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UPDATE OF HYDROLOGIC PARAMETERS FOR THE TOTAL-SYSTEM PERFORMANCE ASSESSMENT CODE

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ABSTRACT

The purpose of this report is to provide an update to the hydrologic parameters used in the Reference Data Set of the Total-system Performance Assessment (TPA) code, Version 3.2. The TPA code is used as a tool for analyzing the effect of important features, events, and processes that might affect the expected performance of a high-level nuclear waste repository proposed to be sited at Yucca Mountain, Nevada. Recommended parameter updates include the thicknesses of hydrostratigraphic units in the unsaturated zone, the saturated zone mass transfer rate coefficient used to simulate matrix diffusion in the tuff aquifer, and the estimated present-day mean annual infiltration rate. Sensitivity analyses are presented to show the effect of recommended parameter changes. Recommendations are made for future analyses, parameter updates, and revisions to the TPA code.

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: There are no CNWRA-generated original data contained in this report. Sources for other data should be consulted for determining the level of quality for those data.

ANALYSES AND CODES: TPA Version 3.2.3, which has been developed following the procedures described in the CNWRA Technical Operating Procedure, TOP-18, was used to conduct sensitivity analyses contained in this report. Calculations used to develop updated parameter estimates are documented in CNWRA Scientific Notebook Nos. 273 and 197.

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1 INTRODUCTION

The Total-System Performance Assessment (TPA) code is a tool used by staff at the Nuclear Regulatory Commission (NRC) and the Center for Nuclear Waste Regulatory Analyses (CNWRA) for making informed decisions regarding the importance of various features, events, and process that might affect the performance of a high-level waste (HLW) repository proposed to be sited at Yucca Mountain (YM), Nevada. Staff, working under the auspices of several key technical issues (KTI), contributed to the development and implementation of this complex code.

As site data from YM emerge in a continuous stream, it is important that the TPA model be continually reviewed and updated to reflect changing conceptual models and uncertainties in model parameters. The purpose of this report is to provide an update of the ranges and statistical distributions of the TPA parameters reviewed under the Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) KTI. Recommendations are also made for future analyses and improvements to the TPA model code to better reflect evolving conceptual models of site hydrology.

Where references in this report are made to "current" TPA model parameters, such references pertain to those parameter ranges and statistical distributions provided as the Reference Data Set for TPA Version 3.2 (Appendix A, Center for Nuclear Waste Regulatory Analyses, 1998). The terms, "nominal case" and "basecase," are used interchangeably throughout this report to refer to the TPA Version 3.2 input file derived from this reference data set. Sensitivity analyses were run with TPA Version 3.2.3 code.

2 RECOMMENDED PARAMETER UPDATES

In this chapter of the report, changes are recommended for values and statistical distributions of selected hydrologic parameters used in the TPA Version 3.2 code nominal case input file. Where referenceable sources for the recommended updates to parameter values do not exist, technical analyses are provided. In all cases, sensitivity analyses are performed to illustrate the effect of the parameter changes on predicted dose.

2.1 UNSATURATED ZONE HYDROGEOLOGIC UNIT THICKNESSES

Estimates of unsaturated zone (UZ) hydrogeologic unit thicknesses used in the current TPA Version 3.2 code nominal case input file (Center for Nuclear Waste Regulatory Analyses, 1998) are listed in table 2-1. These estimates are based on the Department of Energy (DOE) Integrated Site Model (ISM2.0) and zeolite isopach maps (Bodvarsson and Bandurraga, 1996). It should be noted that these unit thicknesses are held constant for the TPA Version 3.2 code, as in previous versions of the TPA model. As such, the importance of the UZ unit thicknesses to repository performance has not been evident from TPA sensitivity analyses conducted to date (Nuclear Regulatory Commission, 1999). Of particular interest is the thickness assigned to the Calico Hills nonwelded vitric (CHnv) unit. The CHnv is of potential importance to repository performance because it can accommodate relatively large percolation fluxes as matrix flow; this can drastically reduce the downward velocity of infiltrating water and provide greater sorption of radionuclides compared to flow in fractures. It can be seen in table 2-1 that zero thickness has been assigned to the CHnv unit in five of the seven modeled subareas. Borehole data suggest, however, that nonwelded vitric units, although sometimes quite thin, are present beneath all seven repository subareas. Because these units provide an important barrier to radionuclide movement to the water table, review and refinement of the vitric horizon thicknesses for each subarea are necessary. The following paragraphs describe the procedure and data used to modify the thicknesses of vitric and zeolitic units in the UZ below the seven subareas.

The reader might be aware that the TPA model includes seven hydrostratigraphic units below the repository for each subarea; however, only six units are included in table 2-1. The additional unit is the unsaturated fracture zone (UFZ), which is used in the TPA model to simulate the conservative bound of all UZ flow and transport occurring in a fault system for a particular subarea. The hydraulic properties for the UFZ layer are set to those representative of a conductive fault zone. The thickness for the UFZ layer, in general, should remain at zero. When it is desired to assess the effects of fault zone flow in a particular subarea, the thicknesses of the other six units in that subarea should be set to zero and the thickness of the UFZ layer should be set to the total UZ thickness from the repository to the water table. The UFZ layer is not mentioned further in this report.

