Ultimate Final Draft 12/19/91

Conf-920430--20-Draft

SAND91-2056C

YUCCA MOUNTAIN PROJECT TOTAL-SYSTEM PERFORMANCE ASSESSMENT PRELIMINARY ANALYSES: OVERVIEW [a]

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SAND--91-2056C

DE92 005320

ABSTRACT

Sandia National Laboratories and Pacific Northwest Laboratory have produced a coordinated initial total-system performance assessment analysis for the potential repository at Yucca Mountain. Analyses included radionuclide transport via groundwater and gas flow, human intrusion, tectonism, and basaltic igneous intrusion. Both abstracted and detailed calculations were used for the analyses. Probabilistic release distributions were calculated for the individual components, and a combined distribution for the overall behavior of the system was constructed. Results from the analyses using abstracted models indicate that this method produces reasonable outcomes based on our current understanding of the site.

INTRODUCTION

In 1991, a set of preliminary total-system performance assessment (TSPA) analyses were performed by Yucca Mountain Site Characterization Project (YMP) participants.[1] Sandia National Laboratories (SNL) and Battelle Pacific Northwest Laboratory (PNL) were both involved in performing the calculations. Other YMP participants who provided data for various elements of the TSPA included Lawrence Livermore National Laboratory, Lawrence Berkeley Laboratory, and Los Alamos National Laboratory.

[a] This work was prepared by Sandia National Laboratories, Albuquerque, New Mexico, 87185, and Livermore, California, 94550, for the United States Department of Energy under contract DE-AC04-76DP00789.

The primary goal of this work for SNL was to work on a particular part of the process described in Section 8.3.5.13 of the Yucca Mountain Site Characterization Plan :[2] namely, to develop abstract, simplified representations of more complex, detailed processes that require extensive numerical calculations. Another goal was to apply these representations to the generation of complementary cumulative distribution functions (CCDFs) of the type that will eventually be used to examine the ability of the Yucca Mountain site to comply with regulations. This type of application is expected to provide information useful in guiding tests to characterize the site and in aiding design studies.

The TSPA analyses reflect our current understanding of the phenomena that may occur at a potential nuclear waste repository at Yucca Mountain. However, there are many uncertainties in our knowledge of the parameters of the problem. Because of this, conservative assumptions were incorporated into many aspects of the problem. This use of multiple conservatisms may result in higher releases than are scientifically defensible.

These calculations, or future calculations that use similar tools, are expected to ultimately contribute to estimates of the site's ability to comply with total-system regulations. This first set of analyses is not comprehensive in terms of components modeled, nor should the data or models be considered validated. The analyses may be the first in a periodic series of preliminary total-system evaluations, if the YMP elects to perform such a series. We would expect subsequent TSPA analyses to expand upon and add new elements of the total-system evaluation not included in this set of calculations.

To develop appropriately abstracted models for use in a total-system analyzer, SNL used the results of prior detailed calculations. An important part of the development for this effort was the construction of these abstracted models. In contrast, PNL relied on calculations using detailed models as the basis for their total-system analyses.

The TSPA analyses by SNL produced an overall measure of system performance in the form of a single CCDF of radionuclide releases from four components: nominal geohydrologic conditions, gas flow, human intrusion, and igneous intrusion. Climate change was treated by using an expanded range of groundwater infiltration rates. The technical bases for these analyses were derived from prior HYDROCOIN[3] and PACE-90[4] work, as well as from detailed calculations performed for the YMP Early Site-

Suitability Evaluation[5] in 1991. The TSPA differed from previous calculations in that these simulations were stochastic, the set of phenomena modeled was expanded, the transport processes were modeled to the accessible environment, and a larger number of radionuclides was included in a more complex source term. In addition, results obtained by both SNL and PNL were used by PNL to calculate doses.[6]

The analyses done by PNL used several performance-assessment codes to model the components of a repository system.[7] All the analyses depended on the results of a detailed geohydrology base-case calculation using SUMO.[8] This base-case calculation was then used as the basis for calculating consequences of release for disruptive scenarios.

