Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix SA

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Sensitivity Analysis

CONTENTS

FIGURES

FIGURES (Continued)

TABLES

ACRONYMS

CCDF	complementary cumulative distribution function
CFR	Code of Federal Regulations
CH	contact-handled
EPA	U.S. Environmental Protection Agency
LHS	Latin hypercube sampling
MB	marker bed
RH	remote-handled
TRU	transuranic
WIPP	Waste Isolation Pilot Plant

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APPENDIX SA

SA.1 Introduction

Sensitivity analyses determine the contribution of the uncertainty in individual input variables to the uncertainty in model predictions. The model prediction used in generating the complementary cumulative distribution functions (CCDFs) described in Chapter 6.0 (Section 6.5) are the final releases to the accessible environment. These final releases are comprised of a total of summed normalized releases along plausible pathways to the accessible environment. As described in Appendix CCDFGF (Section 4.1, Equation 4.1) and Chapter 6.0, these pathways are (1) cuttings and cavings, spallings, and brine releases direct to the surface during intrusion drilling events, (2) long-term releases to the accessible environment at the ground surface or through groundwater flow in the Rustler Formation or overlying units after the intrusion borehole has been plugged and abandoned, (3) long-term releases to the accessible environment at the ground surface or through groundwater flow in the Rustler or overlying units that may result from brine flow through the shaft seal system for either undisturbed or disturbed conditions, and (4) long-term releases through brine flow in the interbeds (Marker Bed [MB] 138, anhydrites a and b, and MB139) in the Salado Formation.

As described in Chapter 6.0 (Section 6.5), the only release pathways along which releases occurred are Pathways 1 and 4 above. Releases for Pathway 4 are few (9 out of 300 realizations) and negligible (summed normalized releases are less than 10^{-6}). Therefore, the summed normalized releases that contribute to the CCDFs presented in Section 6.5 are comprised of direct releases only because all other releases are negligible.

The sensitivity analysis presented in this appendix is for final total releases to the accessible environment. Because total releases are determined solely by direct releases during drilling, only imprecisely known parameters that are inputs to calculating these direct releases can influence uncertainty in total releases. Thus, imprecisely known parameters that are involved only in calculating long-term releases in Pathways 2, 3, and 4 above are not discussed here because they do not influence uncertainty in total releases.

This appendix is organized by the most important direct releases contributing to the mean CCDF described in Section 6.5. The relative importance of these direct releases is displayed in Figure 6-41 of Chapter 6.0 (Section 6.5). The dominant contribution is cuttings and cavings releases. The sensitivity of imprecisely known parameters to uncertainty in cuttings and cavings releases is described in Sections SA.2 and SA.3. Spallings releases have a small impact on the mean CCDF for total releases. The sensitivity of parameters to uncertainty in spallings releases is described in Sections SA.4 and SA.5. Direct brine releases have little impact on the mean CCDF for total releases, but are the only other release of similar order of magnitude although at low exceedance probabilities. The sensitivity of parameters to uncertainty in direct brine releases is described in Sections SA.6, SA.7, and SA.8.

As described above and displayed in Figure 6-41 of Chapter 6.0 (Section 6.5), all releases other than direct releases are negligible. Sensitivity of long-term release parameters to total releases cannot be assessed because these long-term releases are negligible compared to direct releases.

SA.2 Cuttings and Cavings: Uncertainty and Sensitivity

Drilling intrusions through the waste panels at the Waste Isolation Pilot Plant (WIPP) can penetrate the contact-handled (CH) or remote-handled (RH) transuranic (TRU) waste. Specifically, the probabilities that a single intrusion through a waste panel will encounter CH- or RH-TRU waste are 0.880 and 0.120, respectively. As the penetration of CH-TRU waste is more likely than the penetration of RH-TRU waste and the concentrations of CH-TRU waste are higher than those for RH-TRU waste (Figure SA-1), the cuttings and cavings release is dominated by CH-TRU waste.

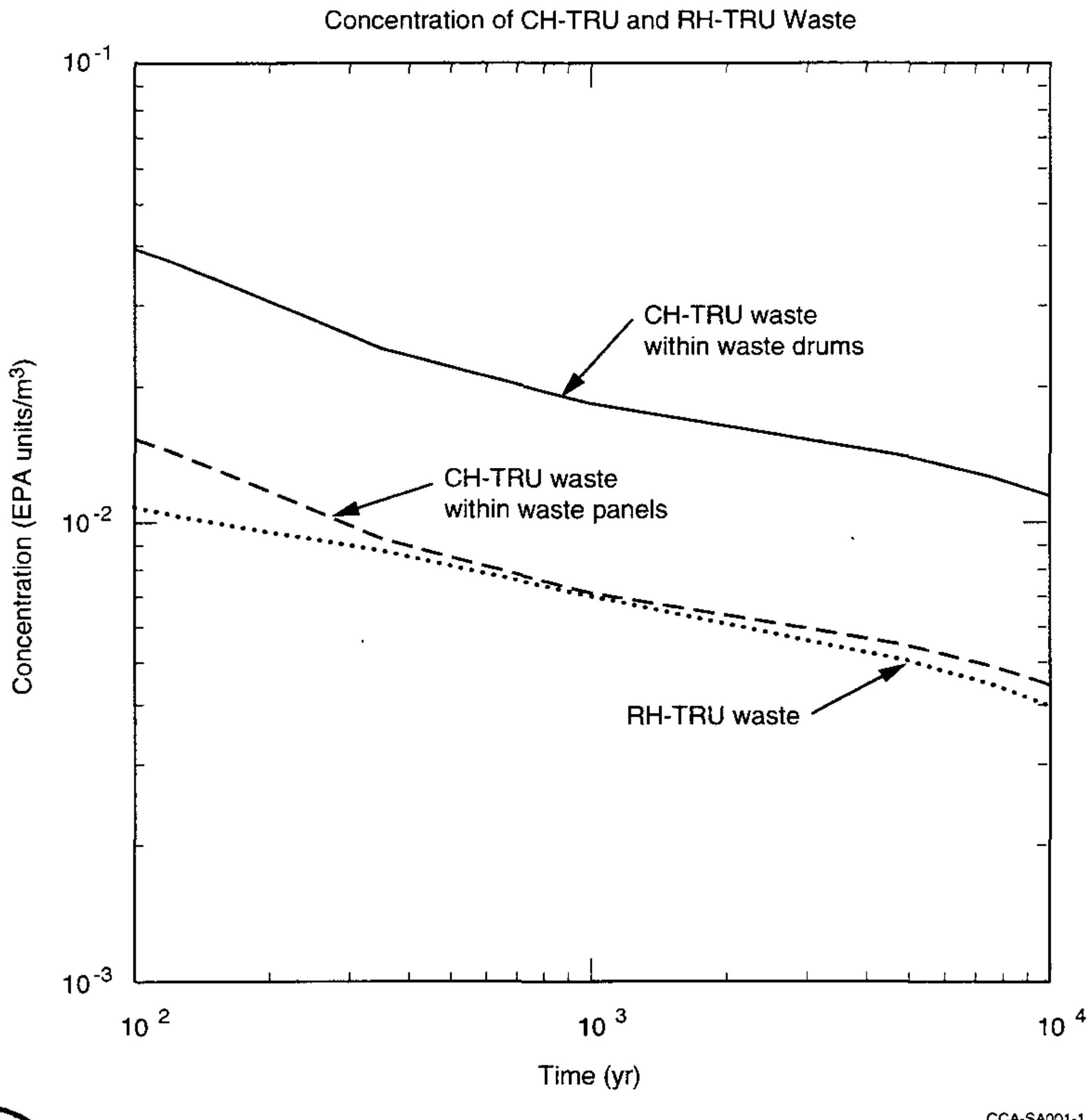
The volume of material removed by a drilling intrusion through RH-TRU waste is fixed at 1.38 cubic feet (0.039 cubic meters) (that is, the drill bit diameter is fixed at 1 foot [0.3115 meters], which yields an intersection area of 0.85 square feet [0.076 square meters], and the effective height of RH-TRU waste is assumed to be 1.7 feet [0.509 meters]). However, uncertainty in inputs used in the performance assessment results in the volume of material removed as the result of a drilling intrusion through CH-TRU waste ranging from approximately 10.6 to 105.9 cubic feet (0.3 to 3 cubic meters) (Figure SA-2). The volumes in Figure SA-2 and also the volume indicated above for RH-TRU waste are the original (that is, uncompacted) volumes of the removed waste. The use of uncompacted volumes simplifies the calculation of the radionuclide concentrations used in the determination of cuttings and cavings releases and permits a combining of removal volumes for intrusions at different times. The uncertainty in the volume of CH-TRU waste removed as cuttings and cavings is determined by the variable *TAUFAIL* (see also Appendix PAR, Parameter 33) (shear resistance for erosion) (Figure SA-3).

SA.3 Cuttings and Cavings: CCDFs

The complementary cumulative distribution functions (CCDFs) used for comparison with Title 40 Code of Federal Regulations (CFR) § 191.13 are constructed conditionally on individual Latin hypercube sample (LHS) elements by randomly sampling futures of the form

$$\mathbf{x}_{st} = [\underbrace{t_1, a_1, b_1, l_1, p_1}_{1^{\text{st}}\ \text{intrusion}}, \underbrace{t_2, a_2, b_2, l_2, p_2}_{2^{\text{nd}}\ \text{intrusion}}, \ldots, \underbrace{t_n, a_n, b_n, l_n, p_n}_{n^{\text{th}}\ \text{intrusion}}, t_{\min}], \qquad (1)$$

where n is the number of drilling intrusions, t_i is the time (year) of the i^{th} intrusion, a_i designates the type of waste penetrated by the i^{th} intrusion (that is, CH-TRU waste, RH-TRU waste), b_i designates whether or not the i^{th} intrusion penetrates pressurized brine in the Castile Formation, l_i designates the location of the i^{th} intrusion, p_i designates the plugging procedure used with the i^{th} intrusion (that is, continuous plug, two discrete plugs, three discrete plugs), and t_{min} is the time (year) at which potash mining occurs. A normalized release is then estimated for the particular



Note: Regenerated and modified from Sanchez et.al. (1996), "EPAUNI: Estimating Probability Distribution of EPA Unit Loading in the WIPP Repository for Performance Assessment Calculations," in SWCF; 12.07.1.1:WA:QA:EPAUNI (WPO 39259)

Figure SA-1. Concentration (EPA units per cubic meter) of CH-TRU and RH-TRU Waste

