by placing greater emphasis on smaller doses than regression with untransformed variables. Also, the t-test on means emphasized relatively high doses. It is not clear that any one of the seven methods is superior to another for determining sensitivity. Consequently, we selected the final list of important parameters on the basis of the number of times the parameter appeared in the highest rankings using different methods.

Regression analyses were performed on a 1000-vector basecase run for 10 and 50 kyr time periods of interest (TPIs). The selected parameters are presented in tables 1 and 2. For example, a score of 6/6 for the subarea wet fraction parameter (SbArWt%) implies that the parameter ranked among the top ten (five for the parameter tree method) in six out of six methods. Also note that among the sensitivity analysis methods, there are two statistical methods (regression with normalized variables, regression with log-normalized variables) and three non-statistical methods (differential analysis, Morris method, and FAST method). The FAST method selected the most influential parameters only out of the top 20, pre-screened by using the Morris Method. The parameters eliminated from the final list include those that were selected by only one of the seven methods, those that were selected by only two statistical methods, and those that were selected by only two out of three non-statistical methods. This resulted in only eight parameters being selected for 10 kyr and 50 kyr TPIs. Comparison of scores between these two TPIs also indicate that the influential parameters are common to most methods for the 10 kyr TPI, whereas significant variation exists for 50 kyr TPI. Also note that for the 10 kyr TPI, all parameters that ranked as the top five in the parameter tree method, also were picked by other sensitivity analyses methods.

RESULTS

Tables 1 and 2 list the influential parameters for 10 kyr and 50 kyr TPIs. Several important conclusions can be drawn by examining the results:

- Numerous parameters affecting the flow of water onto and eventually into the failed WP are important (e.g., Fow, Fmult, SF wetted fraction, SbArWt%). There is no mechanistic basis for the input parameter ranges for these variables used in the TPA Version 3.2 code. This finding suggests that a better understanding of the processes represented by these parameters is necessary.

- Regression techniques were able to distinguish as many as 19 statistically significant variables (at the 95th percent confidence level) for the 10 kyr TPI and 20 variables at the 50,000 yr TPI. For the 10 kyr TPI, 10 of the 19 significant variables were related to WP and fuel wetting, and 5 variables were related to retardation. For the 50 kyr TPI, 8 of the 20 significant variables were related to WP and fuel wetting, 5 to retardation, and 3 to seismically induced rockfall.

- In the analysis of the mean values of input variables leading to the highest doses, there were 24 variables whose difference in means were determined to be statistically significant. Of these, 4 were associated with wetting, 13 with retardation, and 4 with fracture and matrix flow. Thus retardation factors for the SZ take on added importance when considering the conditions that lead to the largest doses.

The influential parameters, identified with these methods were cross-walked to the NRC integrated subissues (ISIs) (NRC, 2000). ISIs are the integrated processes, features, and events that could impact system performance, and thus need to be appropriately abstracted into a performance assessment model. Nine of the fourteen integrated subissues were found to have at least one influential parameter, including the integrated subissues related to disruptive events. The integrated subissues for the 10,000 year compliance period that deserve further examination are primarily due to the delay in radionuclide releases resulting from (1) corrosion resistant material of the inner overpack accounting for WP failure times beyond 10,000 yr, (2) thermal reflux delaying the onset of flow into the repository, (3) bathtub filling time delaying the radionuclide release time by hundreds to thousands of years, and (4) significant delay in the arrival time of radionuclides from radionuclide sorption in the alluvium.

CONCLUSIONS

Preparation by the NRC to review the information from DOE related to the proposed YM repository is an iterative process. The results presented in this paper represents one of these iterations. The methodology presented has aided NRC staff to focus its attention on a limited but significant set of integrated sub-issues and provide specific pre-licensing guidance to DOE on the models and parameters that significantly influence DOE's safety case. Further iterations are being prepared to evaluate substantive changes to DOE's design, new data and conceptual models. We expect the order of importance of some of the key technical issues identified through sensitivity and alternative conceptual model analyses to change throughout this evolution.

ACKNOWLEDGMENTS

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Table 1. Influential parameters for 10 kyr time period of interest from sensitivity analysis studies

Parameter abbreviation	Parameter Name	Score
Fow	Flow focusing factor	6/6
Wp-Def%	Initially defective fraction of WPs	5/6
SbArWt%	Subarea wet fraction	5/5
Fmult	Fmult factor for flow entering a WP	5/6
AAMAI@S	Areal average mean annual infiltration at start	5/6
ARDSAV-Tc	Alluvium matrix R_d for Tc-99	3/5
WPRRG@20	Well pumping rate at 20 km receptor group	4/5
ARDSAV-I	Alluvium matrix R_d for I-129	5/6

Table 2. Influential parameters for 50 kyr time period of interest from sensitivity analysis studies

Parameter abbreviation	Parameter Name	Score
SbArWt%	Subarea wet fraction	6/6
WPRRG@20	Well pumping rate at 20 km receptor group	5/6
ARDSAV-Np	Alluvium matrix R_d for Np-237	4/6
ARDSAV-Tc	Alluvium matrix R_d for Tc-99	3/6
Fmult	Fmult factor for flow entering a WP	3/6
ARDSAV-I	Alluvium matrix R_d for I-129	3/6
ARDSAV-U	Alluvium matrix R_d for U-234	3/6
AAMAI@S	Areal average mean annual infiltration at start	3/6