Other total-system performance assessment analyses are currently being undertaken by Golder Associates[9] and the Electric Power Research Institute.[10] These analyses are somewhat different in approach and have different objectives.

DESCRIPTION OF ANALYSES

A. Groundwater Flow

The groundwater flow analyses considered both matrix-dominated and fracture-dominated groundwater flow and transport processes in the unsaturated zone, and flow and transport in the saturated zone.[1,11,12] Thermal effects were included indirectly in the unsaturated flow model.[13] Although the performance of the entire repository was modeled, the TSPA problem domain was represented by a 2-D cross-section of Yucca Mountain, from drillhole USW H-5 on the west to 500 m east of drillhole UE-25a#1.

The stratigraphy for this cross-section has been somewhat simplified from that used previously.[4] It includes the Ghost Dance Fault, with 14 meters of offset, and five representative stratigraphic layers with varying hydrologic properties (Figure 1). The detailed definition of each stratigraphic layer was based on data from drillholes located along the line of the cross-section. A number of actual tuffaceous layers with similar properties were grouped into the five representative layers, which were identified using the dominant lithology present in these zones.[1] The five layers identified from the repository horizon to the base of the unsaturated zone were the following: Layer 1 - welded tuff, Layer 2 - vitrophyre, Layer 3 - zeolitic tuff, Layer 4 - vitric tuff, and Layer 5 - partially welded tuff. For each of the five layers, hydrologic parameters and probability distribution functions for those parameters were chosen using site and analog data.[1]

The composite-porosity conceptual model for fracture-matrix interactions was used to simulate matrix-dominated flow in the unsaturated zone. To simulate fracture flow, the TSPA that incorporated a fracture-flow model used a simplification of a nonequilibrium matrix-fracture model.[12,14] The abstraction was based on the results of explicit matrix-fracture calculations that include both fracture flow and matrix imbibition. Figure 2 shows some of the factors used to define the models for groundwater flow and transport. Both the fracture- and matrix-dominated detailed flow analyses were parameterized by groundwater infiltration rate and fracture properties. The composite-model analysis was additionally parameterized by using variations of hydrogeologic properties (Figure 2). Release distributions were estimated from the detailed calculations described above combined with an assumed partitioning of occurrence for matrix-dominated versus fracture-dominated flow processes.[11]

Saturated-zone flow and transport within the tuff aquifer was modeled using a composite-porosity treatment of fracture and matrix properties.[15] Flow and transport in the Paleozoic aquifer was analyzed separately.[16] The TSPA saturated-zone model was abstracted from detailed calculations using STAFF2D[17], which was used to demonstrate that the 1D flow fields used in the TSPA model were consistent with the 2D representation. The unsaturated-zone and saturated-zone results were then coupled to produce the geohydrology performance measure.[1]

The source term for radionuclide transport[18] included the effects of near-field interactions for matrix and fracture groundwater movement. Radionuclide mobilization rates were consistent with the far-field infiltration rate and the fracture aperture being studied. They were parameterized by post-emplacement times of mobilization, which depend on assumed thermal effects. Information on appropriate parameter distributions for radionuclide retardation[19] was also included in the transport models.

B. Gas Flow

The SNL gas-flow analysis used travel-time distributions at various temperatures[20] to calculate surface releases from a source term similar to that used for the aqueous releases. The source term was parameterized by the fraction of ^{14}C released from the waste and by the alteration rate of the spent-fuel matrix.[1].

Retardation effects were included implicitly. The calculations used an assumed failure rate for the waste packages to estimate releases and partitioning of occurrence.

C. Human Intrusion

Human-intrusion analyses investigated direct release of radionuclides at the surface and into the aquifers underlying Yucca Mountain. Both of these release modes were modeled using possible future exploratory drilling operations. The SNL surface-release problem includes both "direct hits," in which the contents of all or part of one waste package are released, and "near misses," in which contaminated rock adjacent to emplacement holes is exhumed.