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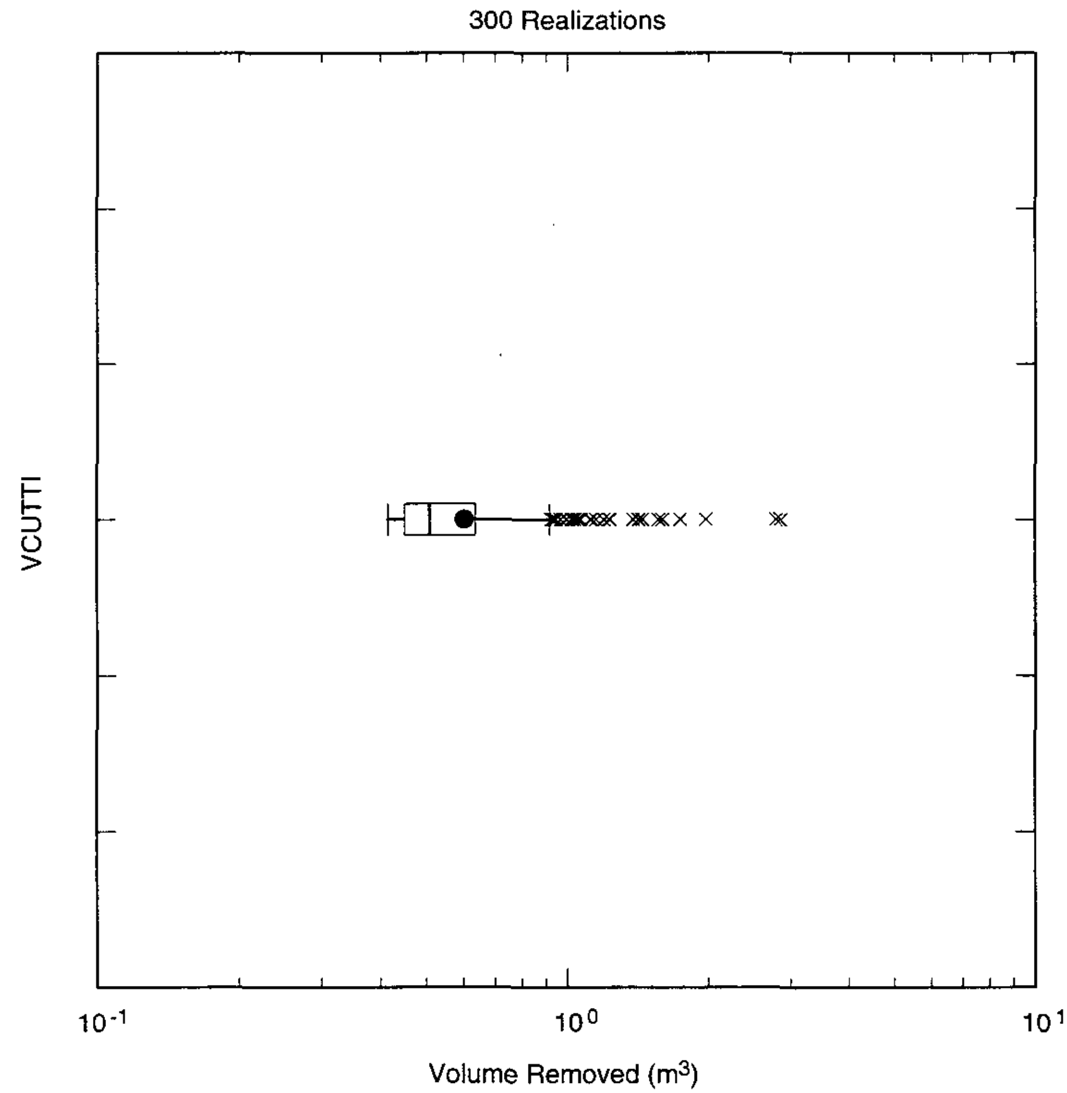

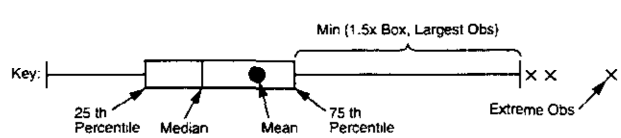

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Figure SA-2. Distribution of Original (that is, uncompacted) Volume of Cuttings and Cavings Removed by a Single Drilling Intrusion through CH-TRU Waste

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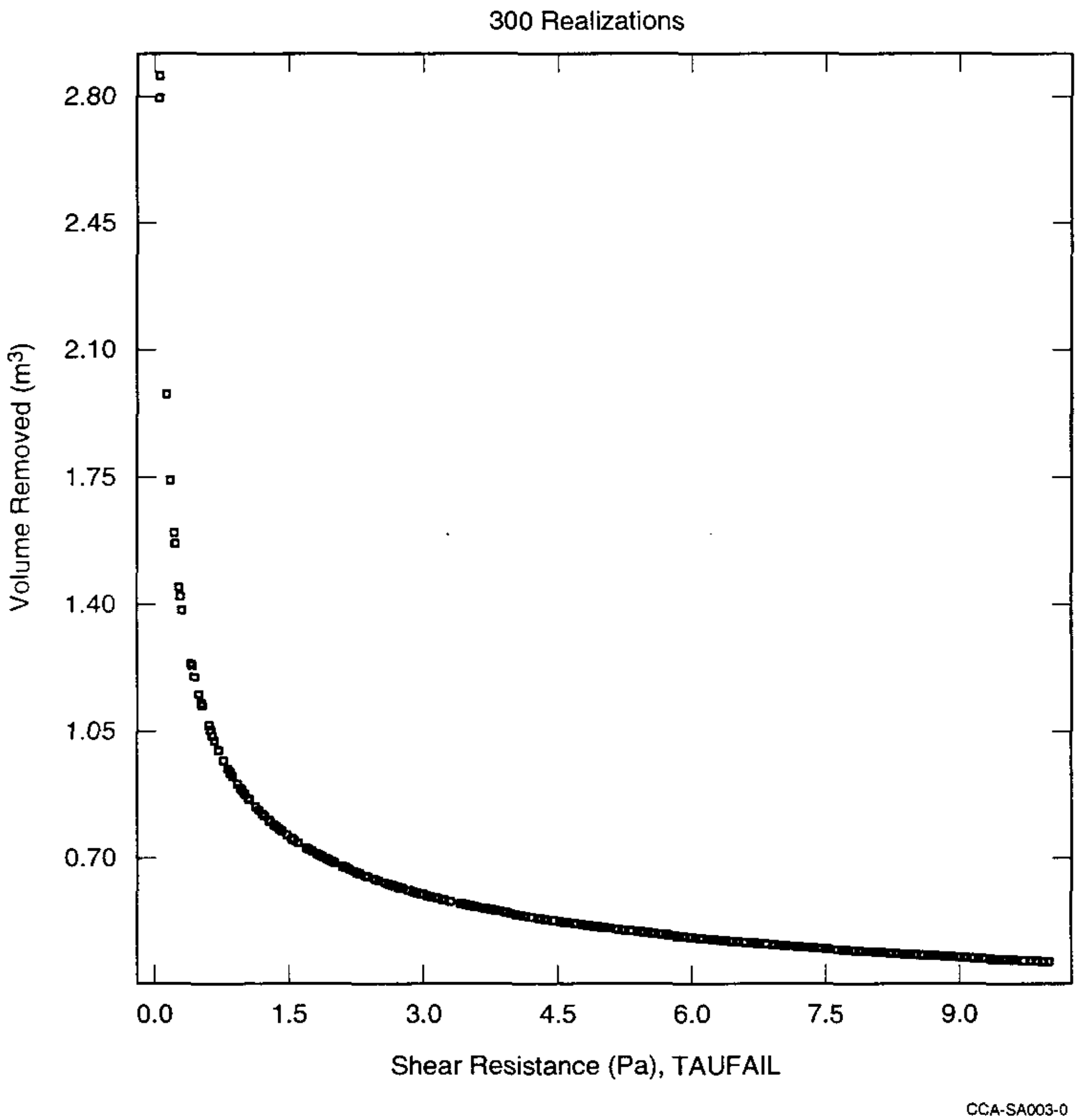

Figure SA-3. Scatterplot for Volume of Material (cubic meters) Removed From Repository Due to a Single Drilling Intrusion through CH-TRU Waste versus Shear Resistance (pascals) for Erosion (TAUFAIL)

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release mode under consideration, which, in this section, is cuttings and cavings removal. Once the normalized releases are available, construction of the corresponding CCDF is straightforward.

The cuttings and cavings release for a given drilling intrusion is the product of the volume of waste removed (cubic meters) and the radionuclide concentration (EPA units per cubic meter) in the removed waste. For RH-TRU waste, the indicated concentration corresponds to the concentrations plotted in Figure SA-1 (see also $C_{RH}(k)$ in Table SA-1). For CH-TRU waste, the situation is slightly more complex because of the presence of 569 waste streams (that is, distinct types of waste), with each waste drum in the repository containing waste from only one waste stream (see $C_{CH}(j,k)$, $P_{CH}(j)$ in Table SA-1). As a result, a single drilling intrusion through CH-TRU waste can intersect several different waste streams. Given that waste drums containing CH-TRU waste are stacked three high in the repository, the concentration of CH-TRU waste associated with a specific intrusion is taken to be the average of the concentrations associated with three randomly selected waste streams, which results in considerable variability in the size of the cuttings releases for individual intrusions (Figure SA-4).

Table SA-1. Results Available for Use in CCDF Construction for Cuttings and Cavings Removal

$C_{CH}(j, k)$	=	concentration (EPA units per cubic meter) in CH-TRU waste stream j, j = 1. 2, ..., 569, at time k, where k = 1, 2, 3, 4, 5, 6, 7, 8, 9 corresponds to 100, 125, 175, 350, 1,000, 3,000, 5,000, 7,500 and 10,000 years, respectively.
$P_{CH}(j)$	=	probability that a randomly sampled drum of CH-TRU waste will come from waste stream j, j = 1, 2, ..., 569.
A_{CH}	=	area (square meter) through CH-TRU waste removed due to cuttings and cavings associated with a single drilling intrusion.
H_{CH}	=	height (meters) of waste panels used for disposal of CH-TRU waste. Value: 3.96 meters.
F_{CH}	=	fraction of volume removed by drilling intrusion through CH-TRU waste that is actually waste. Value: 0.386 = (volume of CH-TRU waste) / (volume of waste panels) = (1.685×10^5 cubic meters / 4.36×10^5 cubic meters).
$C_{RH}(k)$	=	concentration (EPA units per cubic meter) in RH-TRU waste at time k, with k corresponding to the same times as for CH-TRU waste. See Figure SA-1.
A_{RH}	=	same as A_{CH} but for RH-TRU waste. Value: 0.076 square meter = π (drillbit diamater/2)^2 = π $(0.31115/2)^2$. Note: Little erosion around the drillbit takes place for intrusions through RH-TRU waste.
H_{RH}	=	same as H_{CH} but for RH-TRU waste. Value: 0.509 meters. Note: Expected height of RH-TRU cylinder.
F_{RH}	=	Same as F_{CH} but for RH-TRU waste. Value: 1. Note: Consistent with emplacement procedure for RH-TRU waste.

