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Total-System Analyzer
for Performance Assessment of Yucca Mountain*

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Abstract

The Total-System Analyzer is a modular computer program for probabilistic
total-system performance calculations. The code employs stratified random
sampling from model parameter distribution functions to generate multiple
"realizations" of the system. The results of flow and transport calculations
for each realization are combined into a probability distribution function of
the system response as indicated by the performance measure. We give a
detailed description of the code and present results for four example
problems simulating the release of radionuclides from a proposed high-level-
waste repository at Yucca Mountain, Nevada. The example simulations
illustrate the impact of significant variation of percolation flux and
sorption on radionuclide releases. We discuss the effects of numerical
sampling error and of correlations among the model parameters.

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Introduction

Sinnock, Lin, and Brannen conducted the seminal study of the performance of a proposed geologic repository for high-level radioactive waste located in the vadose zone at Yucca Mountain in Nevada; they used simple analyses that attempted to simulate the "total system." At present, a number of research groups are developing integrated computer codes to perform more complex simulations of the total system. These codes are less detailed than the process codes that fully model the subsystems because the total-system codes generally must produce large numbers (>1000) of distinct computations to statistically treat the inherent uncertainties in physical parameters of the geologic media, in conceptual models of flow and transport phenomena, and in changes to the total system caused by man and nature over time scales of 10,000 to 100,000 years. This paper discusses a new code that is the first iteration in a planned evolving family of continually more sophisticated Total-System Analyzer (TSA) codes.

It is our view that a TSA code is only one part of the overall performance-assessment process. Performance assessment encompasses (1) general and detailed engineering analyses; (2) detailed phenomenological models of the engineered- and natural-barrier systems; and (3) total-system analyses and computations. At the present, total-system codes lack refinement and the ability to discriminate among detailed options for design or for technical direction. Nevertheless, total-system codes can be used in conjunction with the other performance-assessment tools to assist in guiding technical direction and setting resource priorities.
Several elements make up a total-system analysis: development of a set of scenarios and their associated probabilities, selection of conceptual models, estimation of parameter uncertainty, calculation of consequences for the scenarios considered, computation of the complementary cumulative distribution function (CCDF), and the analysis of uncertainties as they relate to the performance measures. This paper focuses primarily on the calculations of consequences and CCDFs. Treatment of model and parameter uncertainties is limited. The major emphasis is discussion of the present and near-term capabilities of the analyzer code itself.

Initially, the most useful capability of the TSA is the ability to perform numerical experiments that reflect the uncertainty and variability in the data and models representing the physical system. The computational experiments undertaken for the purposes of this paper explore the significance of preserving the dependencies among the parameters in hydrologic, geologic and transport models when using Monte Carlo simulation; the consequences of using radically different models for transport of radionuclides; the importance of the saturated zone as a component of the hydrologic pathway to the accessible environment; and the effect of percolation rate as the determinant of the dominant flow mechanism in the unsaturated zone. These numerical experiments are intended to demonstrate the utility of the TSA as a simulation tool. Although some of the parameter values are derived from the Yucca Mountain data base, the results should not be construed as performance calculations for a high-level-waste repository.
Overview of the Total-System Analyzer (TSA) Code

The TSA is an assembly of computational modules in a software environment that coordinates execution of the modules and facilitates data manipulation. The various modules include the driver program, the multivariate sampler, the system process simulator, and the post-processor. Figure 1 illustrates the interrelationship of the various segments of the code in the computational process.

The driver program currently in use is RS/1, a commercially developed analysis-software system that integrates data management, statistical analysis, and graphical presentation of data. The primary use of the RS/1 software as applied in the TSA is as a software driver and database manager. As a data manager, RS/1 facilitates the input of the initial data and manipulates the data structures to interface with data format requirements of the computational modules. As a driver, RS/1 coordinates the execution of the modules. In postprocessing, RS/1 is used to assemble and present the output data in the format selected by the user. In its present configuration, the TSA can also be run without the RS/1 shell by constructing the input files using a text editor.