2.1.1 Technical Basis for Parameter Updates

Borehole mineralogic logs were examined in conjunction with x-ray diffraction (XRD) data of zeolite weight percent. Sources of mineralogic logs data include Vaniman et al. (1984), Rautman and Engstrom (1996a,b), Engstrom and Rautman (1996), Bentley et al. (1983), Spengler and Chornack (1984), and as supplemented by Carey et al. (1997). General descriptions of the lithologic and hydraulic characteristics of the units below the repository are contained in Moyer and Geslin (1995), Loeven (1993), and Flint (1998). XRD data of zeolite weight percent are from Carey et al. (1997). The boreholes used in this analysis, with

Table 2-1. Current total-system performance assessment basecase stratigraphic thickness (m) estimates for each of the seven repository subareas

Subareas	1	2	3	4	5	6	7
Topopah Springs—welded	33	116	20	110	20	53	121
Calico Hills—nonwelded vitric	0	0	0	0	113	125	0
Calico Hills—nonwelded zeolitic	163	154	122	132	0	0	114
Prow Pass—welded	34	39	40	34	38	26	43
Upper Crater Flat	67	20	158	57	158	136	63
Bullfrog—welded	0	0	0	0	32	0	0
TOTAL	297	329	340	333	361	340	341

locations shown in figure 2-1, were chosen based on their proximity to the repository footprint and drilled to a depth below the water table. There are other wells not chosen because of questionable or incomplete data, location across a major structural feature, or only partial penetration of the nonwelded units above the water table.

For each borehole, estimates of the total nonwelded tuff thickness from the repository horizon to the water table were obtained. The combined nonwelded tuff thickness was then subdivided into the CHnv unit by lumping the thicknesses of both nonwelded vitric tuff layers and the fine-grained, friable, devitrified tuff layers; the combined thicknesses of various nonwelded zeolitized layers were similarly lumped into the Calico Hills nonwelded zeolite (CHnz) unit. It should be noted that nonwelded layers occur within several hydrostratigraphic units other than the Calico Hills formation. For the modeling approach taken in TPA, however, it is the combined thicknesses of a particular type of unit that is of primary interest. The lumping of different rock types was based on similarity of hydrologic properties as seen in laboratory analyses (Flint, 1998). The threshold for delineation of zeolitically altered from nonaltered rock is 10 percent zeolite by weight, determined by XRD. This threshold is consistent with the bimodal distribution seen in XRD analyses, which indicate few samples fall between 5 and 10 percent; they tend to have either little (less than 5 percent) or significant (greater than 10 percent) zeolitic alteration. The estimated CHnv and CHnz unit thicknesses for each borehole are listed in table 2-2.

The borehole-based unit thickness estimates in table 2-2 were then used to interpolate representative CHnv and CHnz unit thicknesses for each subarea. The interpolation method involved plotting the data with the Tecplot (Version 7.0) graphing software using the inverse distance interpolator. As a preliminary approach, the average of unit thicknesses at five points in each subarea was calculated: the four corner points and one center point. A more conservative approach was also adopted wherein the minimum CHnv thicknesses of the five points in each subarea was taken to be the representative thickness.

An important criterion used in this update of UZ hydrostratigraphic unit thicknesses is that the same total thickness from the repository to the water table must be maintained for each subarea. To comply with this criterion, the Upper Crater Flat (UCF) unit thickness was adjusted to compensate for changes in the combined thicknesses of the CHnv and CHnz units. This convention was adopted more as a matter of

