SENSITIVITY ANALYSES FOR TOTAL-SYSTEM PERFORMANCE ASSESSMENT

Michael L. Wilson
Sandia National Laboratories
Department 6312
Albuquerque, NM 87185
(505) 844-9337

ABSTRACT

As a follow-on to Sandia's 1991 preliminary total-system performance assessment of the Yucca Mountain site, this paper presents results of some sensitivity analyses that were done using results from the 1991 study. Two conceptual models of unsaturated-zone flow and transport at Yucca Mountain were included in the study, including both aqueous and gaseous releases. The sensitivities are quite different for the two models. For the composite-γ-rosity model, the results are most sensitive to groundwater percolation flux, gaseous transport time, container lifetime, and fuel-matrix-alteration rate. For the weeps model, the results are most sensitive to parameters used to characterize fracture flow (fracture aperture and fracture connectivity) and infiltration (percolation flux and weep-episode factor).

INTRODUCTION

As part of the ongoing effort to assess the suitability of Yucca Mountain, Nevada, as a site for a radioactive-waste repository, Sandia National Laboratories recently completed a preliminary performance assessment of the potential repository system. This total-system performance assessment (TSPA) is the first in a projected sequence of iterative total-system performance assessments leading up to the final one that will be part of the license application for the repository.

Because of time and resource constraints, sensitivity analyses for the aqueous- and gaseous-release components of the TSPA were limited. This paper is essentially an addendum to the TSPA report, to partially remedy that limitation.

Sensitivity analyses examine a model system to determine to which parts of the system, and to which system parameters, the performance measures are most sensitive. For total-system performance assessment, the primary performance measure is the normalized...
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Cumulative release of radioactivity to the accessible environment over 10,000 years, as specified by the U. S. Environmental Protection Agency (EPA) in 40 CFR 191.13. (The EPA is currently reconsidering the standard, and recent legislation has instructed the EPA to consider a standard based on individual radiation doses rather than cumulative releases of radioactivity. If in the future the performance measure is defined differently, the change could, in turn, affect some of the details of the sensitivity-analysis methods described in this paper.) Sensitivity analyses are important, especially to preliminary studies such as this one, because a knowledge of which parts of the system are most important can be valuable input to the site-characterization and repository-design activities, and to future modeling efforts. For example, parameters to which results are sensitive need to be measured more precisely, if possible, than parameters to which results are insensitive.

Details of the models used and analysis of the results may be found in the TSPA report. The results are summarized in Figure 1, which shows the distributions of normalized release calculated for the four sub-parts of the TSPA relevant to this paper. The distributions are in the form of complementary cumulative distribution functions, or CCDFs, which show the probability that normalized release exceeds any given value. The cross-hatched region in Figure 1 shows the EPA limits placed on the overall CCDF by 40 CFR 191.13.

Several important sensitivities were discussed in the TSPA report. As shown in Figure 1, gaseous releases of $^{14}$C were found to be greater than aqueous releases, with the models used. The figure also shows that aqueous and gaseous releases were calculated us-
ing two different methods—the "composite-porosity" model and the "weeps" model—and the composite-porosity model was found to have higher gaseous releases than the weeps model, but lower aqueous releases. The two models are two alternative conceptions of how water flows through the unsaturated zone at Yucca Mountain. Briefly, the weeps model assumes that water flow takes place episodically in fracture channels, whereas the composite-porosity model assumes a more uniform distribution of water flow between fractures and the rock matrix. The aqueous-release calculations included a model for transport through the saturated zone from Yucca Mountain to the accessible environment, in addition to the unsaturated-zone transport. The calculated aqueous releases were almost entirely from $^{99}$Tc and $^{129}$I because the other nuclides are retarded by sorption during transport, while technetium and iodine were assumed to be unretarded. Also, technetium and iodine (and carbon) were assumed to be mobilized and dissolved relatively quickly after container failure.