For a given future $\mathbf{x}_{st}$ of the form shown in Equation 1, the cuttings release to the accessible environment is given by

$$f_C(\mathbf{x}_{st}) = \sum_{i=1}^{n} rC_i, \qquad (2)$$

where

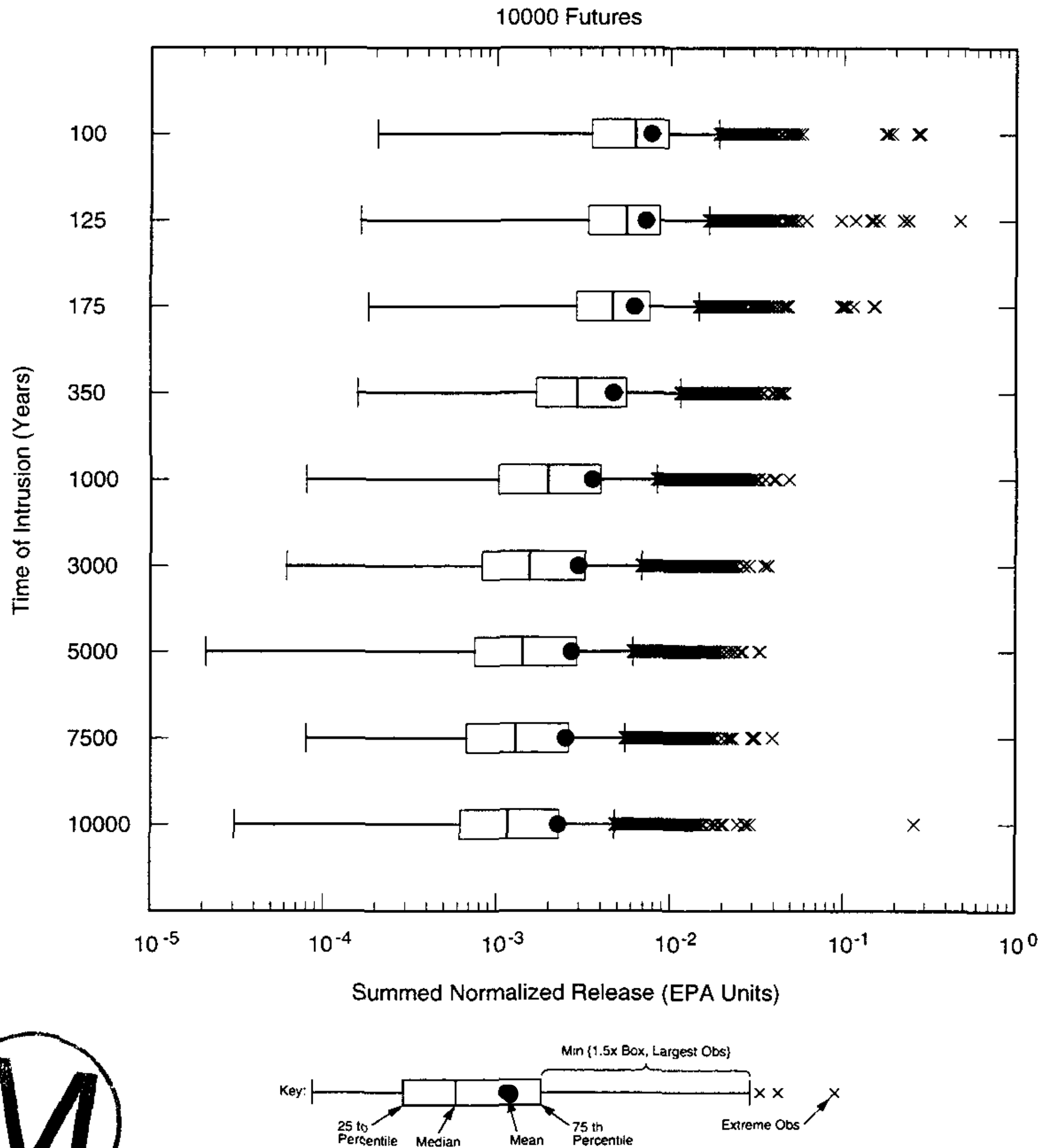
$$
\begin{aligned}
rC_i &= 0 && \text{if } a_i \sim \text{no waste}\\
&= A_{CH}\, H_{CH}\, F_{CH} \left\{ \sum_{r=1}^{3} C_{CH}\left[j(i,r), t_i\right]/3 \right\} && \text{if } a_i \sim \text{CH-TRU waste}\\
&= A_{RH}\, H_{RH}\, F_{RH}\, C_{RH}(t_i) && \text{if } a_i \sim \text{RH-TRU waste}
\end{aligned}
$$

$j(i, r)$ = an integer randomly selected from 1, 2, ..., 569 for r = 1, 2, 3 in consistency with the probabilities $P_{CH}(j)$, j = 1, 2, ..., 569,

and all remaining symbols are defined in Table SA-1. The above summation from $r = 1$ to $r = 3$ corresponds to the determination of an average concentration over three randomly selected waste streams. Further, the appearance of t_i in $C_{CH}[j(i, r), t_i]$ and $C_{RH}(t_i)$ implies interpolation between the actual time values in Table SA-1 at which C_{CH} and C_{RH} are available.

For each LHS element, nS = 10,000 futures are randomly selected and the corresponding cuttings and cavings releases are determined as shown in Equation 2. The resultant CCDFs for cuttings and cavings releases to the accessible environment are then constructed (Figure SA-5). All the CCDFs fall below the boundary line specified in 40 CFR § 191.13(a). Further, the distribution of CCDFs is relatively tight. As volume of removed waste (that is, $A_{CH}\, H_{CH}$ as used in conjunction with Equation 2) is the only quantity used in the determination of cuttings and cavings releases that is affected by a variable in the LHS, the uncertainty in the CCDFs shown in Figure SA-5 is due entirely to the effective shear resistance for erosion (*TAUFAIL*, see Appendix PAR, Parameter 33) (Figure SA-3).

The CCDFs in Figure SA-5 are for summed normalized release, which is not a very intuitive quantity. To help provide perspective, CCDFs for the volume of material brought to the surface (that is, the quantity obtained from Equation 2 when F_{CH}, C_{CH}, F_{RH}, and C_{RH} are equal to 1) can also be constructed (Figure SA-6). The release of more than 10 cubic meters of material is unlikely.



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Note: Results calculated with median volume (0.508 cubic meters) from Figure SA-2, 38.6 percent of removed volume assumed to be CH-TRU waste, and a sample size of 1,000 at each time.

Figure SA-4. Distribution of Normalized Release to Accessible Environment for Cuttings and Cavings Removal from CH-TRU Waste due to Variation in Intersected Waste Streams

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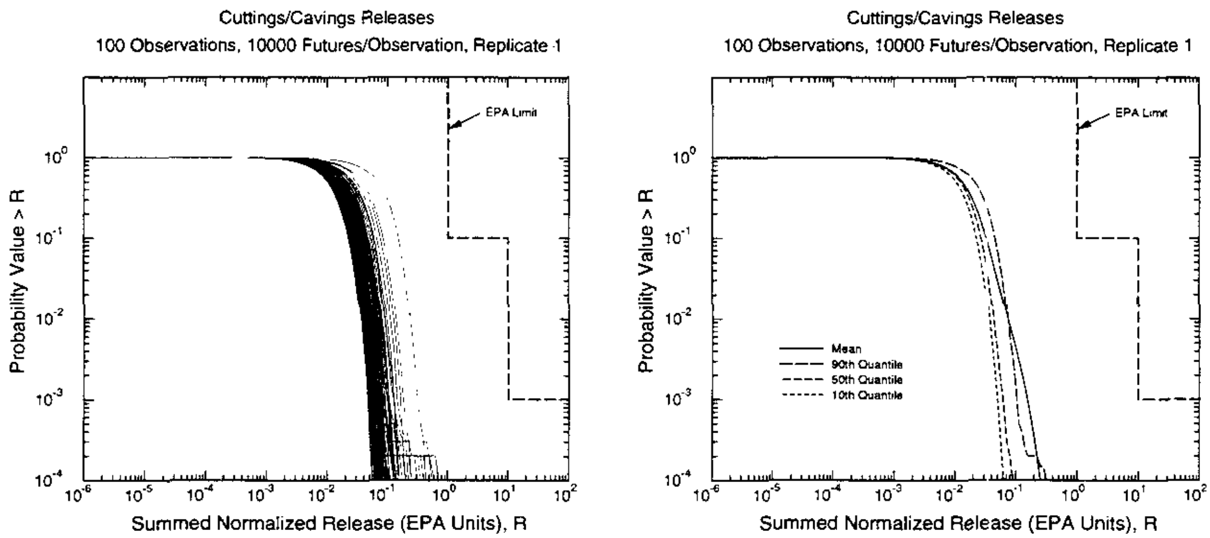

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Figure SA-5. Distribution of CCDFs for Summed Normalized Release to Accessible Environment over 10,000 Years due to Cuttings and Cavings

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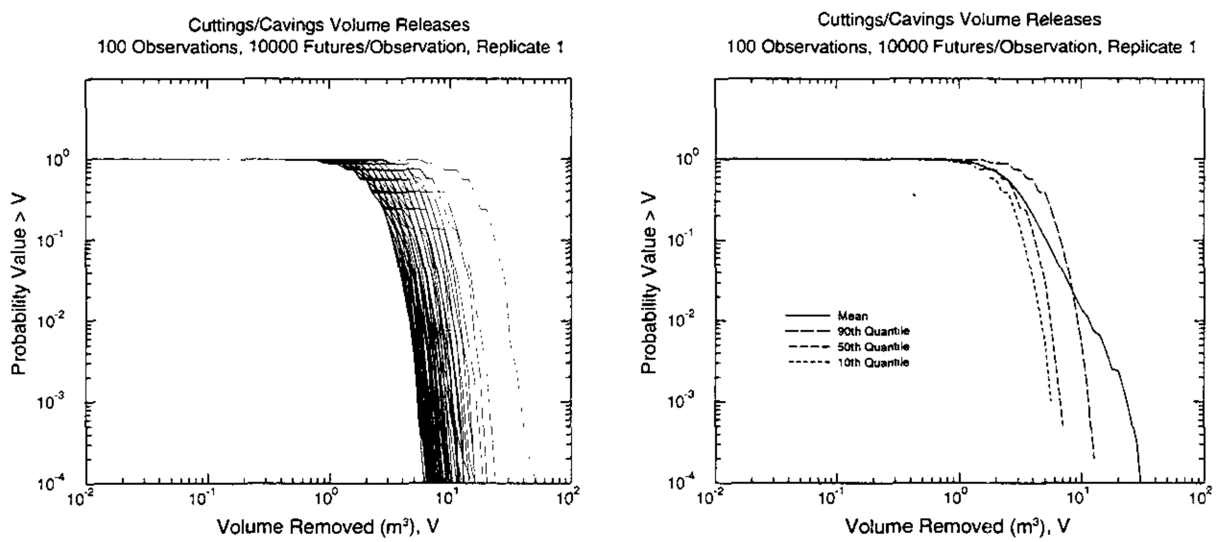

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Figure SA-6. Distribution of CCDFs for Volume of Material (cubic meters) Removed to Accessible Environment over 10,000 Years due to Cuttings and Cavings

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SA.4 Spallings: Uncertainty and Sensitivity

Drilling intrusions through CH-TRU waste can also produce spallings releases, which are releases of solid material as the result of rapid gas movement toward a borehole at the time of intrusion. Because of the low permeability of the region surrounding each RH-TRU waste canister, intrusions into RH-TRU waste are assumed not to produce spallings releases.