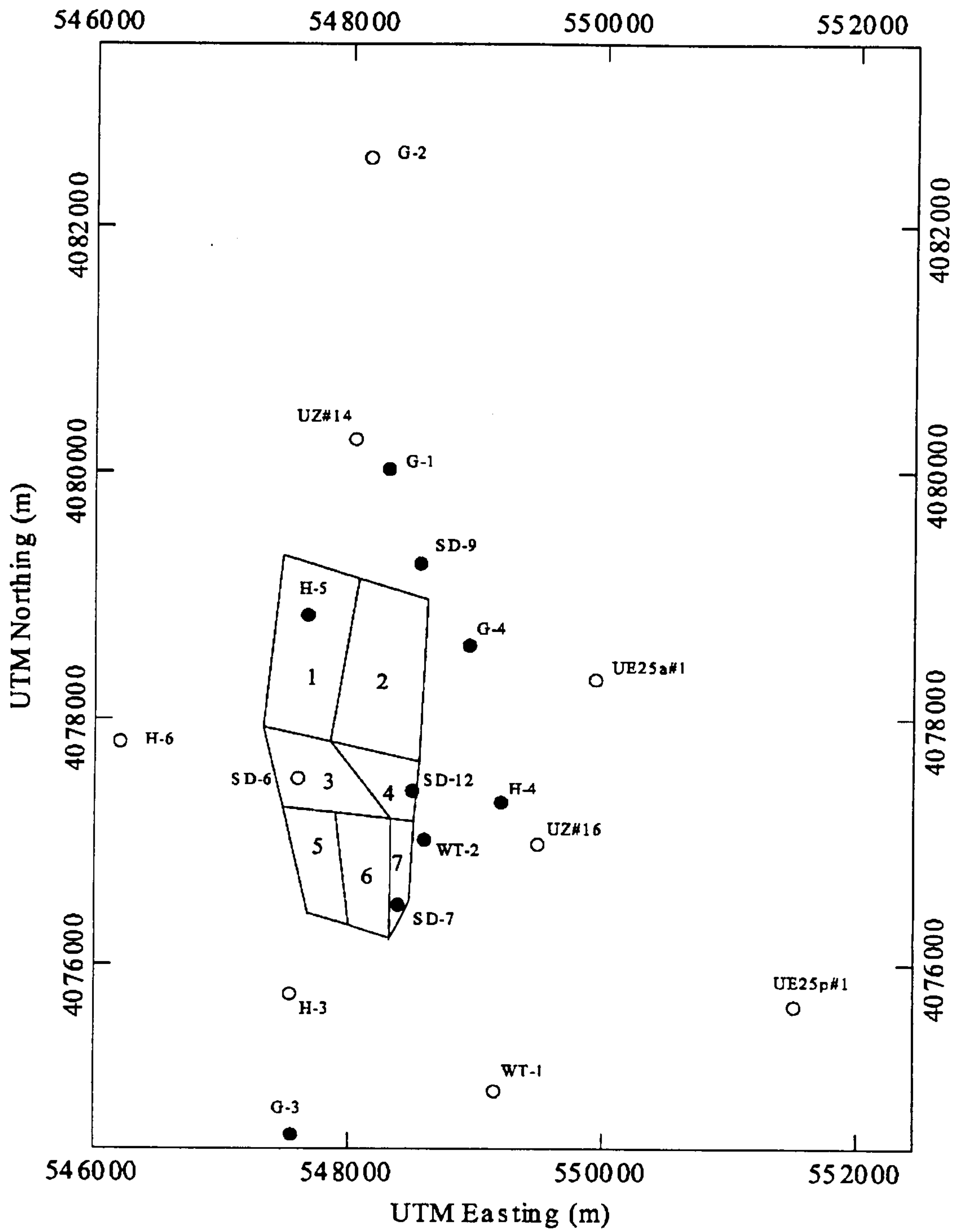

Figure 2-1. Circles indicate locations of boreholes in the vicinity of the proposed repository at Yucca Mountain. Wells used in the present analyses are indicated by filled circles. Solid lines delineate repository subareas 1–7 used in the total-system performance assessment model.

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Table 2-2. Estimated nonwelded vitric and zeolitic horizon thicknesses in the unsaturated zone below the repository for nine boreholes. The second column notes the water table elevation and the stratigraphic unit in which it resides; Tcp = Prow Pass Tuff, Tcb = Bullfrog Tuff.

Borehole	Water Table Elevation (m)	Nonwelded Vitric and Devitrified Thickness (m)	Zeolite Thickness (m)
G–1	754 (in Tcp)	11	137
G–3	730 (in Tcb)	88	59
G–4	730 (in Tcp)	7	123
H–4	730 (in Tcp)	57	87
H–5	775 (in Tcb)	55	51
SD–7	729 (in Tcp)	64	111
SD–9	731 (in Tcp)	0	132
SD–12	730 (in Tcp)	16	117
WT–2	731 (in Tcp)	140	78

convenience than as a rigorous method of grouping rock-types into discrete hydrostratigraphic units. In fact, during this exercise, it became clear that the type of rock intended to be represented by the UCF unit is rather ambiguous. It appears that the UCF unit nomenclature was first adopted by Stirewalt and Henderson (1995) who lumped several layers of non-to-partially welded, devitrified, and zeolitized ash-flow and bedded tuffs under the UCF hydrostratigraphic category. For future work, it is recommended that for TPA analyses closer attention be given to assigning physical and hydrologic parameter values to the UCF unit. The currently used properties of the UCF unit are similar to those of a nonwelded zeolitized tuff.

The representative unit thicknesses obtained from the foregoing analysis are listed in table 2-3; the unit thicknesses obtained by using the minimum CHnv thickness in each subarea are listed in table 2-4.

Ongoing efforts to refine estimated UZ layer thicknesses include developing alternative conceptual models for vitric and zeolite distribution, incorporating the complexity of the multiple subunits in the interpolation, using more sophisticated interpolation techniques, and using more sophisticated methods to estimate representative thicknesses for a subarea. Examination of surface outcrops near the Busted Butte Transport Facility and cores/cuttings from boreholes SD–7, SD–9, G–3, and WT–2 has proven instructive. More boreholes will be examined once follow-up work combining geophysical data and XRD data is complete. Future work will use the data from the following wells either to improve the interpolation or to gain insight into the distribution of alteration in the nonwelded units: UE–25a#1, UE–25b#1, UE–25p#1, UZ#14, UZ#16, SD–6, G–2, WT1, H–3, H–6, and NRG7/7a. All these wells have associated XRD analyses to help correlate the mineralogic logging with geophysical data to delineate nonwelded zeolitically altered tuff from the unaltered nonwelded devitrified and vitric tuffs. Thus, it can be expected that estimates of UZ hydrostratigraphic unit thicknesses used in the TPA code will be refined further in the future.

Table 2-3. Representative stratigraphic thickness (m) estimates for each of the seven repository subareas using new information on the Calico Hills nonwelded vitric horizons

Subareas	1	2	3	4	5	6	7
Topopah Springs—welded	33	116	20	110	20	53	121
Calico Hills—nonwelded vitric	44	24	53	51	66	66	79
Calico Hills—nonwelded zeolitic	78	107	92	96	97	100	92
Prow Pass—welded	34	39	40	34	38	26	43
Upper Crater Flat	108	43	135	41	108	95	5
Bullfrog—welded	0	0	0	0	32	0	0
TOTAL	297	329	340	333	361	340	341

Table 2-4. Minimum stratigraphic thickness (m) estimates for each of the seven repository subareas using new information on the Calico Hills nonwelded vitric horizons

Subareas	1	2	3	4	5	6	7
Topopah Springs—welded	33	116	20	110	20	53	121
Calico Hills—nonwelded vitric	25	2	33	16	61	64	64
Calico Hills—nonwelded zeolitic	78	107	92	96	97	100	92
Prow Pass—welded	34	39	40	34	38	26	43
Upper Crater Flat	127	65	155	77	113	97	21
Bullfrog—welded	0	0	0	0	32	0	0
TOTAL	297	329	340	333	361	340	341

For the present parameter value update, it is recommended that the scenario representing the minimum estimated CHnv unit thicknesses, listed in table 2-4, be used for TPA analyses. Use of the table 2-4 values will provide a conservative lower bound on the CHnv unit thickness until the representative values in table 2-3 can be substantiated better.