Missing from the TSPA report was a detailed discussion of parameter sensitivities for the aqueous- and gaseous-release calculations: which of the model parameters are the most important? As already mentioned, the answer to this question has considerable relevance to the site-characterization program. Unfortunately, the preliminary nature of the models and results for this TSPA prevents any definitive answer to the question, but the preliminary answer is still of interest.

In the course of the TSPA, Monte Carlo simulations were performed for the purpose of generating the probability distributions shown in Figure 1. Thousands of realizations were computed for the Monte Carlo simulations, with the input parameters varying over wide ranges in most cases. The total-system analyzer (TSA)$^{2,3}$ was used to perform the simulations, with latin-hypercube sampling$^4$ being used to generate the Monte Carlo input "vectors." Thus, without any additional work, we have access to the value of normalized cumulative radionuclide release computed at thousands of points in the parameter space. For this paper, those already-available results are used rather than performing additional computations in some systematic manner.

SCATTER PLOTS

Many methods are available for exploring parameter sensitivities.$^{5,6}$ One of the simplest methods is the scatter plot. A scatter plot is simply a plot of the output value (EPA normalized release) versus one of the input parameters. Because the output values were generated with the Monte Carlo method, not by holding the other input parameters fixed, the points usually have considerable scatter, rather than forming a simple curve. However, for a given Monte Carlo simulation there typically are a few parameters whose scatter plots have noticeable patterns. Those are the parameters to which the results are most sensitive.

As an example, see Figures 2 through 4, which show scatter plots for three of the parameters in the aqueous-release weeps simulation (the model and parameters are discussed briefly in the next section).

Figure 2 shows the scatter plot for fracture aperture. Although there is considerable scatter in the points in Figure 2, a clear trend is visible—larger fracture apertures have lower releases of radioactivity to the accessible environment within 10,000 years. This trend is easily explainable in terms of the workings of the model and is discussed in the TSPA.
report: larger fracture apertures generally mean fewer flowing fractures, and hence fewer waste containers contacted by flowing water and releasing radioactivity. The scatter in Figure 2 is caused by the variation in the other model parameters. A realization could have large fracture apertures but still have high releases because of high groundwater percolation flux, high fuel-matrix-alteration rate, etc. Conversely, if the other parameters are favorable, releases may be low even if fracture apertures are small.

Figure 3 shows the scatter plot for the weep-episode factor (the inverse of the fraction of time that fractures flow; for example, a weep-episode factor of 12 indicates fractures that flow one twelfth of the time, or approximately one month per year). The pattern in these points is much less clear than in the previous plot, but a slight upward trend can be seen. Higher weep-episode factors tend to produce higher releases because water runs in the fractures less often and so more fractures must flow when they do flow to obtain the same average water-flow rate (and therefore more waste containers are contacted). However, the effect is nearly swamped by the variation in other parameters.

Figure 4 shows the scatter plot for container lifetime. This time there is no discernible pattern; the points are seemingly random. Even though it is obvious that releases should be higher for shorter-lived containers, other parameters affect the releases much more strongly and spread out the points in the plot, washing out the pattern.

Note that logarithmic scales were used for the axes in Figures 2 through 4. For nonlin-
Figure 3. Scatter plot of normalized release vs. weep-episode factor for aqueous releases using the weeps water-flow model.

ear processes such as we generally have in models of Yucca Mountain, logarithmic axes are more useful than linear axes. Scatter diagrams plotted with linear axes are not very illuminating because most of the releases are small and are indistinguishable from zero on a linear scale. Another technique that can be used for nonlinear problems is to work with "ranks" rather that actual data values. To do this, the input values are put in order from lowest to highest, and further analysis is based on the rank numbers. Similarly, the output values (values of normalized release) are ranked and their rank numbers are used for the analysis. Log values are used for the discussion in this paper rather than rank values because they are more physical, and they in fact represent the patterns better for these simulations.