The probability that the drill intersects radioactive waste was estimated from geometric considerations of the layout of the potential repository, the diameter of the drillhole, projected drilling density (3 boreholes/km^2/10,000 yrs as directed in guidance from the EPA[21]) and the diameter of a waste package and contaminated-rock halo around the package. The probability that drilling will occur at all was assumed to be 1.0 for this analysis; i.e., human intrusion was assumed to have a 100% chance of occurring at some time in the future. However, currently available estimates of the attractiveness of resources in the area indicate that this probability should realistically be set much lower.[5] The time of occurrence of a drilling incident was randomly selected from a uniform distribution that extended from 0 to 10,000 years after closure.

Because there was no unsaturated-zone groundwater transport involved, the source term for human intrusion was simply the entire inventory in a waste package. A conditional CCDF that shows the contributions of both direct hits and near misses was calculated using stochastic methods (Figure 3). PNL performed a similar analysis for their human-intrusion component of the TSPA.[7] Additional SNL analyses investigated the sensitivity of the conditional CCDF to variations in the assumed degree of burnup expected in the inventory, as well as the differing amounts of decay of the inventory resulting from different ages of the spent fuel at the time of emplacement.

The saturated-zone transport analysis used the same saturated-zone calculational module developed for the geohydrology problem, along with retardation values for the two rock types forming the two major aquifers underlying Yucca Mountain.[19]

Sensitivity studies showed that variations using multiple radionuclide inventories (instead of a lumped source term), increasing the extent of contaminated rock, and shifting the time of drilling to later in the regulatory period (to account for loss of markers) had little effect on the final CCDF. However, major shifts were observed as drilling density was increased to ten and twenty times the EPA guidance.[21]

D. Basaltic Volcanism

The volcanic analysis modeled radionuclide release due to the entrainment of waste in a basaltic dike reaching the surface. The actual entrainment and surface-release aspects were treated in a manner, that, although simple, is thought to represent the most significant features of a potential intrusion by a dike.[22] The abstracted features, events, and processes modeled in this problem compose the following sequence: a basaltic intrusion interacts directly with the waste packages in emplacement holes; the waste is fragmented and entrained in the upward flow of basalt in the dike as a result of the thermomechanical effects; and the fragments are erupted as part of the cinder code or lava sheet at the surface. We assume that the dike intrudes along a plane behind an upwardly propagating stress crack. Thus, the country rock at the propagating tip is pushed laterally by the compression caused by dike intrusion. As a result, the entire volume of the country rock displaced by the dike is not engulfed and entrained in the upward-flowing magma.[22] Actual entrainment of the waste is assumed to occur after the dike pathway is formed. Entrainment is accomplished when turbulence in the magma, primarily induced by exsolution of the volatile phases, results in erosion of the wall rock. Chemical interactions between volatiles and the waste, the effect of the engineered barrier system, changes in water circulation, etc. were not included in the formulation of this problem.

The source term developed for human intrusion was used, but the range of outcomes depended on values sampled from probability distribution functions defined for dike length, dike orientation, and the percentage of material estimated to be transported from the affected containers. The amount of material entrained was inferred from data on percentage of wall rock observed in basaltic flows and the volume of material erupted from centers of similar origin.[23]

A conditional CCDF was constructed for the release. The probability of volcanism occurring within the repository was incorporated into a separate overall CCDF for volcanic releases. The current estimates of probability of occurrence are very low (10^{-8}/year).[22,23] In a stochastic simulation of the 10,000 year regulatory lifetime of a repository, the probability of sampling such an event to include in the CCDF is extremely low. Therefore, to show the effects of the consequence calculation, the conditional CCDF is shown (Figure 4). The overall volcanic CCDF is shown in Figure 5. We believe that the simplifying assumptions included in the consequence calculation are conservative and may actually overestimate the extent of release. However, the overall CCDF for release from volcanic activity is still very far removed from the limit established by the EPA, shown in Figure 5 by the shaded area.

Sensitivity studies using variations on parameters in the consequence calculation show very slight changes to this CCDF. Because the parameters are linearly related, it is reasonable that they would have little effect on a logarithmic-scale representation.