2.1.2 Effect of Updated Parameters on Dose Calculations

Figure 2-2 shows results of TPA model outputs for the three conceptual models for UZ hydrostratigraphic unit thicknesses in tables 2-1, 2-3, and 2-4. For this analysis, the *tpa.inp.mean values* file was used as model input. A 10-ky, 20-km exposure scenario with no disruptive events was used; the only difference between the three TPA model runs was the thicknesses of the CHnv, CHnz, and UCF units. From figure 2-2 it can be seen that, at the point in parameter space where all other parameters are set to their estimated mean values, the model is quite sensitive [total effective dose equivalent (TEDE) in 10 ky] to the assumed thicknesses of the CHnv, CHnz, and UCF layers. It is believed, as discussed earlier in this chapter,

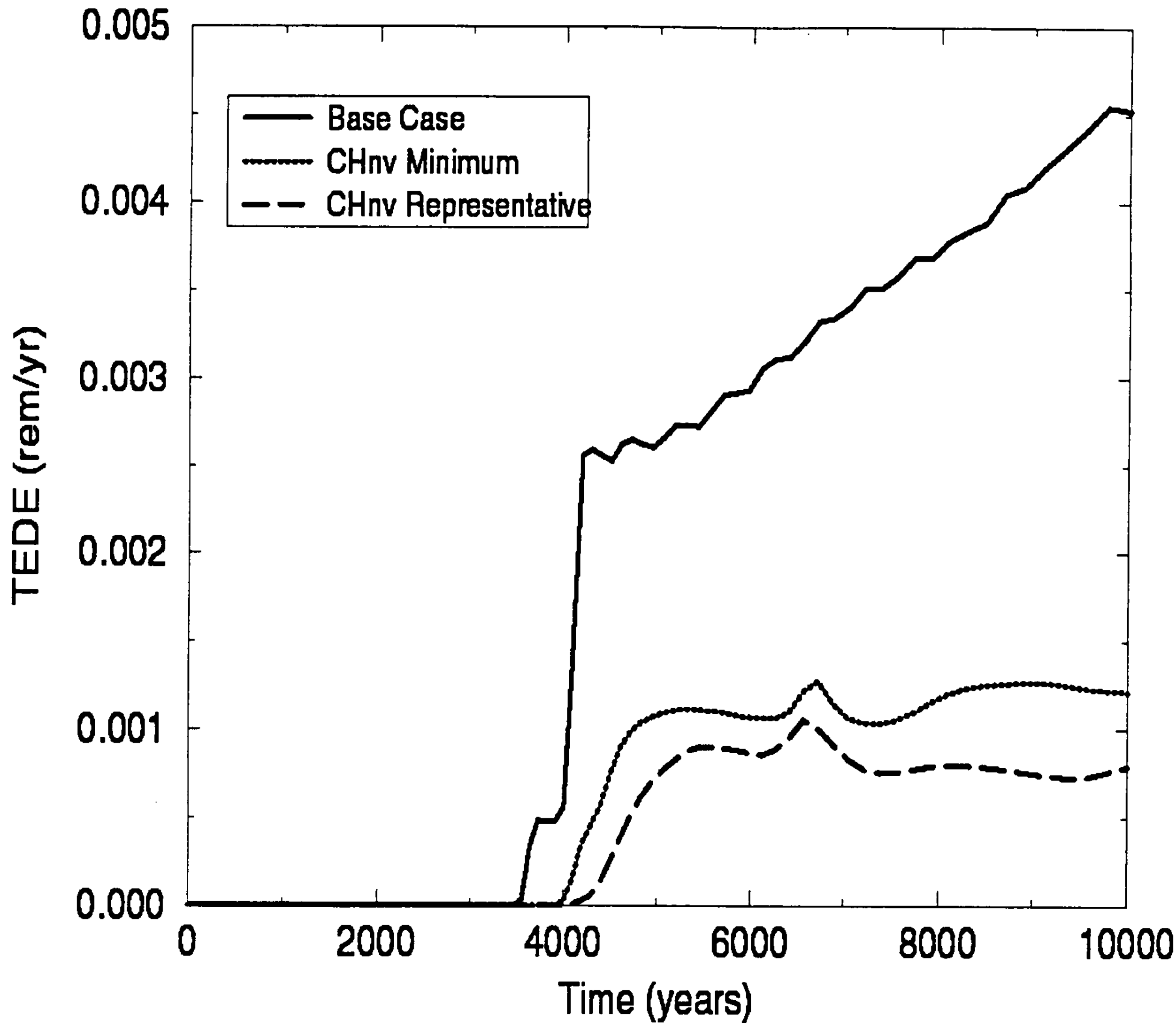

Figure 2-2. Total-system Performance Assessment code sensitivity analysis of alternate conceptual models of Calico Hills nonwelded vitric layer thickness

that the differences in performance predictions are due largely to the varying transport distances through the CHnv layer. For example, in the basecase, five subareas contain no CHnv layer; it can be seen, however, that the addition of even a thin CHnv layer in these subareas, as in the "CHnv Minimum" case, results in a significant delay in contaminant arrival time and a profound decrease in peak doses in the 10-ky scenario. As expected, the "CHnv Representative" case results in further delay in arrival time and reduction in peak dose.

2.2 MATRIX DIFFUSION PARAMETERS

The TPA Version 3.2 code has the capability to account for matrix diffusion—the migration of dissolved contaminants from flowing pores and fractures into the more-or-less stagnant water within the rock matrix pores—in the saturated zone (SZ). However, in nominal case input file for the TPA model, the matrix diffusion rate coefficient in the SZ has been set to a constant value of zero, which eliminates the effects of matrix diffusion from consideration in sensitivity analyses. In recent years, laboratory diffusion tests conducted at Los Alamos National Laboratory (Triay et al., 1996) and interwell tracer tests conducted at the C-Holes Complex near YM (e.g., Reimus et al., 1998) have shown that, although uncertainties remain, there is strong evidence that matrix diffusion in the tuff aquifer plays a role in the attenuation of mobile contaminant concentrations. Given the body of emerging evidence to support matrix diffusion in the tuff aquifer, it is appropriate that the TPA model nominal case input file be updated conservatively to include the contribution of matrix diffusion to attenuation of solute concentrations.