REGRESSION ANALYSIS

The fact that the plotted points in Figures 2 and 3 show a linear trend indicates that there is an underlying power-law relationship between fracture aperture and radionuclide release to the accessible environment and between weep-episode factor and release. These relationships can be quantified by the use of linear regression analysis. Before giving the results, a little background discussion is needed.

For a given Monte Carlo simulation, we have a set of input "vectors"

\[
\{x_{1i}, x_{2i}, \ldots, x_{Ki}\}, \quad i = 1, \ldots, N, \tag{1}
\]

where \(x_{ki}\) is the \(k\)th input parameter for the \(i\)th realization, \(K\) is the number of input param-
Figure 4. Scatter plot of normalized release vs. container lifetime for aqueous releases using the weeps water-flow model.

...eters, and \( N \) is the number of realizations. For each set of input values, there is an output value, in this case the calculated value of normalized release. The set of output values may be written as

\[ \{ y_i \}, \quad i = 1, \ldots, N. \]  

(2)

We wish to obtain a formula for \( y \) as a function of the \( x \)s, as follows:

\[ y = b_0 + \sum_{k=1}^{K} b_k x_k. \]  

(3)

The formula in Equation 3 is appropriate for linear regression analysis, since \( y \) is a linear function of the \( x \)s. Regression based on more complicated functions is possible but difficult, and will not be considered here. As indicated above, logarithms have been found to be more useful than raw values for these problems, so the linear regression is conducted in log space. That is to say, logarithms rather than actual values are used for \( y \) and \( x_k \) in Equation 3.

Given the formula in Equation 3, we can calculate a predicted value of output for each set of inputs. That is, we substitute Equation 1 into Equation 3:

\[ \hat{y}_i = b_0 + \sum_{k=1}^{K} b_k x_{ki}. \]  

(4)

The \( \hat{y}_i \)s will not necessarily agree with the \( y_i \)s; the difference is called the residual, and is
denoted by \( \epsilon_i \):
\[
y_i = \hat{y}_i + \epsilon_i .
\] (5)

The object of regression analysis is to determine the coefficients \( b_0 \) and \( b_1 \) that minimize the \( \epsilon_i \)s. Specifically, the coefficients are chosen in such a way as to minimize the sum of the squares of the residuals, \( \sum_{i=1}^{N} \epsilon_i^2 \). As long as there are enough input vectors (i.e., \( N \geq K \)), there should be a unique choice of the \( b_s \) to minimize this quantity.

In actual practice, rather than including all parameters in the regression formula, as in Equation 3, usually only a subset of the input parameters—those that have the greatest impact on the output—is included. A good description of how this is done may be found in the report by Helton et al., the procedure described there is implemented in the STEPWISE computer program. This procedure quantifies the contribution each input parameter makes to the variability of the output values. There is a quantity called \( R^2 \) that is a measure of the goodness of the fit of the regression model to the data, and the contribution that an input parameter makes to \( R^2 \) is a measure of the importance of that parameter. For the purposes of this paper, we need only know that an \( R^2 \) near 1 implies a good fit of the regression model, whereas a value significantly less than 1 implies a poor fit. The contribution that a given input parameter makes to \( R^2 \) will be denoted by \( \Delta R^2 \), and may be thought of as the fraction of the variability in the output values that is accounted for by the parameter. For details, see Helton et al.

RESULTS

Aqueous Releases for the Weeps Model

Some scatter plots for the aqueous-release simulation using the weeps model have already been presented, so the results for that case will be discussed first. The regression model obtained is given by

\[
\log M_a \approx -9.1 - 2.4 \log b + 0.96 \log E \\
+ 1.0 \log |q| + 0.99 \log A + 0.99 \log C \\
- 0.64 \log w_f + 0.53 \log a_m ,
\] (6)

or

\[
M_a \approx \frac{E^{0.96} |q|^{1.0} A^{0.99} C^{-0.99} a_m^{0.63}}{10^{9.1} b^{2.4} w_f^{0.53}} ,
\] (7)