The spallings model predicts a release of solid material. For computational convenience and also for comparability with cuttings and cavings results, the released volume of material is reported as the volume of the original, uncompacted material emplaced in the repository. For a given drilling intrusion, this volume is multiplied by the average concentration (EPA units per cubic meter) of CH-TRU waste in the waste panels (Figure SA-1) at the time of the intrusion to produce the spallings release.

The size of the spallings release is sensitive to the pressure in the repository at the time of the associated drilling intrusion. In turn, pressure is dependent on both the time of a drilling intrusion and whether or not that drilling intrusion has been preceded by earlier intrusions. Due to the 1-degree dip of the repository, it is also possible that conditions influencing spallings may differ between upper (that is, Panels 1, 2, 3, 6, 7, 8, 9) and lower (that is, Panels 4, 5, 10) panels.

For initial intrusions into the repository, spallings calculations were performed for intrusions at 100, 350, 1,000, 3,000, 5,000, and 10,000 years and also for intrusions into one of the seven updip or upper (U) waste panels and one of the three downdip or lower (L) waste panels (Figure SA-7). Early intrusions often produced no releases, with the number of nonzero releases increasing with time as the result of increasing pressure in the repository (Figure SA-8). The spallings model incorporates the assumption that no spallings release will take place when the repository pressure is less than 8 megapascals (see Appendix CUTTINGS), which results in the switch from zero to nonzero spallings releases in Figure SA-8. The volumes of the nonzero spallings releases are between approximately 18 and 141 cubic feet (0.5 and 4 cubic meters), and the corresponding normalized releases are between approximately 3×10^{-3} and 2×10^{-2} EPA units. The releases from intrusions into an upper or lower panel at the same time are essentially identical (Figure SA-7).

Although pressure determines whether a nonzero spallings release takes place, it has little effect on the actual size of the release (Figure SA-8). Rather, given that a nonzero release takes place, the variable for a diameter of particles available for removal as spallings (*PARTDIA*) determines the actual size of this release (Figure SA-9). Specifically, the size of the release increases as *PARTDIA* decreases.

At a value of *PARTDIA* $\doteq 2.5 \times 10^{-3}$ meters, there is a noticeable change in behavior, with the volume of released material suddenly changing from approximately 88.3 cubic feet (2.5 cubic meters) to a range of values bounded below by approximately 125.6 cubic feet (3.2 cubic meters) (Figures SA-9 and SA-10). Further, below *PARTDIA* $\doteq 2.5 \times 10^{-3}$ meters, there is a stronger relationship between pressure and volume of released material than exists at higher values of *PARTDIA* (Figure SA-8). This discontinuity is caused by an abrupt change in the coefficient of drag for particles at Reynolds (Re) numbers of 2×10^5. Above $Re = 2 \times 10^5$, the boundary layer on the forward surface of smooth spheres changes from laminar to turbulent flow and tends to move the boundary layer point of separation downstream. This movement causes the size of the wake to decrease and reduces pressure drag, which results in the observed discontinuity and larger releases for small values of *PARTDIA*. (See Fox and McDonald 1973, 404 – 408.)

Spallings calculations were also performed for intrusions subsequent to an initial intrusion into the repository for the following cases: (1) an initial E1 intrusion at 350 years followed by a second intrusion at 550, 750, 2,000, 4,000, or 10,000 years (Figure SA-11), (2) an initial E1 intrusion at 1,000 years followed by a second intrusion at 1,200, 1,400, 3,000, 5,000, or 10,000 years (Figure SA-11), (3) an initial E2 intrusion at 350 years followed by a second intrusion at 550, 750, 2,000, 4,000, or 10,000 years (Figure SA-12), and (4) an initial E2 intrusion at 1,000 years followed by a second intrusion at 1,200, 1,400, 3,000, 5,000, or 10,000 years (Figure SA-12). Further, spallings releases were calculated for two cases for each of the second intrusion times: (1) Intrusion into the same waste panel as the first intrusion, and (2) intrusion into a different waste panel than the first intrusion. Intrusion times 200 and 400 years after the initial time (that is, 550 and 750 years for an initial intrusion at 350 years, and 1,200 and 1,400 years for an initial intrusion at 1,000 years) were selected to give results just before and after the borehole plug at the Rustler and Salado interface is assumed to fail for plugging patterns 2 and 3 (see Section 6.4.7.2). Wider time intervals were used at later times because gas pressure tends to change rather slowly at later times, thus allowing the use of larger times between calculations. The distinction between an intrusion into same and different panels was made because of the possible effects of the resistance to flow between waste panels as the result of the presence of panel closures and the occurrence of brine flow down a borehole into the intruded panel.

Scatterplots for second intrusions equivalent to those in Figures SA-8 and SA-9 for initial intrusions show exactly the same patterns; the occurrence of a spallings release depends on whether the pressure is above 8 megapascals, and the actual size of the release depends on *PARTDIA*. For most sample elements, there is no spallings release for the second intrusion because the pressure is less than 8 megapascals. The greatest number of nonzero spallings releases occurs when the second intrusion is 200 years after the first intrusion, because the borehole plug at the Rustler and Salado interface has yet to fail and, as a result, the pressure has not been reduced by gas flow up the first borehole.

SA.5 Spallings: CCDFs

As for cuttings and cavings, each LHS element leads to a CCDF for spallings releases that is obtained by randomly sampling futures of the form in Equation 1 and then constructing the corresponding spallings release for each future. This construction is based on the volumes of material (cubic meters) released by spallings under different conditions and the radionuclide concentration (EPA units per cubic meter) in that material (Table SA-2).

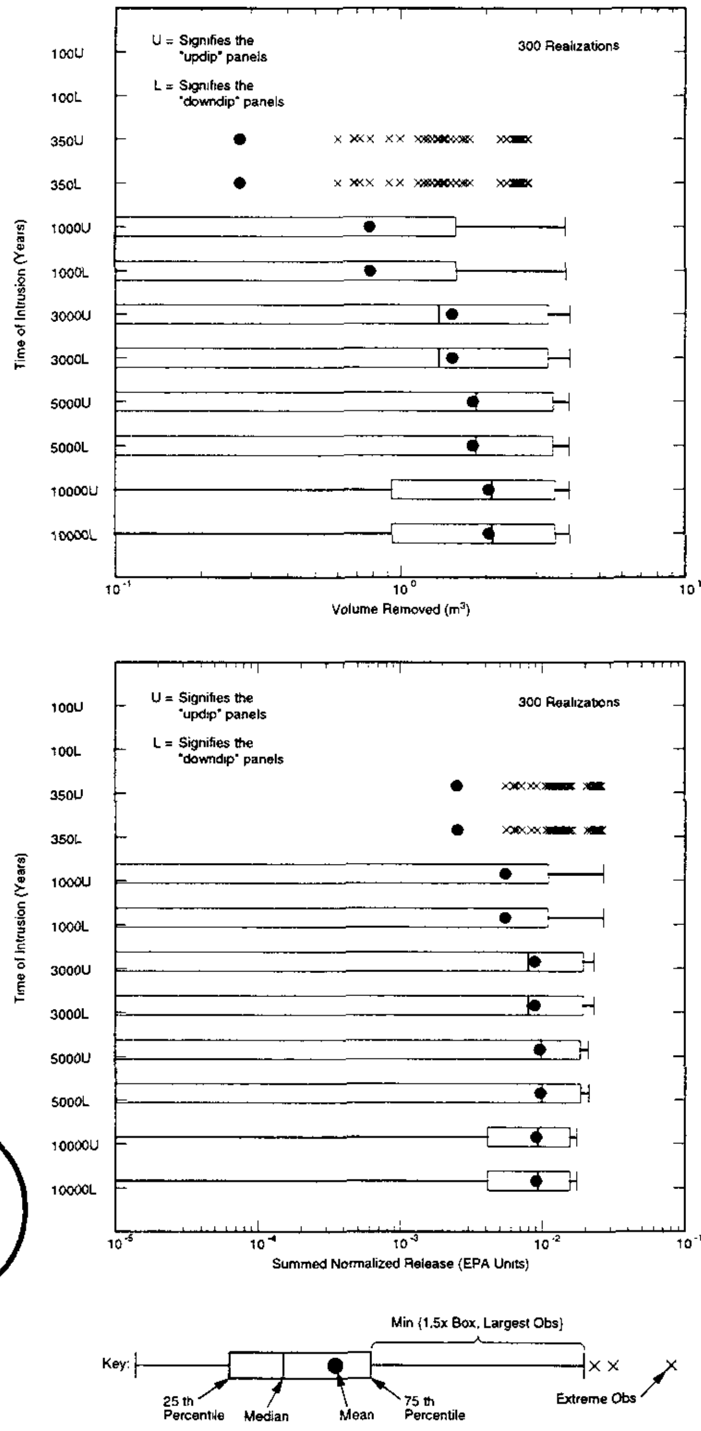

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Figure SA-7. Distribution of Original (that is, uncompacted) Volume Removed (cubic meters) and Summed Normalized Release (EPA units) due to Spallings for a Single Drilling Intrusion into a Previously Unintruded Repository that Encounters CH-TRU Waste

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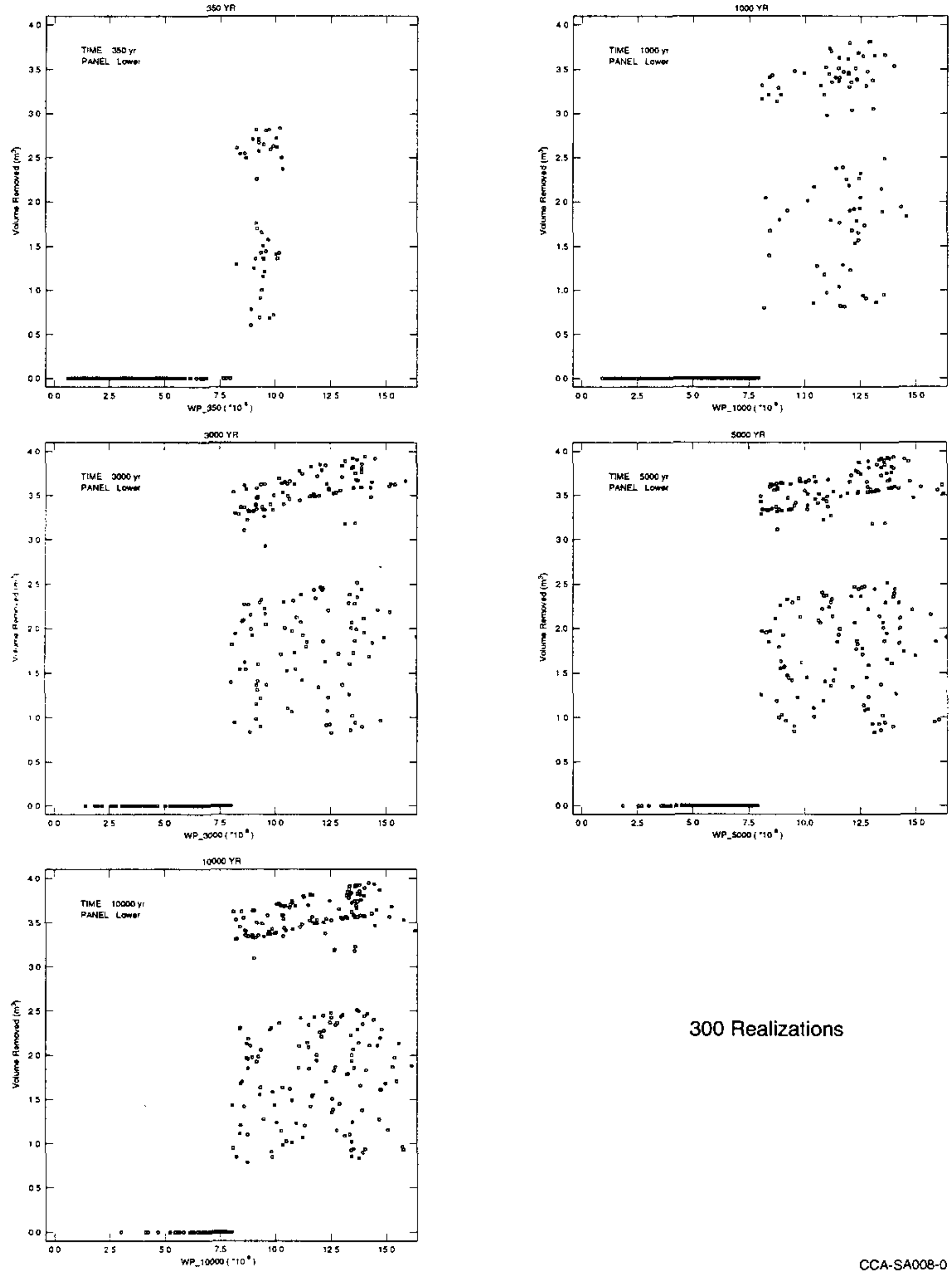