2.2.1 Technical Basis for Parameter Update

The TPA model handles matrix diffusion within the SZFT module by invoking the stand-alone code NEFTRAN II (Olague et al., 1991) to track radionuclide mass transport. Within NEFTRAN II, the governing equation to account for the partitioning of solutes between flowing pores and fractures (mobile domain) and rock matrix (immobile domain) is

$$\theta_i R_i \frac{\partial C_i}{\partial t} = \beta \left[C_m - C_i \right] \tag{2-1}$$

where θ_i is the immobile water-filled effective porosity of the rock matrix, R_i is the retardation factor for the solute in the immobile domain, C_i is the volume-averaged concentration of the solute in the immobile domain, β is a first-order mass transfer rate coefficient, and C_m is the concentration of the solute in the mobile domain. The parameters of interest for updating the TPA model nominal-case input file are θ_i (unitless) and β (yr^{-1}), which are assigned constant values of 0.01 and 0.0 yr^{-1} in the current nominal case (Center for Nuclear Waste Regulatory Analyses, 1998).

The most likely fractured rock flow paths in the SZ are in the Prow Pass and Bullfrog members of the Crater Flat group. Flint (1998) reports a range of matrix porosities for these units from about 0.1 to 0.3. It should be noted, however, that the use of a volume averaged immobile concentration in Eq. (2-1) implies an assumption that the immobile volume is essentially well-mixed and concentration gradients within the immobile domain are ignored. For the case where flowing fractures are spaced far apart (i.e., large matrix blocks), solutes may not be able to penetrate fully the immobile domain on the time scale of transport through the fracture system. When such is the case, the immobile porosity available for matrix diffusion may be less than the rock matrix porosity. The appropriate value for the θ_i TPA parameter is a function of the distance between flowing fractures, flow velocity, transport distance through fractures, and solute diffusion rates; all of which are somewhat uncertain.

Based on the forgoing discussion, it is recommended that the updated TPA input file use a range of θ_i values from the current highly conservative estimate of 0.01 to 0.1, which is at the low end of matrix porosities estimated from core samples. Given that there is currently no basis for weighting a particular portion of this range, a uniform sampling distribution is also recommended. The *tpa.inp.meanvalues* file should use a θ_i value of 0.055.

The matrix diffusion mass-transfer rate coefficient, β, can be estimated from an equation developed by van Genuchten (1985):

$$\beta = \frac{\theta_i^2 D_p}{0.28a^2} \tag{2-2}$$

where D_p is the effective matrix pore-water diffusion coefficient, a is the effective matrix-block half-width, and the constant 0.28 is a shape factor used for parallel, slab-shaped matrix blocks (shape factors are available for other matrix-block geometries).

To estimate a range and statistical distribution for β, a Monte Carlo analysis was performed by randomly selecting parameter values for Eq. (2-2) from uniform distributions. A range of 0.01 to 0.1 was used for θ_i, as previously discussed. A range of 1×10^{-11} to 4.9×10^{-11} m^2/s was used for D_p: this range is based on the range of laboratory-determined values for pertechnitate (TCO_4^-) diffusion in YM tuffs obtained by Triay et al. (1996). Because TCO_4^- is a large anion, it diffuses slowly relative to other radionuclide species, owing to its high molecular weight and anion exclusion processes. Because a single mass-transfer coefficient is used in NEFTRAN II for all dissolved species, it was considered prudently conservative to estimate this coefficient based on such a slow-diffusing species. Finally, the range of the parameter matrix-block half-width [a in Eq. (2-2)] was taken to be 1–30 m, based on borehole flow surveys and geochemical analyses that suggest separations between flowing fractures ranging from a few to several tens of meters. The results of 10,000 randomly estimated mass-transfer rate coefficients yielded a lognormal distribution with a mean $\log_{10}$ value of -7.5 ($\beta = 3.2 \times 10^{-8}$ yr^{-1}) and a standard deviation of 0.94. In the TPA Version 3.2.3 code, the end points of the 99 percent confidence interval are used to define parameters with lognormal distributions; these endpoints are 4.8×10^{-11} yr^{-1} and 2.1×10^{-5} yr^{-1}.

2.2.2 Effect of Updated Parameters on Dose Calculations

Figure 2-3 shows results of TPA model outputs for the three conceptual models for matrix diffusion. For this analysis, the input file supplied with TPA Version 3.2 code was used, with all parameters set to their mean values. A 10-ky, 20-km exposure scenario with no disruptive events was used; the only difference between the three TPA model runs being the value of β (named DiffusionRate_STFF in the input file). The value of θ_i (ImmobilePorosity_STFF in the input file) was set to the constant value of 0.055, as previously recommended. The first run represents the mean values basecase, which assumes no matrix diffuion; thus, the parameter DiffusionRate_STFF was set to zero. In the second run, DiffusionRate_STFF was set to the mean value of 3.2×10^{-8} yr^{-1} as determined in the preceding analysis. Note that this mean-value scenario has a negligible effect on calculated dose at this point in parameter space (i.e., 20-km scenario with all other parameters set to mean values). In the third run, DiffusionRate_STFF was set to a value of 2.4×10^{-6} yr^{-1}, which represents the upper 95 percentile of the parameter range; in this scenario, matrix diffusion lends to only a modest reduction in predicted dose.

Although matrix diffusion appears to be a process of minor significance in these analyses, it must be recognized that under circumstances other than those assumed for the TPA basecase, matrix diffusion may be a more significant contributor to dose attenuation at the exposure point. For example, in the 20-km transport scenario considered here, solute attenuation in the saturated tuff is small relative to that attained in the saturated alluvium part of the flow path; scenarios in which the saturated portion of the transport path is dominated by tuff are likely to be impacted more by matrix diffusion. Matrix diffusion might also have a larger effect for longer time periods of interest if, for example, it slows down the transport of Np-237 and other actinides.