E. Total-System CCDF

The TSPA analysis resulted in the calculation of a single measure of the performance of the potential repository system, including both nominal and disturbed conditions.[1] First, conditional probabilistic estimates of the releases were calculated for each of the individual components listed above. Because there are different logical relationships among the processes and events described by the various CCDFs, the conditional CCDFs themselves were combined using several different techniques.[1] Events and processes were considered to be correlated, mutually exclusive, or independent. To combine the CCDFs, the releases for correlated processes (such as matrix flow and fracture flow) were added for each probability value. Releases for mutually exclusive events (such as human-intrusion surface release vs saturated-zone release) were assigned probability weights based on their probabilities of occurrence, and the weighted probabilities added.[1] The CCDFs for independent events (such as human intrusion and groundwater flow) were randomly sampled to construct the combined CCDF. By using these techniques and appropriate weightings for combining CCDFs, the releases from the four analyses can be combined into single probability distributions for releases from the total repository system.[1] Because site characterization has yet to yield data that will guide the choices of weightings, the study has produced a family of "single" CCDFs, each expressing a distribution that cannot be ruled out by the current knowledge of the Yucca Mountain site.

DISCUSSION AND CONCLUSIONS

For the models and parameters used in the TSPA, gas flow dominated the total-system CCDFs constructed using the processes described above. Groundwater flow and human intrusion had a reduced effect, and volcanism made no significant contribution to these CCDFs. More work needs to be done on specifics of the simulations of gas and groundwater flow and transport. One of the major factors influencing the estimates of releases was the suite of assumptions in the source-term mobilization profiles. All of the assumptions in the near-field processes, such as flux distributions, should be consistent with those assumptions included in the far-field processes. Additionally, sensitivity studies, like those already performed for the disturbed conditions in this preliminary study, are needed to help identify important processes.

The current estimates of the probability of occurrence of volcanism in the repository is so low that we believe no further development of consequence calculations is necessary, unless new information significantly changes either the probability distribution functions or the understanding of magmatic processes involved in transporting waste.

The abstracted models used as a basis for this TSPA were based on our current understanding of the site and on prior detailed analyses. The results appeared to adequately represent our current understanding of the processes likely to occur at the site. They were also reasonably sensitive to variations in the input parameters. The sensitivities identified in this study may, in fact, prove useful as guides to future field and laboratory testing.

A number of very conservative assumptions have been included in each of the conditional CCDFs presented above. Where little information is available, the tendency has been for TSPA-style analyses to use the most conservative models and estimates of parameters. However, such analyses do not provide a scientifically reasonable representation of the performance or the suitability of the site. As part of a future total-system analysis, an attempt will be made to modify overly conservative assumptions. This may be possible, in part, as site data that provide insight into the processes active at Yucca Mountain become available.