where \( M_a \) is normalized aqueous release (dimensionless); \( b \) is fracture aperture of the flowing fractures (in m); \( E \) is the weep-episode factor (dimensionless); \( q \) is groundwater percolation flux (in m/yr); \( A \) is the absorption factor (dimensionless), which is used in the weeps model to account for reduction in releases due to movement of radionuclides out of fractures and into the rock matrix during transport; \( C \) is the connectivity factor (dimensionless), which is used to account for the possible lack of connectivity in fracture paths from the surface to the repository (and consequent reduction in the number of flowing fractures interacting with waste containers); \( w_f \) is horizontal extent of the flowing fractures (in m); and \( a_m \) is fuel-matrix-alteration rate (in yr\(^{-1}\)), which determines how quickly volatile species (including \(^{14}\)C, \(^{99}\)Tc, and \(^{129}\)I) are mobilized and available for release from the spent-fuel pellets. Details of
Table 1. Parameters important to weeps aqueous releases.

<table>
<thead>
<tr>
<th>No.</th>
<th>Variable</th>
<th>Units</th>
<th>$\Delta R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$b$</td>
<td>m</td>
<td>0.63</td>
</tr>
<tr>
<td>2</td>
<td>$E$</td>
<td>none</td>
<td>0.10</td>
</tr>
<tr>
<td>3</td>
<td>$q$</td>
<td>m/yr</td>
<td>0.10</td>
</tr>
<tr>
<td>4</td>
<td>$A$</td>
<td>none</td>
<td>0.06</td>
</tr>
<tr>
<td>5</td>
<td>$C$</td>
<td>none</td>
<td>0.06</td>
</tr>
<tr>
<td>6</td>
<td>$w_f$</td>
<td>m</td>
<td>0.02</td>
</tr>
<tr>
<td>7</td>
<td>$a_m$</td>
<td>yr$^{-1}$</td>
<td>0.01</td>
</tr>
</tbody>
</table>

The weeps model and its parameters may be found in the TSPA report; see also References 3 and 8. Note that the weep-episode factor is denoted by $F$ rather than $E$ in the previous reports.

The regression model in Equation 7 is a good fit to the simulation results, with an $R^2$ of 0.98. Thus, the seven model parameters in the equation account for about 98% of the calculated variability in the normalized release to the accessible environment. The individual contributions (i.e., the $\Delta R^2$s) are given in Table 1. Equation 7 and Table 1 include all model parameters with $\Delta R^2$ of 1% or greater. The same will be true of the regression models for the other three simulations discussed below.

Table 1 shows that the fracture aperture $b$ is by far the most important parameter in the aqueous-release weeps simulation. This fact is reflected in the clear pattern visible in its scatter plot, Figure 2. Releases have some sensitivity to six other model parameters, but the relationship between input and output is not nearly so striking for those parameters, as can be seen in Figure 3. Releases have very little sensitivity to the model parameters that are not included in Equation 7 (see, for example, Figure 4). It is worth pointing out three things about the results. (1) $M_a$ is essentially directly proportional to $E$, |$q$|, $A$, and $C$. An examination of the model equations shows that this relationship makes sense.\(^1,8\) (2) The $\Delta R^2$ for $A$ and $C$ is smaller than that for $E$ and $q$, even though they all have nearly the same role in Equation 7. This occurrence results from the fact that $\Delta R^2$ is a function of both the intrinsic relationship between release and a given parameter and the form of the probability distribution for the parameter. A wide distribution will tend to increase the $\Delta R^2$, and the input distributions used for $E$ and $q$ are broader than those used for $A$ and $C$. (3) It is important to realize that the fracture aperture $b$ used in the weeps model cannot be determined simply by studying the distribution of fracture apertures in Yucca Mountain. The parameter $b$ represents the fracture aperture of flowing fractures, so determination of $b$ requires studying how water flows in Yucca Mountain—much harder than measuring sizes of fractures in rocks. Similar comments could be made about $E$, $A$, $C$, and $w_f$.