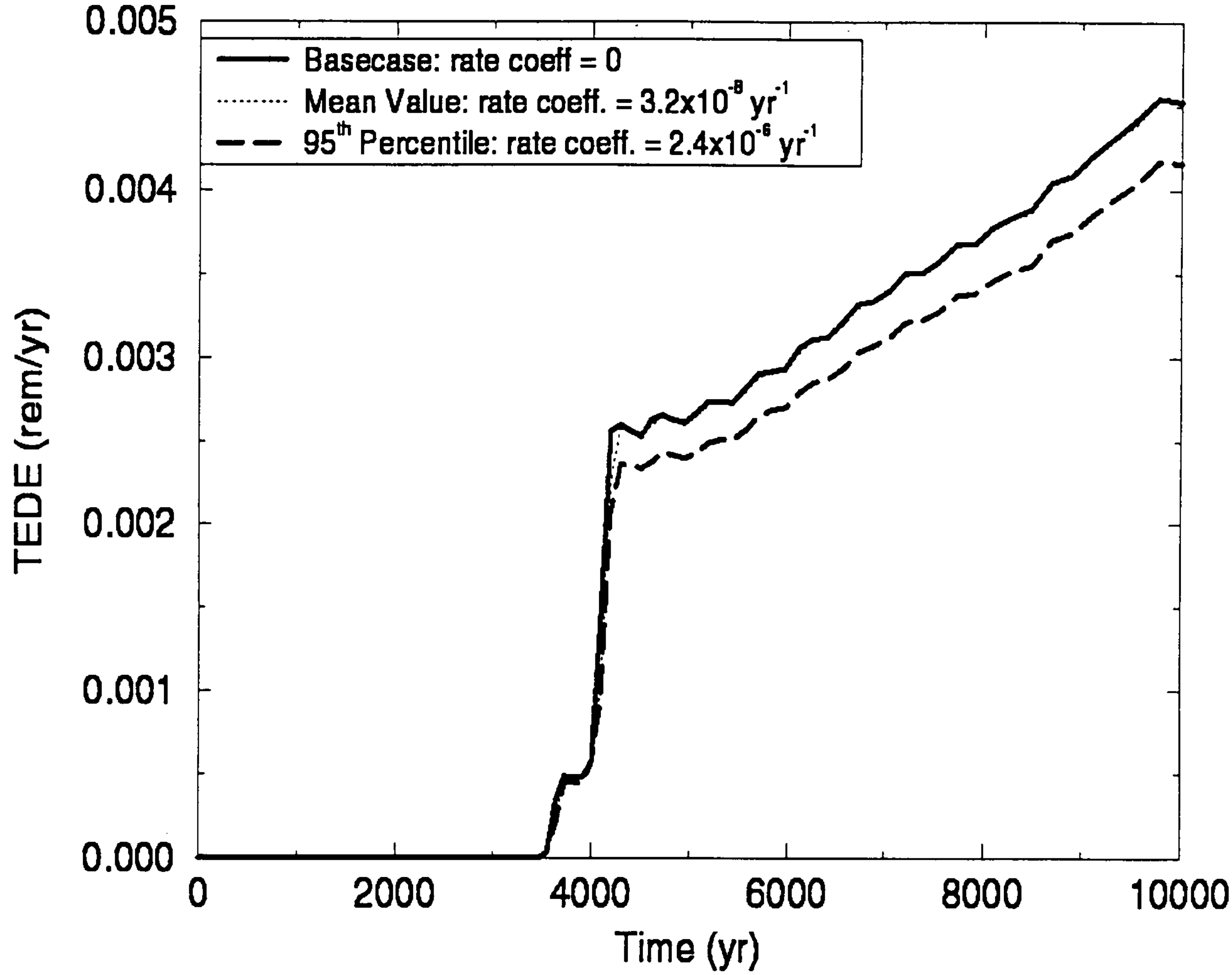

Figure 2-3. Plot showing the effect on predicted total effective dose when credit for matrix diffusion in saturated tuffs is taken

2.3 PRESENT-DAY AREA-AVERAGED MEAN ANNUAL INFILTRATION

Recent sensitivity analyses (Nuclear Regulatory Commission, 1999) reveal that one of the most important TPA model parameters is the assumed present-day area-averaged annual infiltration rate above the proposed repository. This sampled parameter is used to scale each of the subarea infiltration rates such that the present-day area-average infiltration over the repository is equal to the sampled value. The current TPA Version 3.2 code input file assumes a uniform distribution for this parameter with a range of 1–10 mm/yr. The scaling is done after the subarea averaging of 30 m × 30 m pixel results from the NRC regression equations for infiltration as a function of mean annual precipitation (MAP), mean annual temperature (MAT), and soil thickness (Center for Nuclear Waste Regulatory Analyses, 1998).

Recent process modeling at CNWRA resulted in a predicted value of 9 mm/yr for average mean annual infiltration (MAI) over the repository. DOE modeling leads to an average of 7.7 mm/yr (Flint et al., 1996) over the repository footprint. Hence, the uniform distribution of this parameter should be changed to reflect that the average from physically-based modeling simulations should lie in the middle of the range for present-day infiltration rates, not near the upper end of the TPA-allowed range. It is thus recommended that the TPA nominal-case parameter value distribution for ArealAverageMeanAnnualInfiltrationAtStart (mm/yr) be updated to a range of 4–13 mm/yr. Given the assumed uniform distribution of this parameter, this recommended range maintains the currently assumed difference between minimum and maximum values, while increasing the mean parameter value to 8.5 mm/yr. Admittedly, the parameter range and distribution, used to incorporate uncertainty, is somewhat arbitrary; future work should be conducted to provide more rigorous constraints on the range and distribution of this important parameter.

Figure 2-4 shows results of the TPA model sensitivity analysis for both the current basecase expected value of 5.5 mm/yr and the recommended updated value of 8.5 mm/yr for the parameter ArealAverageMeanAnnualInfiltrationAtStart (mm/yr). For this analysis, the input file supplied with TPA Version 3.2 code was used; all parameters were set to their basecase expected values. A 10-ky, 20-km exposure scenario with no disruptive events was used. It can be clearly seen in figure 2-4 that the recommended increased range or present-day area-averaged infiltration will result in predictions of greater doses and earlier arrival times at the receptor location. Note that, although not shown, at the higher MAI rate the TPA model remained sensitive to changes in CHnv unit thickness, as shown in figure 2-2.