To reflect the variability and uncertainty associated with the system, multiple realizations of the system are generated using constrained random sampling. Values of the geologic, hydrologic, and waste-system properties are randomly selected from specified distributions for each parameter. The technique used is Latin hypercube sampling (LHS), a stratified sampling technique that can yield more precise estimates than those obtained by a
random Monte Carlo sample of the same size; conversely, it can achieve the same precision with a sample of smaller size. The code provides for eight common probability distribution functions, and an option for user-defined distributions may be implemented. The range of each user-selected variable distribution is subdivided into the same number of equal-probability intervals as the specified number (N) of realizations. A value for the variable is randomly selected from each sub-interval. Values of the variable are paired successively in a random manner with values of variables previously selected to form N ordered vectors of the input variables for the simulation of N realizations.

In stochastic simulation using the Monte Carlo method, each realization of the system ideally would be sampled from a K-dimensional multivariate distribution of the K system parameters. Practical application of the Monte Carlo technique generates each realization by sampling from K independent parameter distributions. Dependencies among parameters are not preserved in the corresponding values of the parameters in the realizations. Preservation of dependencies may be of considerable importance in process models that demonstrate a sensitivity to the extreme parameter values that are located in the tails of the distributions. The LHS procedure used in the TSA incorporates the option of a restrictive pairing technique\textsuperscript{4} that preserves the appropriate rank correlation structure among specified variables.\textsuperscript{5}

The simulation module calculates water flow and radionuclide transport in the unsaturated and saturated zones for each of the realizations generated by the multivariate sampler. At present, only aqueous transport is included. Transport of $^{14}$C in the gas phase as carbon dioxide may be important,\textsuperscript{6} but is
not included in this paper. For flow and transport in the unsaturated zone, we are using TO\textsc{spac},\textsuperscript{7} a computer code for isothermal, one-dimensional, vertical groundwater flow and contaminant transport through partially saturated, fractured, porous media. A composite-porosity model,\textsuperscript{8} based on an assumption of pressure equilibrium between the matrix and the fractures, is used in calculating the flow field. Constitutive relations for permeability and saturation as a function of effective pressure head are as formulated by Mualem\textsuperscript{9} with van Genuchten\textsuperscript{10} fitting parameters. Calculations are based on the solution of finite-difference formulations of the governing differential equations. The steady-state flow field is obtained by solving the equation expressing Darcy’s law for unsaturated media. The contaminant transport dual-continuum model accounts for advection, diffusion, hydrodynamic dispersion, radionuclide source, and radioactive decay. Adsorption is modeled by including a retardation factor in the advective and dispersive terms. A matrix/fracture coupling term allows diffusive or advective transfer of contaminants between the fluid in the matrix and the fractures.

The radionuclide source term being used is a slight variation of the congruent-leach source described by Dudley et al.\textsuperscript{7} Most nuclides are assumed to be released congruently with the uranium dioxide as it dissolves. For the more volatile species (only $^{99}$Tc and $^{129}$I, of the nuclides included in this paper), a quick-release fraction is included. The quick-release fraction of the inventory is contained in the pellet-cladding gap and the grain boundaries of the spent fuel, and is assumed to be released immediately upon canister failure. The rest of the inventory can start dissolving after the canister fails. An exponential canister-failure distribution is assumed in the \textsc{tospac} source term.
To extend the flow path from the bottom of the one-dimensional unsaturated columns calculated by TOS PAC through the saturated zone to the accessible environment 5 km away, a simple semianalytic solution to the advection-dispersion equation was used. The formula used is

\[ R = \int_0^r dr \Sigma(r) \int_0^{T-r} dt P(t)e^{-\lambda t}, \]

\[ P(t) = \left[ \frac{d + vt/R_d}{2t} \right] \left[ 4\pi Dt/R_d \right]^{-1/2} \exp \left[ -\frac{(d-vt/R_d)^2}{4Dt/R_d} \right]. \]

Here, \( R \) is the cumulative amount of radioactivity reaching the accessible environment within the regulatory period \( T \) (10,000 yr); \( \Sigma(r) \) is the rate at which radioactivity reaches the water table in Ci/yr, taken from the TOS PAC calculation; \( \lambda \) is the radioactive decay rate; \( d \) is the distance to the accessible environment; \( v \) is the effective water velocity; \( R_d \) is the sorptive retardation factor; \( D = \alpha_L \) is the dispersion coefficient; and \( \alpha_L \) is the dispersivity. The above double integral is calculated numerically for each realization. Note that, although TOS PAC correctly calculates radioactive decay and generation for radionuclide chains, the formulas used for the saturated-zone transport are only valid for simple radioactive decay and not for decay chains.