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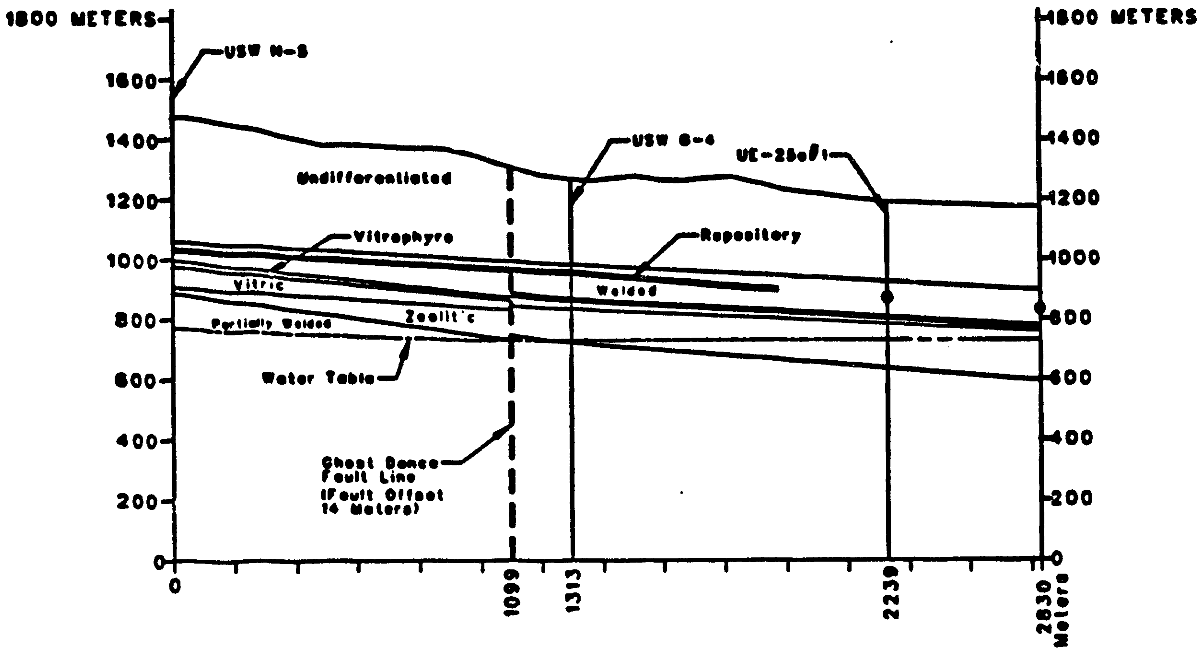

Figure 1

Stratigraphic Cross-Section Used as the Basis for the Total-System Performance Assessment