Aqueous Releases for the Composite-Porosity Model

Analysis of aqueous releases using the composite-porosity model has an additional complication in that six aqueous composite-porosity Monte Carlo simulations were performed for the TSPA, for six one-dimensional stratigraphic columns. Releases from the six columns were added, assuming the columns to be independent of each other, to produce the release.
distribution shown in Figure 1. Details may be found in the TSPA report; additional details on the composite-porosity model may be found in Reference 9. For the present discussion, results of the regression analysis for one of the columns will be presented. It was found that column number 6 (representing the eastern part of the potential repository) had the highest releases, so column 6 is used for the regression analysis. Results of regression analyses for the other five columns are essentially the same.

Regression analysis for the simulation of aqueous releases using the composite-porosity model reveals only one model parameter to which normalized release is sensitive—the groundwater percolation flux \( q \). The regression model (for column 6) is given by

\[
M_a \approx 10^{48} \left| q \right|^{19}.
\]

The fit is not as good as for the weeps model—the \( R^2 \) is only 90%; see Table 2. The remarkable sensitivity of aqueous composite-porosity releases to percolation flux can be seen in the scatter plot for that model parameter, shown in Figure 5. Note that the normalized-release axis varies over 40 orders of magnitude. Since the regression model contains only one independent parameter, it is simply a line on a log-log plot, and it is shown as the solid line in Figure 5. However, the points from the Monte Carlo simulation are visibly nonlinear—they are below the regression line at both ends and above it in the middle. Note that 24 of the 300 realizations in the Monte Carlo simulation for column 6 had calculated release to the accessible environment of zero. They are indicated by triangles in Figure 5. (Because of computer truncation error, etc., the smallest nonzero values were in the neighborhood of \( 10^{-38} \); any value below that would end up being calculated as a zero.) In doing the regression analysis in log space for this simulation, it was necessary to discard the realizations with zero release. The regression results are undoubtedly affected by leaving out some of the points in this way, but the conclusion—that percolation flux is the most important parameter and no other parameters have significant influence on release—would still be valid if some other procedure were used for dealing with the zeros.

The points in the scatter plot do not follow a simple line because several processes contribute significantly. At high fluxes, radionuclide transport should be dominated by advection, and cumulative release should be directly proportional to flux (see, for example, Figures 3.3-11 through 3.3-14 and the accompanying discussion in TOSPAC Volume 110). Thus, the slope should approach 1 at the right side of Figure 5. The points are too sparse in that region to be able to confirm the expected behavior with any confidence. At low flux, when the advective transport time is much greater than 10,000 years, radionuclides reach the accessible environment only because of hydrodynamic dispersion and diffusion, so the release-flux relationship is dominated by those processes. As can be seen from the figure, those processes produce a slope much greater than 1. In addition to the physical processes expected to occur, numerical artifacts probably contribute significantly to the very lowest releases; the lowest release points are probably higher than they should be because of "numerical dispersion."10

Table 2. Parameters important to composite-porosity aqueous releases.

<table>
<thead>
<tr>
<th>No.</th>
<th>Variable</th>
<th>Units</th>
<th>( \Delta R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( q )</td>
<td>m/yr</td>
<td>0.90</td>
</tr>
</tbody>
</table>


Figure 5. Scatter plot of normalized release vs. percolation flux for aqueous releases using the composite-porosity water-flow model. The line shows the linear-regression model.

Gaseous Releases for the Weeps Model

The "weeps" and "composite-porosity" models deal with groundwater flow, so speaking of gaseous releases for the weeps model could be a little confusing. The source term for gaseous transport (that is, the amount of $^{14}$C released from the repository) depends on groundwater flow, and so gaseous releases to the accessible environment are different for the two models even though the gas-flow calculation itself is the same for both cases. For details on the model used for gas flow and transport, see the TSPA report and Reference 11.