The EPA regulations in 40 CFR Part 1911 specify restrictions on the probability distribution for cumulative releases of radioactivity to the accessible environment within 10,000 years after repository closure. For each radionuclide with half-life greater than 20 years, there is an "EPA
"limit" which depends on the amount and category of radioactive waste. For a
given realization, the ratio of a radionuclide's calculated release to its EPA
limit is its "EPA ratio". The sum of the EPA ratios for all species is
referred to as the EPA sum, and according to the EPA regulations a
probability distribution is to be constructed for the EPA sum. The
regulations state that there should be less than one chance in ten of the EPA
sum being greater than one, and less than one chance in 1000 of the EPA sum
being greater than ten. The complementary cumulative distribution function
(CCDF) is defined as the probability that the EPA sum exceeds any given
value. If we denote the CCDF by \( G(m) \), the regulatory requirements may be
restated as \( G(1) < 0.1 \) and \( G(10) < 10^{-3} \).

The random sampling is executed in such a way that all realizations are
equally likely, so the CCDF, \( G(m) \), is given by the number of realizations in
which the EPA sum is greater than \( m \) divided by the total number of
realizations. In the EPA regulations, the calculated CCDF is expected to
take into account all significant features, events, and processes and the
effects of alternative conceptual models and uncertainties in the model
parameters. A CCDF calculated with a restricted set of assumptions, like
those presented later in this paper, is a "conditional" CCDF. It is possible
to construct the total CCDF from conditional CCDFs as long as all possible
features, events, and processes, and conceptual models are taken into account
without overlap.
Results

In this section, we will present results of a number of TSA calculations. These results are intended solely as illustrations of the capabilities of the TSA rather than as definitive simulations of Yucca Mountain. The following four problems were selected; they describe phenomena that are expected to be important to considerations of the suitability of Yucca Mountain for a high-level radioactive-waste repository: (1) A "base" case that will be described below; (2) a "high flux" case, in which the percolation rate of water at depth is increased by a factor of 10 over the base case; (3) a "fast plutonium" case, in which it is assumed that plutonium does not sorb to the rock or diffuse from fractures into the matrix pores; and (4) a "high flux, fast plutonium" case that is a combination of (2) and (3).

The parameter values for the base case were chosen to be in ranges that we consider to be reasonably representative of what is known about Yucca Mountain. No attempt was made to make the parameter values conservative (in the sense of tending to produce higher releases of radioactivity to the accessible environment); some of the parameter distributions could be considered conservative, but others clearly are not. One of the most important issues regarding the safety of a repository at Yucca Mountain is whether the water flow is primarily through the rock matrix or through fractures. In the base case, the distribution of percolation rates is chosen to have a mean value of 0.2 mm/yr, which produces water flow mainly through the matrix (according to the flow model being used, as discussed above). In the high-flux case, the mean percolation rate is taken to be 2 mm/yr, which
is high enough to produce significant amounts of flow in the fractures. In the base and high-flux cases, transport of plutonium and the other actinides is negligible because of large retardation factors due to sorption and matrix diffusion. The fast-plutonium cases are included here to illustrate the effect of eliminating retardation from plutonium transport. The fast-plutonium cases may be thought of as extreme representations of the effects of colloid transport of plutonium. A realistic model of colloid transport would be expected to have lower releases than our fast-plutonium cases for two reasons: first, it is unlikely that 100% of the plutonium would form colloids, so the releases would be reduced by a factor equal to the fraction of plutonium that is transported as colloids; and second, the transport of colloids through fractures would be reduced by filtering of colloidal particles by restrictions in fractures and trapping by fracture termination.12

Only five radionuclides were included in these calculations: 238U, 239Pu, 240Pu, 99Tc, and 129I. Because these five nuclides are expected to account for most of the releases in the problems considered, so the EPA sums would not be dramatically different if all radionuclides were included. EPA release limits per 1000 metric tons of heavy metal are 100, 100, 100, 10,000, and 100 curies, respectively, for the radionuclides selected (from 40 CFR Part 191).11 In the base case and the high-flux case, most releases are from 99Tc and 129I because of their low retardation factors, their high solubility, and the 1% quick-release fraction assumed for those nuclides. In the fast-plutonium cases, most releases are from plutonium because of the very low retardation assumed. We included 238U in the calculations primarily
because of its role in the source term. The spent-fuel pellets are mostly uranium dioxide, and most of the uranium is \(^{238}\text{U}\). Thus, for the congruent-leach source term used, releases from the waste canisters are determined by how fast the \(^{238}\text{U}\) dissolves.