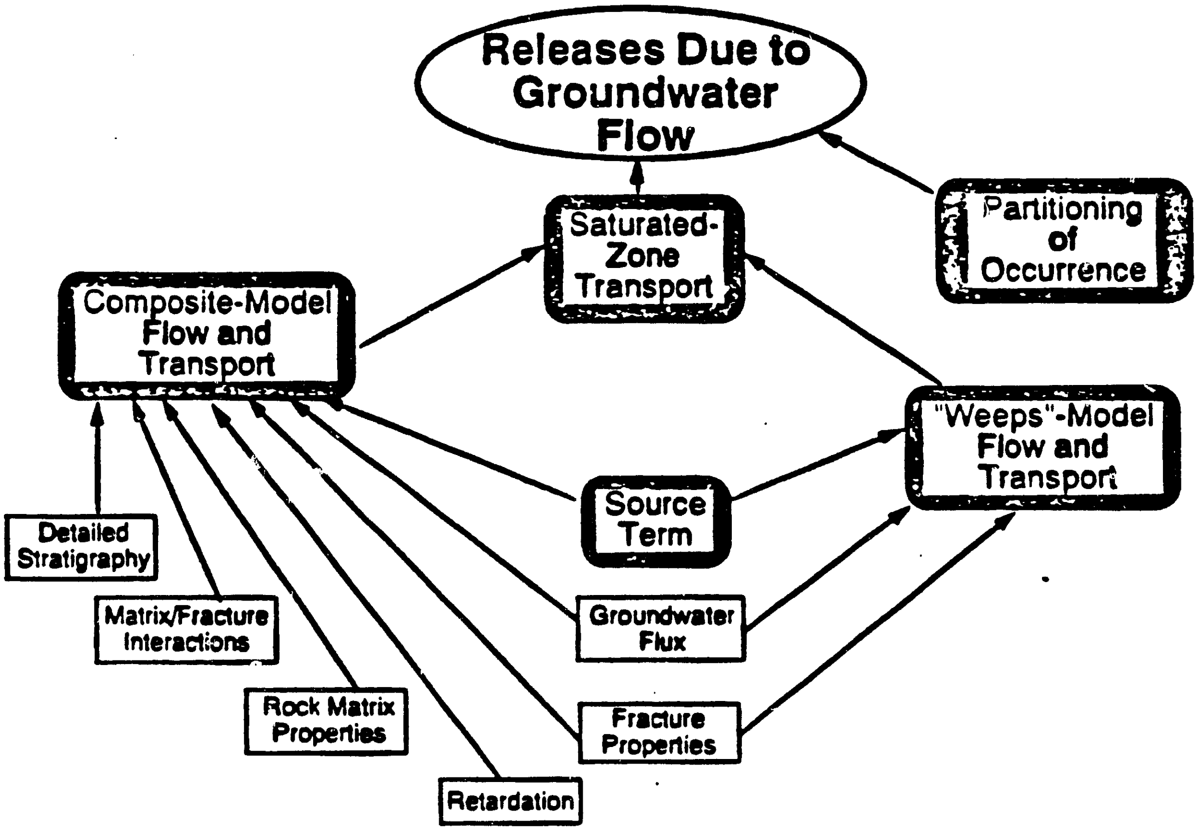

Figure 2
Factors Included in the Groundwater Flow and Transport Portion of the Total-System Performance Assessment

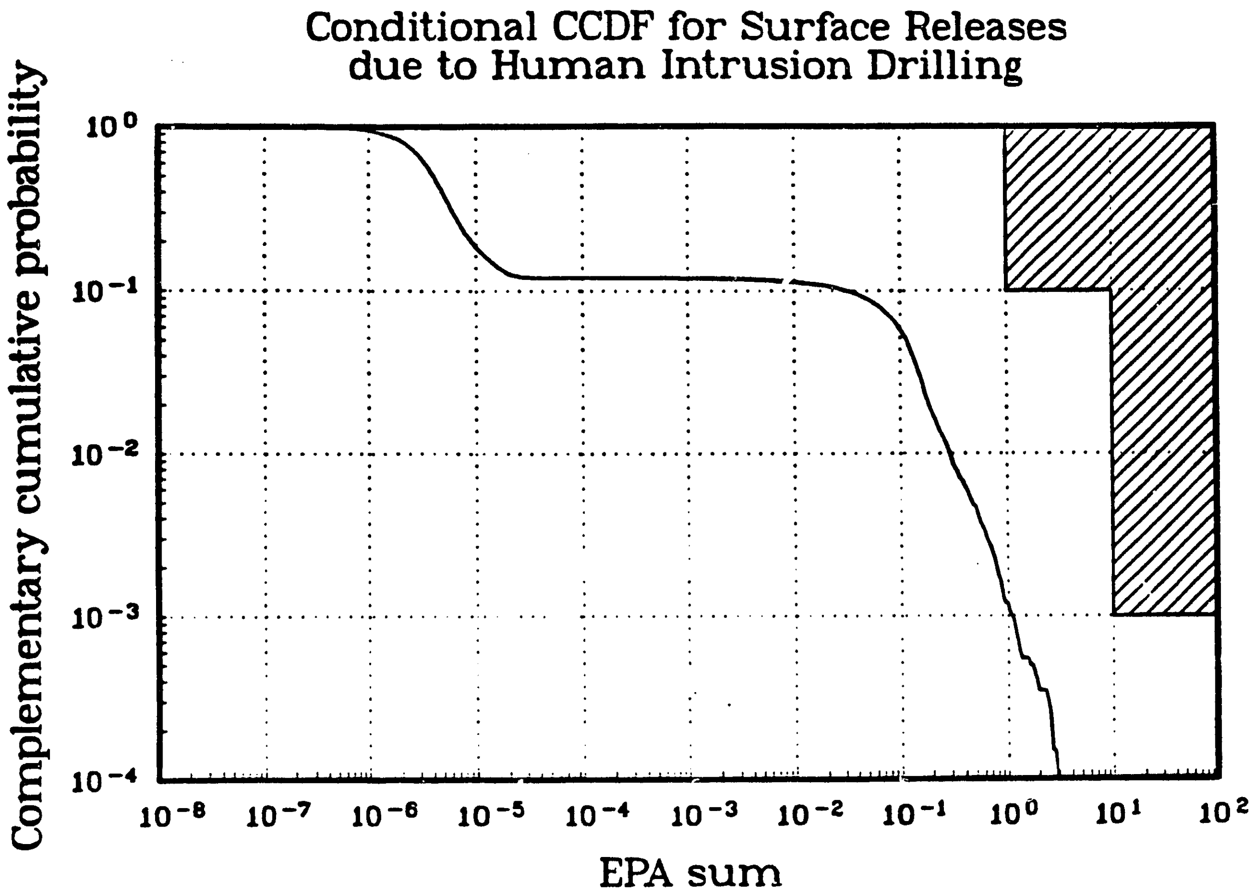

Figure 3
Conditional CCDF for Surface Release from Human Intrusion due to Exploratory Drilling.