Figure SA-8. Scatterplots for Volume of Material (cubic meters) Removed from Repository due to Spallings Resulting from a Single Drilling Intrusion into a Previously Unintruded Repository that Passes through CH-TRU Waste in a Lower Waste Panel versus Pressure (pascals) in Repository

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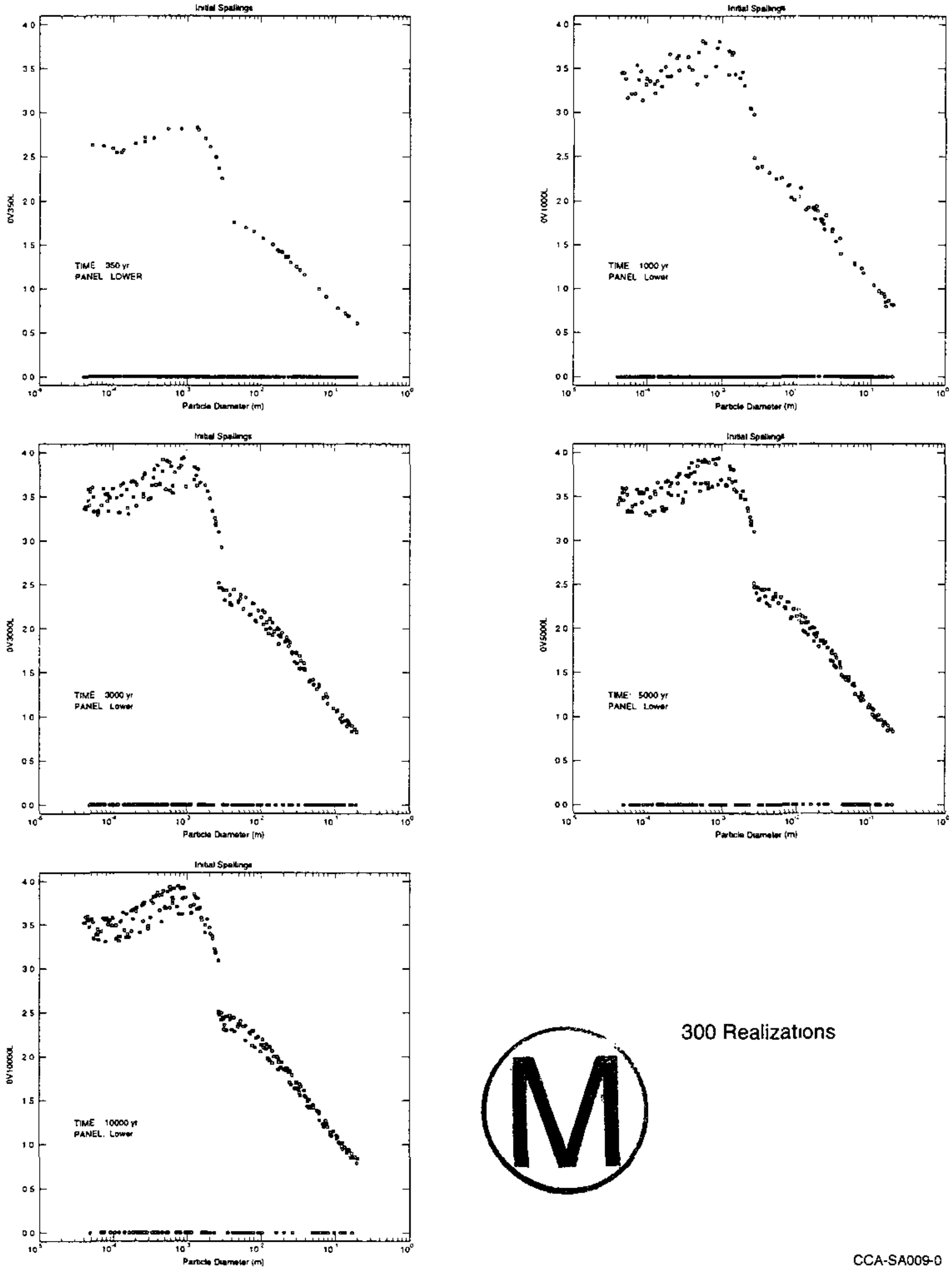

Figure SA-9. Scatterplots for Volume of Material (cubic meters) Removed from Repository due to Spallings Resulting from a Single Drilling Intrusion into a Previously Unintruded Repository that Passes through CH-TRU Waste in a Lower Waste Panel versus Diameter of Particles Available for Removal as Spallings (PARTDIA)

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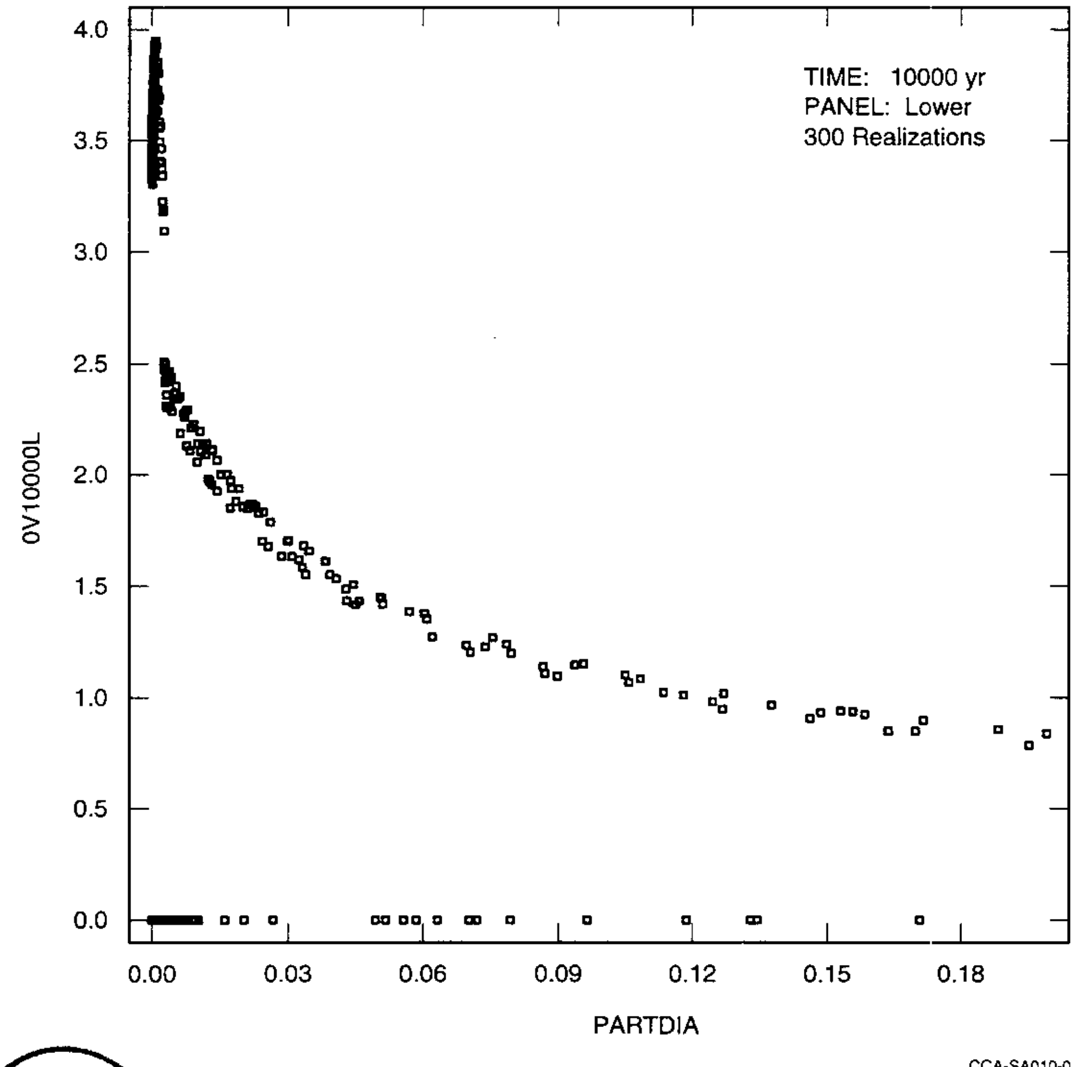

Figure SA-10. Scatterplot for Volume of Material (cubic meters) Removed from Repository due to Spallings Resulting from a Single Drilling Intrusion at 10,000 Years into a Previously Unintruded Repository that Passes through CH-TRU Waste in Lower Waste Panel versus Logarithm of Diameter of Particles Available for Removal by Spallings (PARTDIA)