To model the problems, four one-dimensional columns representative of Yucca Mountain were selected. Each column was considered to contain one-fourth of the 70,000-metric-ton radionuclide inventory. The locations of the columns and the four stratigraphies used are shown in Figure 2. For each column, model parameters were assumed to be constant within each hydrogeologic unit but the parameters were varied for different realizations, with beta probability distributions used for each variable. A list of the model parameters and their values in the base case is given in Table 1. Detailed definitions of all the parameters may be found in the TOSpac reference. Only the mean and coefficient of variation are given for each variable. For the beta probability distribution, it is also necessary to specify maximum and minimum values for each variable; however, the reader can obtain a good idea of the distributions used by examining Table 1. For the base case and the three other cases discussed above, all variables were assumed to be uncorrelated. The effects of correlations among the model parameters within each unit were explored to a limited extent and are discussed later. In all cases, values of the variables in different columns were assumed to be uncorrelated because of the large distances separating the columns; that is, the columns were completely independent of each other. Inclusion of spatial correlation of the same parameters in different columns is the subject of future work.
A detailed discussion of the origins of all the numbers in Table 1 would be too long for the present paper. Briefly, however, the hydrologic parameters are based on data from Peters et al.,13 the distribution coefficients (KdS) are based on data from Tien et al.,14 the saturated-zone properties are based on the discussion in Sinnock et al.,1 and the matrix tortuosities are based on data from Daniels et al.15 No data for dispersivity are known to us, but de Marsily16 has suggested as a general rule of thumb that dispersivity is about one-tenth of the path length. The velocity-correlation-length parameters are also unknown, but a small value such as 10 m is somewhat conservative. The initial inventories were taken from Roddy et al.,17 and are based on 70,000 metric tons of spent fuel from a pressurized-water reactor with burnup of 33,000 MWD/MTHM. The value of the percolation rate at depth is unknown, but Montazer and Wilson18 estimated the average recharge below Yucca Mountain at between 0.5 mm/yr and 4.5 mm/yr. A recent modeling study by J. H. Gauthier (in preparation), based on measured in-situ saturations, suggests that the percolation rate may be 0.01 mm/yr or lower. Our base value of 0.2 mm/yr is a compromise, roughly at the geometric mean of 0.01 mm/yr and 4.5 mm/yr. The high-flux value of 2 mm/yr is near the middle of Montazer's and Wilson's range. For the distribution used in the high-flux case, approximately 10% of the fluxes were over 4.5 mm/yr. The coefficients of variation were not generally based on actual data, but rather were chosen to give broad distributions, to reflect the great uncertainty in the values. Where a zero is indicated for the coefficient of variation, the parameter was taken to be constant for these calculations. This was for convenience, not because we believe there is no variation. Beta probability
distributions were used because they are convenient to work with, and they have been recommended for problems of this sort by Kaplan and Yarrington.\textsuperscript{19}

For each problem, 200 realizations were run for each of the four columns, making a total of 800 runs for each problem. The runs were made on a VAX 3600 and a Sun SPARCstation; the Sun is almost three times as fast as the VAX, so most of the runs were made on the Sun. Individual runs required between 1 and 4 min. The 800 runs for a full problem took about 1 to 2 days of computer time. The results of the calculations, in the form of CCDFs for the EPA sum, are shown in Figure 3. The limits imposed by the EPA regulations are shown as a solid line, and the CCDFs for the example calculations are shown with various broken line-types. Except for the high-flux, fast-plutonium case, most of the sampled EPA sums are off the scale in Figure 3. Only about 1% of the base case sums and about 40% to 45% of the sums for the high-flux and fast-plutonium cases were greater than 10\textsuperscript{-18}. Not surprisingly, the two fast-plutonium cases have much higher releases than the other two cases. All cases except the high-flux, fast-plutonium case are well below the EPA limits. With the higher flux distribution and the fast-plutonium assumption, the EPA limits are exceeded slightly. This is not a cause for concern, because we consider the fast-plutonium cases to be highly unrealistic, as discussed earlier. However, it does show that we must be able to rule out such behavior with high confidence in order to have a reasonable expectation of satisfying the EPA regulations.