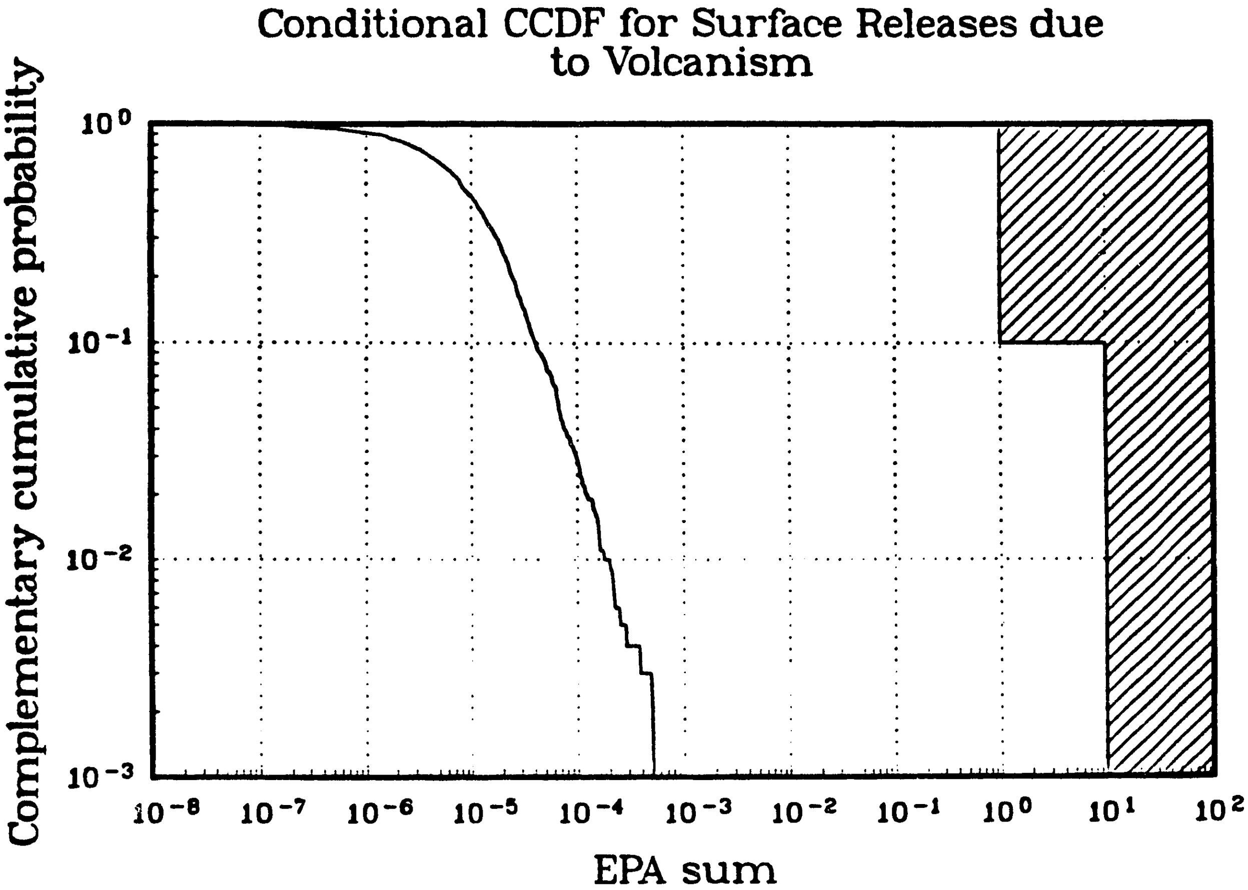

Figure 4.
Conditional CCDF for Surface Releases due to Basaltic Volcanism.