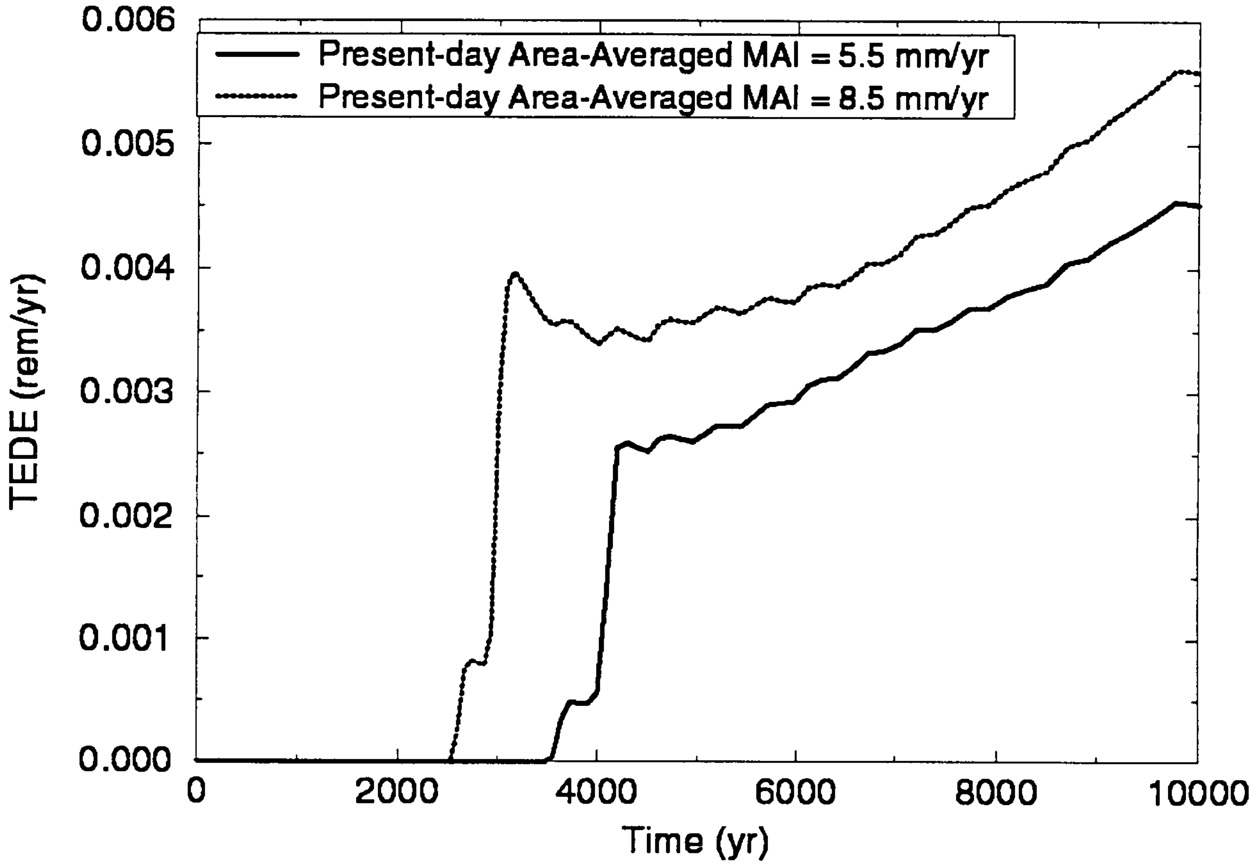

Figure 2-4. Total-system performance assessment model sensitivity to increased present-day infiltration rate

3 RECOMMENDATIONS

The continual updating of TPA model parameter values is an integral part of the scientific investigations aimed at evaluating the expected performance of a HLW repository at YM. Updates to the TPA model code are also important to ensure that the model remains useful as a tool for identifying the features, events, and processes that warrant closer scrutiny due to the combination of high uncertainty and importance to repository performance predictions.

3.1 UPDATE MODEL PARAMETERS

It is recommended that the parameter values and distributions for the TPA model nominal case be updated in accordance with the analyses in the preceding chapters. Appendix A contains the recommended updated parameter values in the same format used in the TPA model input file, *tpa.inp*.

3.2 CONDUCT ANALYSES FOR FUTURE UPDATES

3.2.1 Seepage Parameters

The TPA model parameters used to abstract the effects of water seepage into drifts and dripping onto waste packages are among the most important affecting dose calculations in performance assessment (Nuclear Regulatory Commission, 1999). Three of these parameters, identified in the TPA code as "*SubAreaWetFraction*," "*FowFactor*," and "*FmultFactor,*" are, at present, poorly constrained. Emerging data from DOE investigations conducted in niches and alcoves of the exploratory studies facility at YM are expected to provide an improved basis for assessing the parameter values and subsystem abstraction methods currently used in the TPA code. Plans for improving these parameter estimates include the examination of statistical assumptions underlying the computation of these parameters. This analysis will include evaluation of the seepage parameters for many realizations based on different input assumptions and also will facilitate the incorporation of new information and design alternatives into the existing TPA code.

3.2.2 Physical and Hydraulic Properties of Flow and Transport Pathways

Several years have passed since the last update of TPA model parameters used to represent the physical and hydraulic properties of the geologic formations in the SZ and UZ. These parameters include effective porosity, hydraulic conductivity, and moisture retention parameters. In those years, new site characterization data and site-scale UZ flow model calibrations have been published (e.g., Flint, 1998; Bodvarsson and Bandurraga, 1997). Thus, in the next year USFIC staff will conduct literature reviews and independent analyses of these important model parameters[1] and make appropriate recommendations for changes to parameter values. A review of the basis for and model sensitivity to UZ subarea delineation would also be useful in this context.