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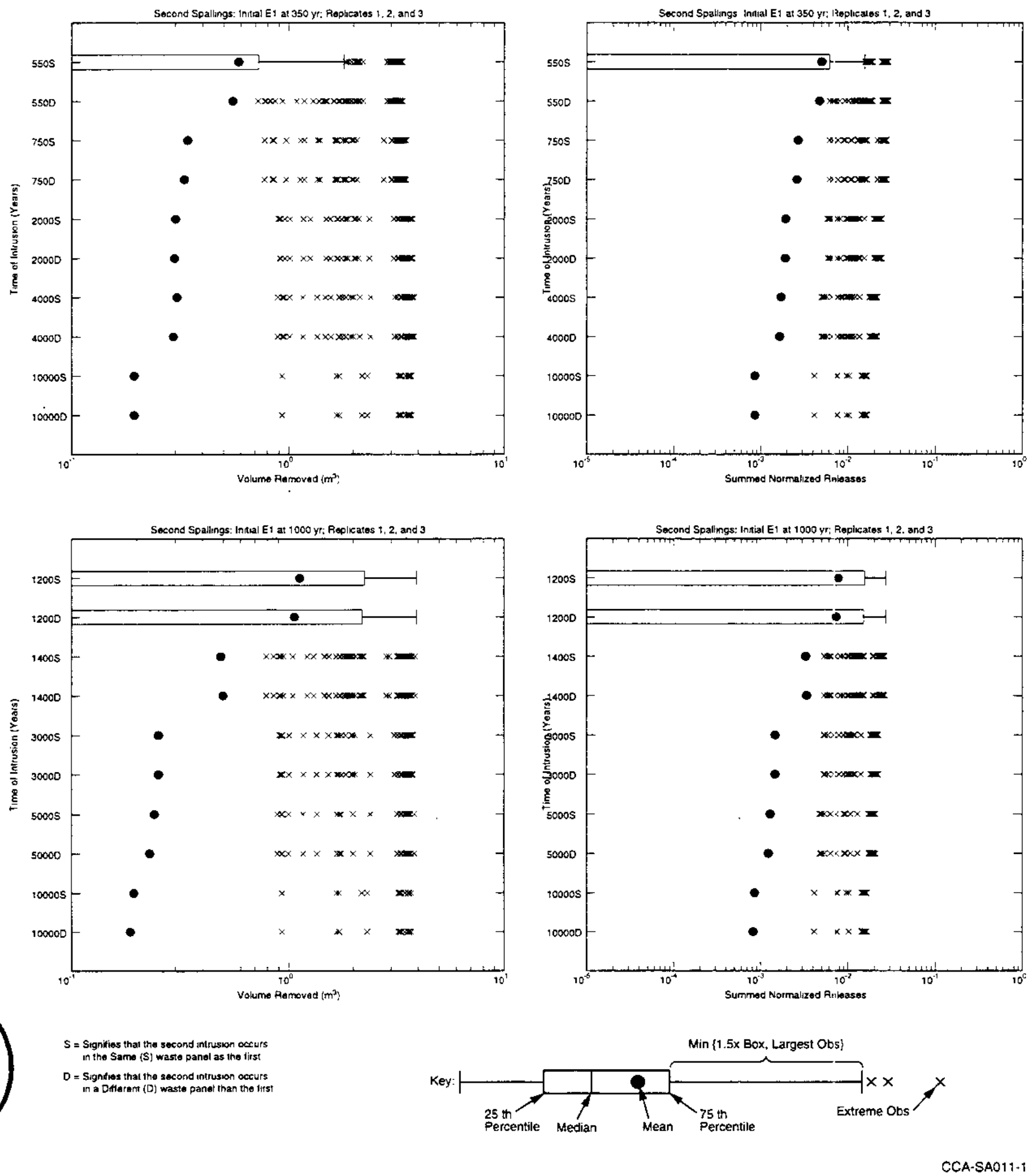

Figure SA-11. Distribution of Original (that is, uncompacted) Volume Removed (cubic meters) and Summed Normalized Release (EPA units) due to Spallings for the Second Drilling Intrusion into CH-TRU Waste after an Initial E1 Intrusion at 350 or 1,000 Years

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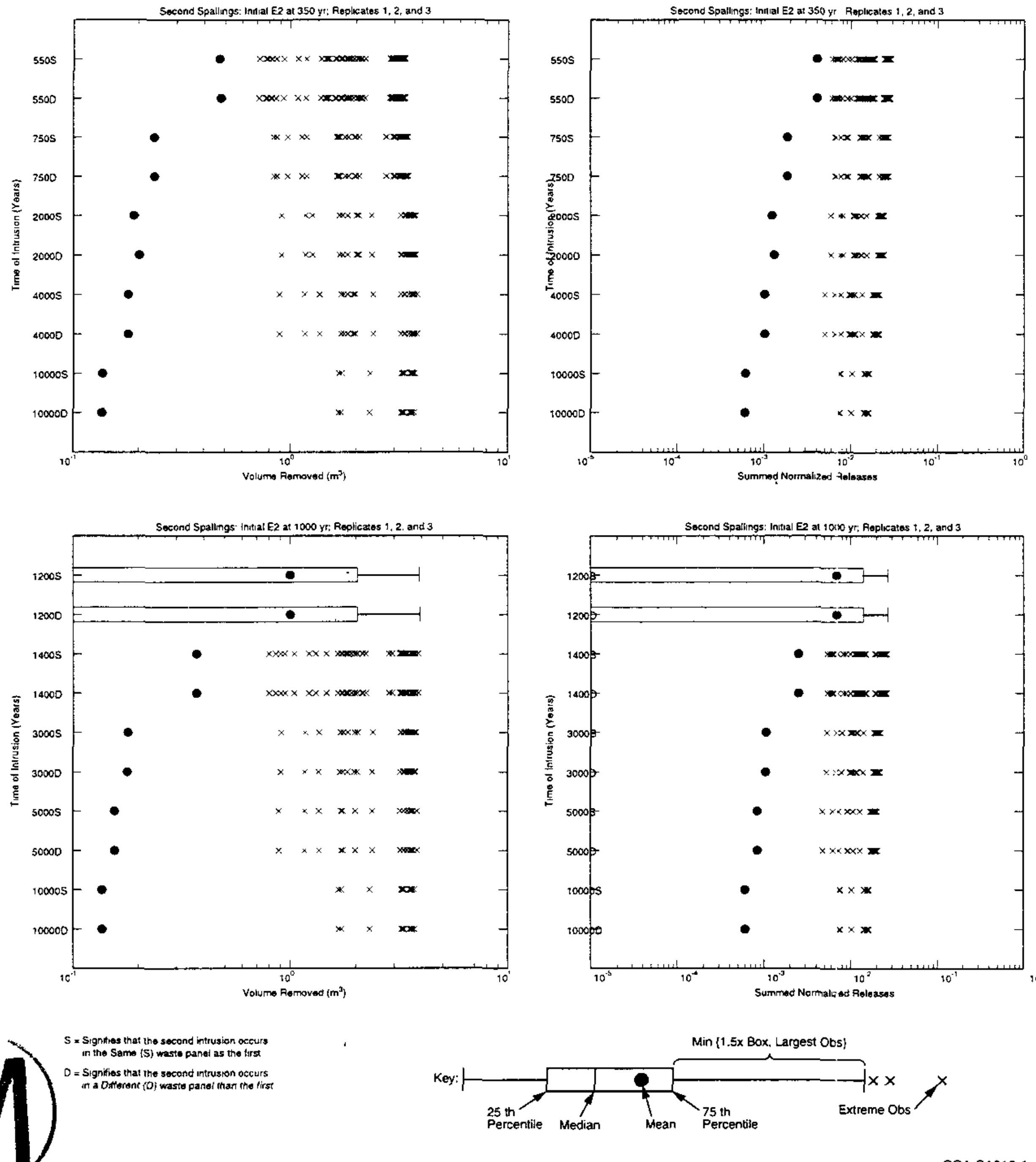

Figure SA-12. Distribution of Original (that is, uncompacted) Volume Removed (cubic meters) and Summed Normalized Release (EPA units) due to Spallings for the Second Drilling Intrusion into CH-TRU Waste after an Initial E2 Intrusion at 350 or 1,000 Years

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Table SA-2. Results Available for Use in CCDF Construction for Spallings Releases

$C_{CH}(\tau_k)$	=	concentration (EPA units per cubic meter) in CH-TRU waste at time τ_k, where τ_k, $k = 1, 2, \ldots, 9$, corresponds to 100, 125, 175, 350, 1,000, 3,000, 5,000, 7,500 and 10,000 years, respectively. See curve "CH-TRU waste within waste panels" in Figure SA-1.
$VS_{E0,U}(\tau_k)$	=	volume (cubic meters) of original (that is, uncompacted) material released by a drilling intrusion into a previously unintruded repository at time τ_k that encounters CH-TRU waste in an upper waste panel, where τ_k, $k = 1, 2, \ldots, 6$ corresponds to 100, 350, 1,000, 3,000, 5,000, and 10,000 years, respectively. See Figure SA-7.
$VS_{E0,L}(\tau_k)$	=	same as $VS_{E0,U}(\tau_k)$ but for intrusion into a lower waste panel. See Figure SA-7.
$VS_{E1,S}(\tau_j, \Delta\tau_{jk})$	=	volume (cubic meters) of original (that is, uncompacted) material released by second drilling intrusion at time $\tau_j + \Delta\tau_{jk}$ into the same waste panel penetrated by an initial E1 intrusion at time τ_j, where τ_j, $j = 1, 2$, corresponds to 350 and 1,000 years; $\Delta\tau_{1k}$, $k = 1, 2, \ldots, 7$, corresponds to 350, 550, 750, 2,000, 4,000, 10,000, and 10,250 years (that is, $\Delta\tau_{1k} = 0$, 200, 400, 1,650, 3,650, 9,650, 9,900 years), results for $k = 2, 3, \ldots, 6$ are summarized in Figure SA-11, $VS_{E1,S}(\tau_1, \Delta\tau_{11}) = VS_{E1,S}(\tau_1, \Delta\tau_{12})$ (that is, $VS_{E1,S}(350, 0) = VS_{E1,S}(350, 200)$), and $VS_{E1,S}(\tau_1, \Delta\tau_{16}) = VS_{E1,S}(\tau_1, \Delta\tau_{17})$ (that is, $VS_{E1,S}(350, 9{,}650) = VS_{E1,S}(350, 9{,}900)$); and $\tau_2 + \Delta\tau_{2k}$, $k = 1, 2, \ldots, 6$, corresponds to 1,000, 1,200, 1,400, 3,000, 5,000 and 10,000 years (that is, $\Delta\tau_{2k} = 0$, 200, 400, 1,000, 4,000, 9,000 years), results for $k = 2, 3, \ldots, 6$ are summarized in Figure SA-11, and $VS_{E1,S}(\tau_2, \Delta\tau_{21}) = VS_{E1,S}(\tau_2, \Delta\tau_{22})$ (that is, $VS_{E1,S}(1{,}000, 0) = VS_{E1,S}(1{,}000, 200)$). The assignments $VS_{E1,S}(350, 0) = VS_{E1,S}(350, 200)$ and $VS_{E1,S}(1{,}000, 0) = VS_{E1,S}(1{,}000, 200)$ are made to bracket the time period between the occurrence of the first drilling intrusion and the failure of the plug at the Rustler and Salado interface; the assignment $VS_{E1,S}(350, 9650) = VS_{E1,S}(350, 9{,}900)$ is made to facilitate the use of $VS_{E1,S}(\tau_1, \Delta\tau_{1k})$ for initial intrusions before $\tau_1 = 350$ years.
$VS_{E1,D}(\tau_j, \Delta\tau_{jk})$	=	same as $VS_{E1,S}(\tau_j, \Delta\tau_{jk})$ but for intrusion into a different waste panel. See Figure SA-11.
$VS_{E2,S}(\tau_j, \Delta\tau_{jk})$	=	same as $VS_{E1,S}(\tau_j, \Delta\tau_{jk})$ but for initial E2 intrusion. See Figure SA-12.
$VS_{E2,D}(\tau_j, \Delta\tau_{jk})$	=	same as $VS_{E1,D}(\tau_j, \Delta\tau_{jk})$ but for initial E2 intrusion. See Figure SA-12.