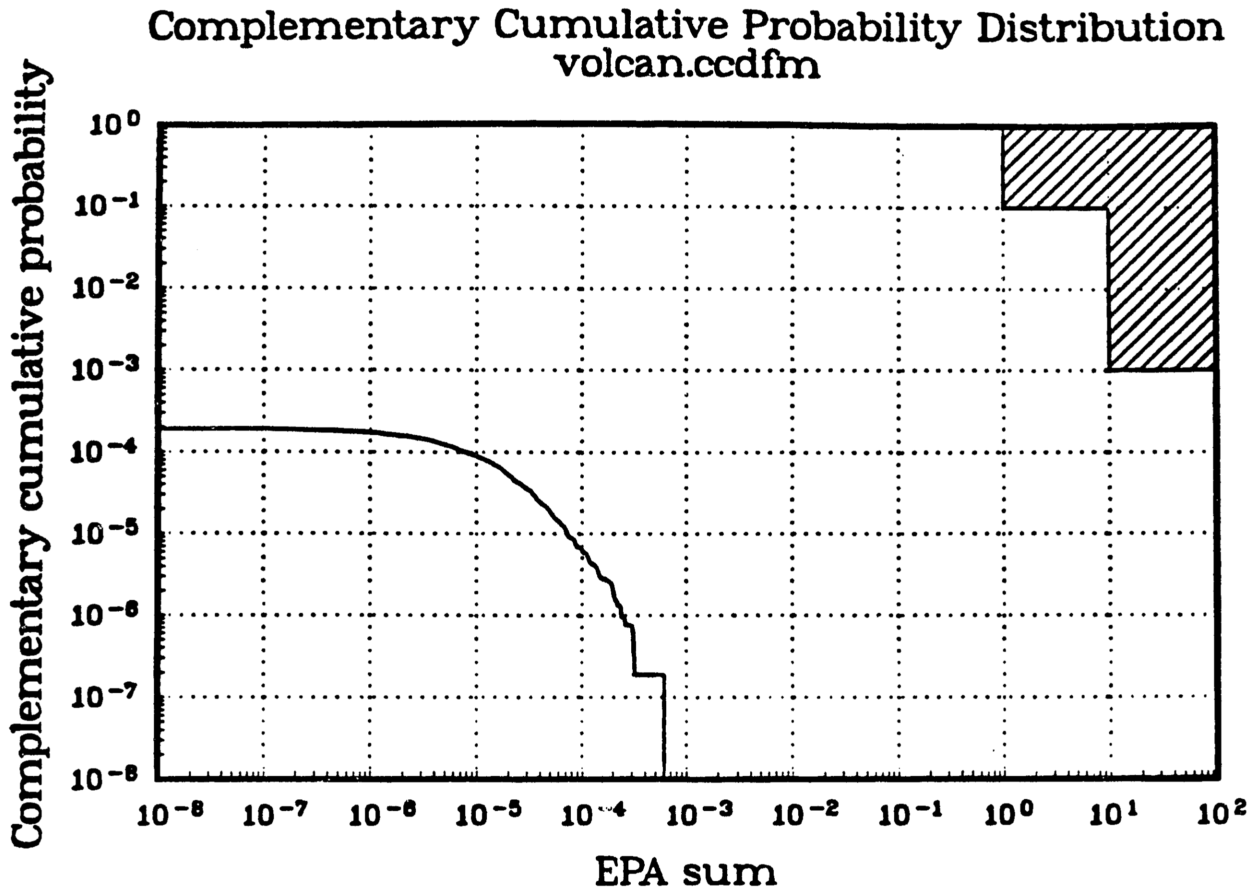

Figure 5.
Overall CCDF for Surface Releases due to Volcanism

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