The regression model obtained for the gaseous-release simulation with the source term calculated using the weeps model is as follows:

$$M_g \approx \frac{|q|^{1.0} E^{0.99} C^{0.99} d_m^{0.56}}{10^{-7.4} b^{2.5} f^{0.80} w_f^{0.71} l_c^{0.56}}$$

(9)

where $M_g$ is normalized gaseous release (dimensionless); $F$ is a "retardation/permeability factor" that is used to scale the gaseous transport times (dimensionless); and $l_c$ is container lifetime (in years). The absorption factor $A$ does not appear because it does not apply to gaseous transport. The fit is a good one, with an $R^2$ of 99%. The $\Delta R^2$s for the individual model parameters are given in Table 3. The results are very similar to the results for the weeps aqueous releases. The scatter plot for the most important parameter, fracture aperture, is given in Figure 6.
Table 3. Parameters important to weeps gaseous releases.

<table>
<thead>
<tr>
<th>No.</th>
<th>Variable</th>
<th>Units</th>
<th>$\Delta R^2$</th>
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<tr>
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<td>m</td>
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</tr>
<tr>
<td>2</td>
<td>$q$</td>
<td>m/yr</td>
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<tr>
<td>3</td>
<td>$E$</td>
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</tr>
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<td>4</td>
<td>$C$</td>
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<td>$w_f$</td>
<td>m</td>
<td>0.02</td>
</tr>
<tr>
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<td>$a_m$</td>
<td>yr$^{-1}$</td>
<td>0.01</td>
</tr>
<tr>
<td>8</td>
<td>$t_c$</td>
<td>yr</td>
<td>0.01</td>
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</table>

Figure 6. Scatter plot of normalized release vs. fracture aperture for gaseous releases using the weeps water-flow model.

Gaseous Releases for the Composite-Porosity Model

The regression model obtained for gaseous releases using the composite-porosity model to generate the source term is given by

$$M_8 \approx \frac{10^{4.2} a_m^{0.56} |q|^{0.13} f_p^{0.31}}{F^{0.82} t_c^{0.68} |q_0|^{0.12}}$$

(10)

where $q_0$ is the threshold flux for fracture flow (in m/yr) and $f_p$ is the prompt-release fraction of the $^{14}$C inventory (dimensionless), which is available for release as soon as containers fail. The fit is good, but not quite as good as for the weeps model, with an $R^2$ of 95%.
Table 4. Parameters important to composite-porosity gaseous releases.

<table>
<thead>
<tr>
<th>No.</th>
<th>Variable</th>
<th>Units</th>
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</tr>
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<td>yr$^{-1}$</td>
<td>0.22</td>
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<tr>
<td>4</td>
<td>$q$</td>
<td>m/yr</td>
<td>0.03</td>
</tr>
<tr>
<td>5</td>
<td>$q_0$</td>
<td>m/yr</td>
<td>0.02</td>
</tr>
<tr>
<td>6</td>
<td>$f_p$</td>
<td>none</td>
<td>0.02</td>
</tr>
</tbody>
</table>

The $\Delta R^2$s for the important model parameters are given in Table 4. It can be seen that composite-porosity gaseous releases are much more sensitive to the gaseous transport time (represented by the retardation/permeability factor $F$) than the weeps gaseous releases were. The retardation/permeability factor is a combination of two factors that affect the gaseous transport time—retardation due to exchange of $^{14}$C between gas, aqueous, and solid phases, and permeability of the rock to gas flow. Two source parameters, container lifetime and $f_m$ matrix-alteration rate, are also quite important in this simulation. Scatter plots for retardation/permeability factor and alteration rate are given in Figures 7 and 8.