To get an idea of the sampling error (the random error associated with taking a finite number of samples in the Monte Carlo simulation), we ran the calculation of column D for the high-flux case four times with different
seeds for the random-number generator. The results are shown in Figure 4. The high-flux case is used for this discussion rather than the base case because releases are so low in the base case that the results have very low statistical significance; the situation is somewhat better in the high-flux case, but the number of samples showing significant release is still rather low even with the higher flux. In Figure 4, the four curves are quite close together for EPA sums below about $10^{-13}$. At $10^{-13}$, the complementary cumulative probability is approximately 0.15. Since each calculation includes a total of 200 samples, a probability of 0.15 represents about 30 samples. That is, of the 200 runs only about 30 had EPA sums greater than $10^{-13}$. The curves extend down to a probability of 0.005, which represents one sample. It is not surprising that there would be a great deal of random error in the part of the curve that represents only a few samples, but it is a good sign that when the curves are high enough to represent ten samples or so, they are reasonably stable. It should be kept in mind when looking at all the other figures that the random sampling error makes them uncertain, and the amount of the uncertainty may be estimated from Figure 4. In particular, it should be noted that even though the curves in Figure 3 go down to a probability of $10^{-3}$, the sampling error makes them unreliable below about $5 \times 10^{-2}$. It should also be kept in mind that there are non-random errors due to uncertainties in the models and parameter values used. We make no attempt to quantify this source of error in the present report.

In Figure 5 we show the individual CCDFs for the four flow columns in the high-flux case. It can be seen that most of the releases are through column D, which is the shortest of the four columns. The behavior is similar in the
other three cases. In addition to the shorter flow path, both units in column D have low matrix conductivity (see Table 1), which tends to favor diversion of water into the fractures. It should be emphasized at this point that such conclusions are dependent on the choices we have made for flow models and parameter values.

To go from CCDFs for the individual columns such as the ones shown in Figure 5 to the problem CCDFs shown in Figure 3, it is necessary to combine the results for the four columns for each case into a single CCDF. Since we are assuming the four columns to be independent, the proper way to merge the CCDFs is to take all combinations of four EPA sums, one from each column. The four individual sums are added to obtain the EPA sum for the combination. With 200 release numbers for each of the four columns, there are $200^4 = 1.6 \times 10^9$ possible combinations. It is impractical to calculate this many combinations, so we randomly chose 10,000 combinations and used these to generate the combined CCDF. This step introduces additional random error to the CCDF but, by choosing a large number of combinations, the error should be small compared to the random error associated with taking only 200 samples for each column.

To illustrate the importance of the saturated zone as a barrier to releases, the CCDFs for the four example problems, calculated as if the accessible environment were at the water table under Yucca Mountain rather than 5 km away, are shown in Figure 6. If Figures 3 and 6 are compared, it can be seen that the saturated zone reduces releases in the base case and the high-flux case considerably, but has little effect on releases in the fast-plutonium cases. The reason for this is simple: in Table 1, it can be seen
that in the base case (and in the high-flux case, also) the mean effective water velocity in the saturated zone was taken to be 0.1 m/yr. For a distance of 5 km, that translates into a travel time of 50,000 yr. In the fast-plutonium cases, however, the effective velocity of plutonium was taken to be 1000 times higher, leading to a mean travel time of only 50 yr. The reason for taking a higher velocity for plutonium is that one of the assumptions in the fast-plutonium cases is that there is no matrix diffusion; we assume that matrix diffusion provides an effective retardation factor of 1000 in the saturated zone (that is, the matrix porosity is 1000 times greater than the fracture porosity), so plutonium travels 1000 times faster than the other species.