For each sampled intrusion time, radionuclide concentration can be obtained by interpolating on $C_{CH}(\tau_k)$. Further, for an initial intrusion, the volume of released material can be obtained by interpolating on $VS_{E0,U}(\tau_k)$ and $VS_{E0,L}(\tau_k)$. Obtaining results for second and subsequent intrusions is more difficult for two reasons. First, results are available for initial intrusions at only 350 and 1,000 years. Second, results are available for second intrusions but not for subsequent intrusions.

The availability of results for initial intrusions at only 350 and 1,000 years is handled by extending these results to initial intrusions at other times on the basis of the assumption that the elapsed time from the first to the second intrusion (that is, $\Delta\tau_{jk}$) is the primary determinant of the spallings release for the second intrusion. Specifically, the following assignments are made:

$$VS_{E1,S}(\tau, \Delta\tau_{1k}) = VS_{E1,S}(\tau_1, \Delta\tau_{1k}) \tag{3}$$

for $100 \le \tau \le \tau_1 = 350$ years, and

$$VS_{E1,S}(\tau, \Delta\tau_{2k}) = VS_{E1,S}(\tau_2, \Delta\tau_{2k}) \tag{4}$$

for $\tau_2 = 1{,}000 \le \tau \le 10{,}000$ years. Similar assignments are also made for $VS_{E1,D}$, $VS_{E2,S}$ and $VS_{E2,D}$. The lack of results for more than two intrusions is handled by assuming that spallings releases for third and subsequent intrusions can be estimated by ignoring intermediate intrusions and treating the initial intrusion and the particular subsequent intrusion under consideration as if they were the only two intrusions in existence (Table SA-2).

For each LHS element, nS = 10,000 futures are randomly selected and the corresponding spallings releases are determined as shown in Table SA-2. As an aside, the same 10,000 futures are used for all CCDF constructions for a given LHS element, which ultimately permits the combining of all release modes (that is, cuttings, spallings, direct brine release, and groundwater transport) into a single CCDF. The resultant CCDFs for spallings releases to the accessible environment are then constructed (Figure SA-13). All the CCDFs fall below the boundary line specified in 40 CFR § 191.13(a). Overall, the CCDFs tend to be farther from the boundary line and also more scattered than the CCDFs for cuttings and cavings (Figure SA-5), with 18 out of 100 CCDFs being degenerate (that is, having no nonzero releases) for the first replicate.

The division of the CCDFs in Figure SA-13 into four distinct groups depends on when an initial intrusion into the repository will produce nonzero releases. With the drilling rate into the excavated regions of the repository given by $\lambda = 5.90 \times 10^{-6}\ \text{yr}^{-1}$ during the 600 years of passive institutional controls and by $\lambda = 5.90 \times 10^{-4}\ \text{yr}^{-1}$ after passive institutional controls are assumed to have ended, the probabilities of no drilling intrusions by 1,000, 3,000, and 5,000 years are given by 0.83, 0.26 and 0.079, respectively. These probabilities approximately correspond to the point at which the three lower groups of CCDFs emerge from the ordinate. The uppermost group of CCDFs emerges at approximately 1, which implies that initial intrusions at all times for the corresponding LHS elements are producing nonzero releases. The probabilities given above are actually overestimates because spallings gives releases only for intrusions into CH-TRU waste. The CCDFs tend to emerge at lower probabilities because there is no guarantee that the specified time will actually have nonzero releases associated with it.

The primary determinant of the uncertainty in the CCDFs in Figure SA-13 is the pressure conditions in the repository (Figure SA-8), with no spallings releases taking place at pressures less than 8 megapascals. Given that the pressure is above 8 megapascals, the uncertainty in the spallings release is determined by *PARTDIA* (Figure SA-9).

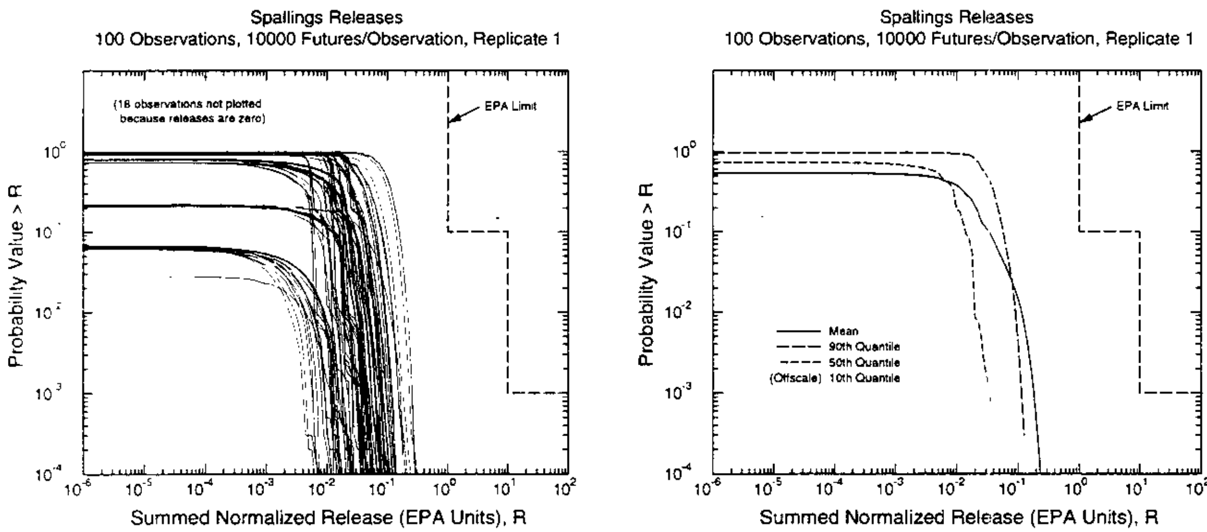

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Figure SA-13. Distribution of CCDFs for Summed Normalized Release to Accessible Environment over 10,000 Years due to Spallings

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To provide additional perspective, CCDFs for the volume of material released by spallings (that is, the quantity obtained from Table SA-3 when C_{CH} is set to 1) can also be constructed (Figure SA-14). Similarly to cuttings and cavings, the release of more than 353 cubic feet (10 cubic meters) of material over 10,000 years is unlikely.

The spallings releases for individual futures were constructed with the assumption that each intrusion could result in a spallings release (Table SA-3). However, releases after the first intrusion occur only if the pressure in the repository remains above 8 megapascals. The pressure in the repository subsequent to an intrusion is dependent on the borehole permeability. In the present analysis, there is no variation in the permeabilities among boreholes above the repository horizon for plugging patterns 2 and 3; specifically, all boreholes for a given LHS element are assumed to have the same permeability. As the repository rapidly drops below 8 megapascals, unless a borehole has a very low permeability, it is probably unreasonable to assume that the pressure in the repository after multiple intrusions has the same value as after a single intrusion. Rather, once a higher permeability borehole occurs, the pressure would drop below 8 megapascals and no additional spallings releases would take place. Inclusion of this depressurization mechanism in the analysis would reduce the spallings releases (Figure SA-15).

SA.6 Direct Brine Release: Uncertainty and Sensitivity

Drilling intrusions through CH-TRU waste can produce direct brine releases and hence dissolved radionuclides, as the result of rapid fluid movement toward a borehole at the time of intrusion. Because of the low permeability of the region surrounding each RH-TRU waste canister, intrusions into RH-TRU waste are assumed not to produce direct brine releases.

The direct brine release model predicts a release of brine (cubic meters). For a given drilling intrusion, the volume of released brine is multiplied by the concentration (EPA units per cubic meter) of dissolved radionuclides in CH-TRU waste (Section SA.7) at the time of the intrusion to produce the direct brine release. Prior to an E1 intrusion, solubilities associated with brines derived from the Salado are used; after an E1 intrusion, solubilities associated with brines derived from the Castile are used.

The amount of brine associated with a direct brine release is sensitive to both the pressure and brine saturation in the vicinity of the drilling intrusion. In turn, pressure and saturation are dependent on both the time of a drilling intrusion and whether the drilling intrusion has been preceded by earlier intrusions. Because of the 1-degree dip of the repository, it is also possible that conditions influencing direct brine release may differ between upper (that is, Panels 1, 2, 3, 6, 7, 8, 9) and lower (that is, Panels 4, 5, 10) panels.

The preceding considerations involving the time and location of drilling intrusions also affect spallings releases. Therefore, direct brine release calculations were performed for the same times as spallings calculations. Specifically, direct brine release calculations were performed for initial intrusions at 100, 350, 1,000, 3,000, 5,000 and 10,000 years and also for intrusions into one of

Table SA-3. Determination of Spallings Release $f_{SP}(\mathbf{x}_{st})$ for an Arbitrary Future $\mathbf{x}_{st}$ of Form in Equation 1

Notation:

nH_i = number of intrusions prior to intrusion i that penetrate pressurized brine and use plugging pattern 2 (that is, two discrete plugs)

nD = number of intrusions required to deplete brine reservoir

$\tilde{b}_i$ = 0 if intrusion i into (1) nonexcavated area or (2) excavated area and plugging pattern 1 used (that is, continuous plug)

= 1 if intrusion i into excavated area, penetrates pressurized brine, plugging pattern 2 used, and $nH_i \le nD$

= 2 if intrusion i into excavated area and either (1) penetrates pressurized brine, plugging pattern 2 used, and $nH_i > nD$, (2) does not penetrate pressurized brine and plugging pattern 2 used, or (3) plugging pattern 3 used (that is, three discrete plugs)

Release rSP_i for intrusion into pressurized repository at time t_i (that is, $i = 1$ or $\tilde{b}_j = 0$ for $j = 1, 2, \ldots, i-1$):

rSP_i	$= 0$	if intrusion penetrates RH-TRU waste or no waste
	$= C_{CH}(t_i)$[a] $VS_{E0,U}(t_i)$	if l_i in upper waste panel
	$= C_{CH}(t_i)\, VS_{E0,L}(t_i)$	if l_i in lower waste panel.

Release rSP_i for intrusion into a depressurized repository at time t_i with no E1 intrusion in first $i-1$ intrusions (that is, $\tilde{b}_k = 0$ for $k = 1, 2, \ldots, j-1$, $\tilde{b}_j = 2$, $\tilde{b}_k \ne 1$ for $k = j+1, j+2, \ldots, i-1$):

rSP_i	$= 0$	if intrusion penetrates RH-TRU waste or no waste
	$= C_{CH}(t_i)\, VS_{E2,S}(t_j, t_i - t_j)$[b]	if l_j, l_i in same waste panel
	$= C_{CH}(t_i)\, VS_{E2,D}(t_j, t_i - t_j)$	if l_j, l_i in different waste panels.

Release rSP_i for intrusion into a depressurized repository at time t_i with first E1 intrusion at time $t_j < t_i$ (that is, $\tilde{b}_k \ne 1$ for $k = 1, 2, \ldots, j-1$, $\tilde{b}_j = 1$):

rSP_i	$= 0$	if intrusion penetrates RH-TRU waste or no waste
	$= C_{CH}(t_i)\, VS_{E1,S}(t_j, t_i - t_j)$	if l_j, l_i in same waste panel
	$= C_{CH}(t_i)\, VS_{E1,D}(t_j, t_i - t_j)$	if l_j, l_i in different waste panels.