[1]Although no single TPA parameter representing rock physical or hydraulic properties has been established as important to predicted repository performance, it is expected that the combined effect of updating all such parameters would be significant.

3.3 MODIFY TOTAL-SYSTEM PERFORMANCE ASSESSMENT CODE MODULES

3.3.1 Infiltration Module

The existing TPA module for calculating MAI uses a regression equation developed for shallow soil above an unfilled-fracture continuum. Inputs to the regression equation include MAP, MAT, and soil thickness. The regression equation is applied for all grid blocks representing the surface above the repository, with each block having 30-m sides. Present-day climatic inputs are calculated as a function of elevation and adjusted as a function of climate change. Elevation and soil thickness are provided for each grid block using a digital elevation model (DEM).

The currently used infiltration module was developed several years ago when the only regression relationship available was for the case of bare (no vegetation), shallow soil over an unfilled-fracture continuum. Since then, relationships have been developed for shallow soil over a filled-fracture continuum and over bedrock. In addition, the effect of vegetation can be heuristically accounted for in the relationships. Further, the properties of the bedrock and soil are better known today. Accordingly, it is proposed to update the TPA infiltration module to reflect this improved process understanding.

The proposed changes are for the infiltration regression alone. Treatment of climate is to be unchanged, as is the scaling of the predicted MAI according to a sampled parameter for present-day MAI. Additional TPA model input data required to implement this proposed change to the infiltration regression include:

- DEM coverage providing an index for the type of bedrock at or near the surface of YM [the Day et al. (1998) coverage is readily available]
- A table describing the following fracture and bedrock characteristics for each bedrock type in the DEM
  - Bedrock hydraulic-property data would be based on Flint (1998)
  - Fracture filling hydraulic-property data would be based on limited data to be obtained from literature searches
  - Fracture-area data would be based on Flint et al. (1996) and other geologic information sources
  - Estimates of the relative proportion of unfilled, carbonate-filled, and soil-filled fractures also would be based on Flint et al. (1996), geologic sources, and field observations
- Parameters accounting for the effect of transpiration would be developed.

3.3.2 Drift Seepage Abstraction

The relative simplicity of seepage abstraction in the TPA Version 3.2 code may be an advantage due to its flexibility in accommodating design changes. For example, the effects of dripshields[2] and backfill in the emplacement drifts could be included easily in the *FmultFactor* parameter, which is used to account for near- and in-drift flow diversions. This flexibility notwithstanding, the seepage abstraction in the TPA code could be improved by allowing the seepage parameters to be time variant so that various stages of repository evolution can be represented. For example, during the early, thermal period of the repository, the *FmultFactor* parameter would likely be small and may represent only potential breaches in dripshields. As the repository ages, however, this parameter should progressively increase representing the physical degradation of drifts and dripshields. Probabilistic models of dripshield degradation and drift failure could be used to calculate time-varying distributions of the *SubAreaWetFraction*, *FowFactor*, and *FmultFactor* parameters.

3.3.3 Saturated Zone Transport-Leg Path Length

The SZ solute transport pathways from the proposed repository site to the 20-km exposure group include transport through both fractured tuff and valley-fill alluvium pathways. It is accepted generally that the saturated alluvium portion of the transport pathway is the most effective portion of the natural barrier system for delaying and attenuating the potential migration of dissolved radionuclides through groundwater. Given the potential for anisotropic or structurally controlled flow through the tuff aquifer system and the absence of a clearly defined location of the tuff-alluvial aquifer transition, there is considerable uncertainty in the relative SZ transport distances through tuff versus alluvium. Despite this uncertainty, the NEFTRAN II transport legs used to represent tuffaceous and alluvial flow systems are "hard-coded" in the current TPA model Version 3.2.3. Thus, the model does not allow readily for an analysis of the sensitivity of performance predictions to the assumed transport distance through alluvium. It is therefore recommended that parameters be added to the TPA input file whereby the user can specify a value range and statistical distribution for relative transport distances through tuff and alluvium in each of the NEFTRAN II stream tubes used to model SZ solute transport.

[2]Dripshields may or may not be used in the final repository design.

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APPENDIX

** ***>>> UZFLOW <<<***
**
uniform
ArealAverageMeanAnnualInfiltrationAtStart[mm/yr]
4.0, 13.0
**
** ***>>> UZFT <<<***
**
constant
CHnvThickness_1SubArea[m]
25.0
**
constant
CHnzThickness_1SubArea[m]
78.0
**
constant
UCF_Thickness_1SubArea[m]
127.0
**
constant
CHnvThickness_2SubArea[m]
2.0
**
constant
CHnzThickness_2SubArea[m]
107.0
**
constant
UCF_Thickness_2SubArea[m]
65.0
**
constant
CHnvThickness_3SubArea[m]
33.0
**
constant
CHnzThickness_3SubArea[m]
92.0
**
constant
UCF_Thickness_3SubArea[m]
155.0
**
constant
CHnvThickness_4SubArea[m]
16.0
**
constant
CHnzThickness_4SubArea[m]
96.0
**
constant
UCF_Thickness_4SubArea[m]
77.0
**
constant
CHnvThickness_5SubArea[m]
61.0
**
constant
CHnzThickness_5SubArea[m]
97.0
**
constant
UCF_Thickness_5SubArea[m]
113.0
**
constant
CHnvThickness_6SubArea[m]
64.0
**
constant
CHnzThickness_6SubArea[m]
100.0
**
constant
UCF_Thickness_6SubArea[m]
97.0
**
constant
CHnvThickness_7SubArea[m]
64.0
**
constant
CHnzThickness_7SubArea[m]
92.0
**
constant
UCF_Thickness_7SubArea[m]
21.0
**
** ***>>> SZFT <<<***
**
constant
ImmobilePorosity_STFF
0.055
**
lognormal
DiffusionRate_STFF
4.8e-11, 2.1e-5
**