Additional simulations were conducted to evaluate the sensitivity of the flow and transport models used in the TSA to dependencies among some of the variables. The calculations included, as discussed above, a baseline with no correlations and two other calculations, each with different correlation structures. The first correlation structure was based on published relations between the saturated conductivity, residual saturation, and the van Genuchten \( \alpha \) and \( \beta \) parameters for twelve distinct soil types, as determined by Carsel and Parrish.\(^{20} \) These correlations were intended as generalized relations among the specified hydrogeologic parameters. The specific numerical values determined from Carsel and Parrish were categorized as high or medium positive correlations or similar negative categories. These categories were expressed numerically as 0.99, 0.5 for the positive values and -0.99, -0.5 for the negative. A value of zero represented no correlation between parameters. For the matrix of the hydrogeologic units, values of the

-16-
Carsel and Parrish correlations associated with the least permeable soil type, silty clay, were used; for the fractures, the correlations obtained for sand were appropriated. The same correlation structure was assumed for all the units in the columns used. The second set of correlations was constructed subjectively using intuition and experience to estimate dependencies among parameters. For the rock matrix the correlations among the porosity, saturated conductivity, bulk density, and the van Genuchten $\alpha$ parameter were quantified as discussed above. Similarly for fractures, the porosity, saturated conductivity, van Genuchten $\alpha$, and percolation flux were assigned correlations. The two correlation structures are represented by matrices in Table 2.

The CCDFs associated with the uncorrelated and correlated cases are illustrated in Figure 7 for one of the columns in the high-flux case. From the figure, the effect of the first correlation set on the resultant CCDF appears to be minor. The second correlation set has a noticeably greater effect near the tail of the distribution. The three calculations shown in Figure 7 all used the same random seed, so the differences arise only from the different correlation structures. The degree of sensitivity to the correlations and the relevance of correlation structure on the simulations can only be established through additional efforts that aim to identify the dominant parameters and the appropriate correlation structure among them and to simulate their effects.
Conclusions

The effort described in this paper is ongoing. Many simplifying assumptions are required at present to construct a full system code that can be used for a large number of numerical simulations at reasonable cost. Therefore, calculated results from this and similar codes must not be used by themselves to draw firm conclusions or to make decisions at this time. Much work remains before our confidence in system codes can increase significantly. Improvements in the quantity and quality of site data are also indispensable in the overall evolution of performance-assessment capabilities.

We have created a modular program that will evolve in the future. In the next few years, we expect to make significant modifications to the code, including advanced source-term models, two-dimensional transport models for the vadose zone, two-dimensional transport models for the saturated zone, gas-phase transport models, and several additional scenario-class models. Farther in the future will be fully three-dimensional transport computational models, perhaps employing advanced, massively parallel, computers.
References


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<th>Parameter</th>
<th>Value (Standard Deviation)</th>
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<td>CPFv</td>
<td>0.29 ± 0.73</td>
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Table 1: Parameter values for the base-case calculation.

- **TSW**: Total Soluble Waste
- **CPFu**: Chromium(III) Pyrophosphate
- **CPFv**: Chromium(VI) Pyrophosphate

Units are meters-kilograms-years-moles. First value is mean of the probability distribution, value in parentheses is coefficient of variation (standard deviation divided by mean).
Table 2. Parameter Correlation Structure

**First Correlation Structure, Soil Model**

Matrix Parameter Correlations, Silty-clay Model

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Fracture Parameter Correlations, Sand Model

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**Second Correlation Structure, Subjective Model**

Rock Matrix Parameter Correlations

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Fracture Parameter Correlations

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Figure 1. Total-system analyzer flow chart.
Figure 2. Hydrogeological stratigraphy at selected locations at Yucca Mountain.
Figure 3. Conditional CCDFs for the four example problems.

(a) High-flux, fast-plutonium case; (b) fast-plutonium case;
(c) high-flux case; (d) base case. The solid line shows the EPA limits.
Figure 4. Partial CCDFs for column D in the high-flux case using four different seeds for the random-number generator.
Figure 5. Partial CCDFs for the four one-dimensional columns in the high-flux case.
Figure 6. Conditional CCDFs for the four example problems with the accessible environment taken to be at the water table. (a) High-flux, fast-plutonium case; (b) fast-plutonium case; (c) high-flux case; (d) base case. The solid line shows the EPA limits.
Figure 7. Partial CCDFs for column D in the high-flux case with three different correlation structures. (a) No correlations between parameters; (b) the first correlation structure (soil data); (c) the second correlation structure (subjective).
Appendix

Information from the Reference Information Base
Used in this Report

This report contains no information from the Reference Information Base.

Candidate Information
for the
Reference Information Base

This report contains no candidate information for the Reference Information Base.

Candidate Information
for the
Site & Engineering Properties Data Base

This report contains no candidate information for the Site and Engineering Properties Data Base.
END

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03/07/91