A nonlinear trend can be seen in the retardation/permeability scatter plot, Figure 7. For $F > 1$, the trend is linear, but there appears to be a bend at approximately $F = 1$. This behavior makes sense physically because for very short $^{14}$C transport times (small values of $F$) all $^{14}$C released from the repository may reach the accessible environment within 10,000 years, whereas if the transport time is long (large values of $F$) only a small fraction of the released $^{14}$C can reach the accessible environment within 10,000 years and transport becomes a controlling process. Thus, we would expect that, if the distribution of retardation/permeability were extended to smaller values, the low-$F$ part of the log-log scatter plot would have a linear trend with slope zero. The observed nonlinear behavior in the most important parameter ($F$) is likely the reason that the $R^2$ is only 95% for this simulation.

CONCLUSIONS

An obvious first observation is that the results presented here are highly sensitive to the choice of model for unsaturated-zone flow and transport ("weeps" or "composite-porosity"). Therefore, it is important to come to a better understanding of how water flows through Yucca Mountain. This understanding cannot come from modeling alone, but must be attained through study of the site. The recent resumption of work on site characterization should help to alleviate some of the uncertainty. If episodic fracture flow is found to be important in Yucca Mountain, then the weeps model may be the better representation of the flow. If it is found that most episodic fracture flow is damped out before it reaches the potential repository depth, then the composite-porosity model may be the better representation. Additional study of the effects of heterogeneity and of thermal effects is needed, because those effects are not well represented in the present study.

It must be emphasized that the results presented regarding which model parameters are most important are very much dependent on the particular models chosen for the study.
If the wrong models were used, or the wrong parameter distributions, sensitivity analysis would not tell us so. But sensitivity analysis should give us a better idea of where to expend our resources—which models or parameter distributions need improvement and which ones appear to be unimportant to the final results. It is likely that the parameters identified here as important are indeed important, but there may be other important quantities that are not identified. The models used are preliminary; too much has been left out to be able to draw strong conclusions on which to base program decisions.

It is important to keep in mind that we can only see sensitivity to the parameters that are included in the models. Also, if a parameter is held constant, sensitivity of results to it cannot be determined. For this TSPA, many variables (especially source-term parameters and saturated-zone parameters) were assigned constant values simply for the sake of expediency. The lists of important parameters in this paper may be incomplete because of this simplification. If, in the future, distributions are assigned to parameters that were held constant this time, or if distributions are changed significantly for parameters that had distributions this time, the rankings of importance could change.

With these caveats in mind, the findings of this sensitivity study may be summarized by the following observations. For the composite-porosity model, percolation flux is a critical parameter for aqueous releases. It has two important roles in the calculations, affecting both the release rate from the engineered-barrier system (EBS) and the aqueous transport velocity. Percolation flux does not affect gaseous releases as strongly as it affects aqueous releases.

Figure 7. Scatter plot of normalized release vs. retardation/permeability factor for gaseous releases using the composite-porosity water-flow model.
Most important for the gaseous releases are the $^{14}$C transport time and the $^{14}$C release rate from the repository. These processes are represented by the retardation/permeability factor, container lifetime, and fuel-matrix-alteration rate in the list of important parameters. The results indicate a need for more information on large-scale bulk permeability and on retardation mechanisms for $^{14}$C. They also indicate that the EBS is more important for limiting gaseous releases than aqueous releases.

The weeps model is basically a simple method of estimating how many waste containers may be affected if water flow is primarily in the form of episodic flow down fractures. Going into that estimate are parameters describing the fracture network (fracture aperture, width, and connectivity) and parameters describing water infiltration (mean percolation flux, weep-episode factor). Because of the functional dependence, fracture aperture turns out to be the most important parameter in the weeps model, but the others are important, too. For the weeps model, transport times and EBS release rates are much less important than for the composite-porosity model. Source parameters (container lifetime, fuel-matrix-alteration rate) and transport parameters ("absorption factor" for aqueous transport, "retardation/permeability factor" for gaseous transport) affect the weeps results only weakly.

REFERENCES


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