Spallings release $f_{SP}(\mathbf{x}_{st})$::

$$f_{SP}(\mathbf{x}_{st}) = \sum_{i=1}^{n} rSP_i$$

[a] Here and elsewhere, appearance of an undefined time implies interpolation between defined times in Table SA-2.
[b] Here and elsewhere, appearance of two undefined times implies two-dimensional interpolation between defined times in Table SA-2.

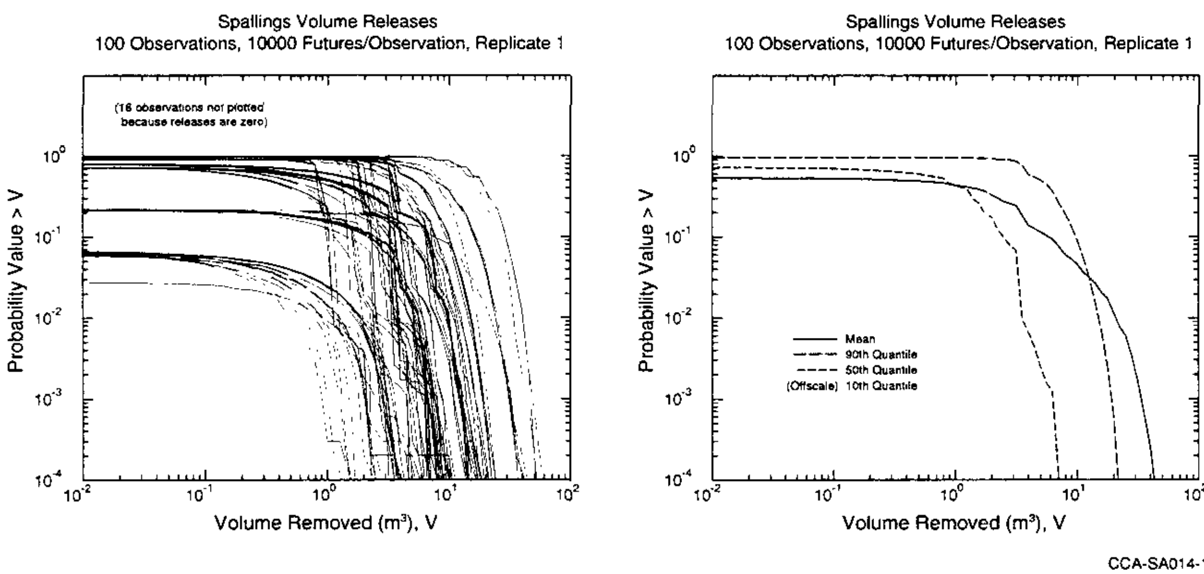

Figure SA-14. Distribution of CCDFs for Volume of Material (cubic meters) Removed to Accessible Environment over 10,000 Years due to Spallings

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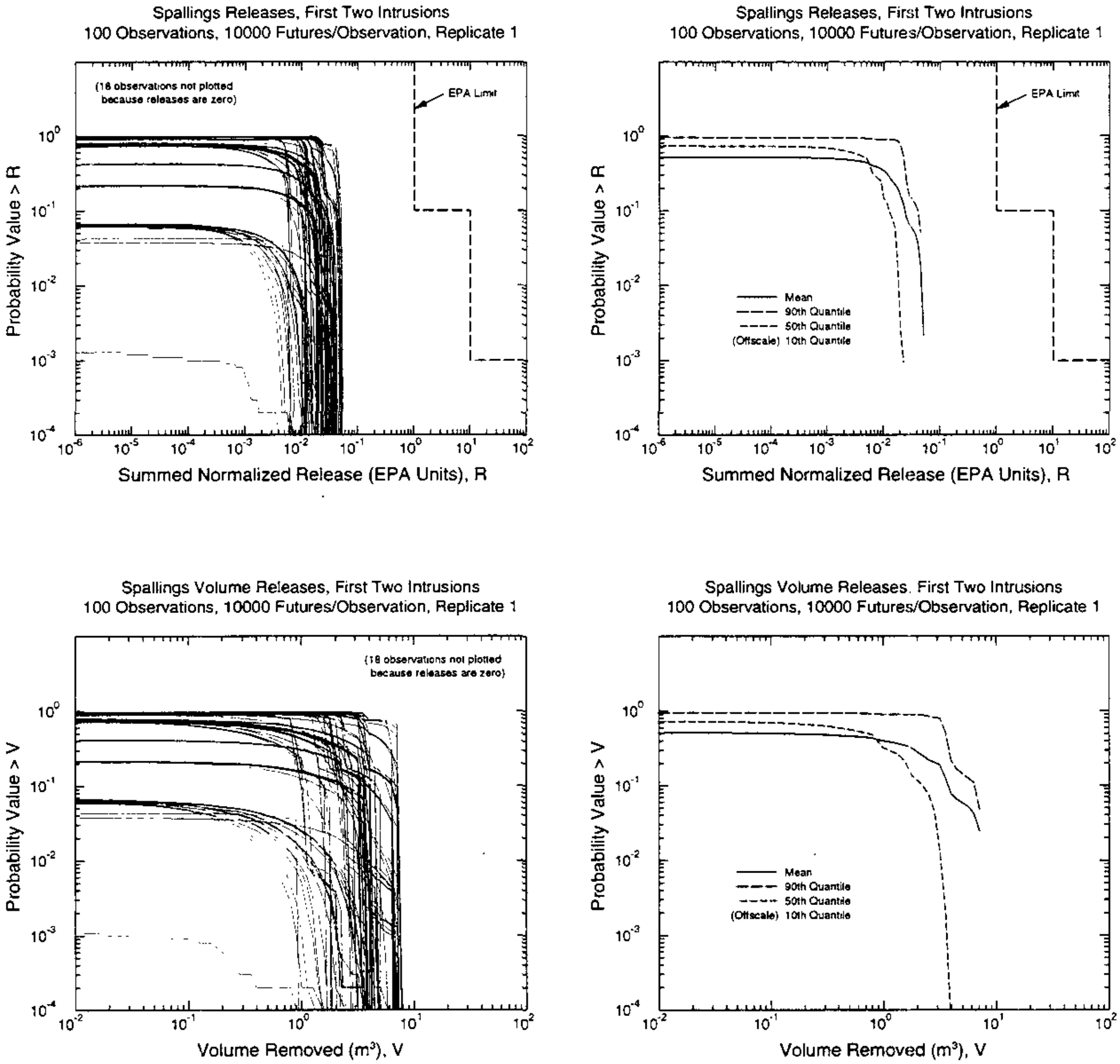

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Figure SA-15. Distributions of CCDFs for Summed Normalized Release to Accessible Environment and Volume of Material (cubic meters) Removed to Accessible Environment over 10,000 Years due to Spallings with the Assumption that Spallings Releases Will Occur Only for the First Two Drilling Intrusions into the Repository

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the seven updip (upper) waste panels and one of the three downdip (lower) waste panels (Figure SA-16). Most LHS elements produce no releases. Further, most of the nonzero releases occurred for intrusions into the lower waste panel.

Examination of the results for intrusion into the lower waste panel shows that nonzero brine releases tend to be associated with larger values for brine saturation and intermediate values for pressure (Figure SA-17). The largest gas pressures tend to be associated with low brine saturations (Figure SA-18) caused by the consumption of brine in the corrosion of steel and hence result in no direct brine releases. As pressure is almost constant throughout the repository, the greater number of zero releases for intrusions into the upper waste panel is the result of lower brine saturation (Figure SA-16). When a nonzero brine release does occur, the size of the corresponding normalized release tends to increase as the dissolved radionuclide concentration in the brine increases (Figure SA-19).

Direct brine release calculations were also performed for intrusions subsequent to an initial intrusion for the same intrusion combinations as used for spallings (Figures SA-20 and SA-21). As for initial intrusions, most LHS elements result in no brine release for second intrusions. Because of the effects of the brine reservoir, intrusions subsequent to an E1 intrusion tend to have more nonzero releases than intrusions subsequent to an E2 intrusion. Further, intrusions into the same waste panel tend to result in larger releases than intrusions into a different waste panel. As pressure is almost constant throughout the repository, the greater number of zero releases from intrusions into different waste panels is the result of lower brine saturation. However, it should be recognized that, in the computational implementation of the analysis, what is described as two intrusions into the same panel is actually two intrusions into the same lower panel, and what is described as two intrusions into different panels actually consists of an initial intrusion into a lower waste panel and a subsequent intrusion into an upper waste panel.

Borehole permeability (*BHPERM*), brine saturation and repository pressure (megapascals) interact to determine the volume of brine (cubic meters) released by a second drilling intrusion (Figure SA-22).

SA.7 Solubility: Uncertainty and Sensitivity

Given that a nonzero brine release takes place, radionuclide concentration is a major determinant of the size of a direct brine release (Figure SA-19). The concentrations used in determining a direct brine release depend on whether the conditions in the repository are dominated by brine from the Salado (upper frame, Figure SA-23) or brine from the Castile (lower frame, Figure SA-23). For the performance assessment, releases from a previously unintruded repository and also releases not preceded by an E1 intrusion use the Salado-dominated concentrations; releases after an E1 intrusion use the Castile-dominated concentrations. Thus, the normalized releases in Figures SA-16 and SA-21 were calculated with the appropriate time-dependent concentrations from the upper frame of Figure SA-23; similarly, the normalized releases in Figure SA-20 were calculated with the appropriate time-dependent concentrations from the lower frame of Figure SA-23.

Each curve in Figure SA-23 results from one LHS element and derives from the values of several uncertain variables.

The noticeable downward shift of the concentration curves in Figure SA-23 results when the number of EPA units in solution changes as a result of radioactive decay from being dominated by ^{241}Am to being dominated by ^{239}Pu. A similar but less conspicuous shift also takes place at earlier times in the upper frame of Figure SA-23 when the number of EPA units in solution changes from being dominated by ^{238}Pu to being dominated by ^{241}Am.

SA.8 Direct Brine Release: CCDFs

As for cuttings and spallings, each LHS element leads to a CCDF for direct brine release that is obtained by randomly sampling futures of the form in Equation 1 and then constructing the corresponding direct brine release for each future. This construction is based on the volumes of brine (cubic meters) released directly under different conditions and the radionuclide concentration (EPA units per cubic meter) in that brine (Table SA-4). The structure of the results in Table SA-4 for direct brine releases is the same as the structure of the results in Table SA-2 for solid material releases from spallings.

For each sampled intrusion time, radionuclide concentration can be obtained by interpolating on $C_{E0}(\tau_k)$ and $C_{E1}(\tau_k)$ as appropriate. Specifically, $C_{E0}(\tau_k)$ is used before any Castile brine has entered the repository from an E1 intrusion, and $C_{E1}(\tau_k)$ is used after an E1 intrusion has allowed Castile brine to enter the repository. Further, for an initial intrusion, the volume of released material can be obtained by interpolating on $VB_{E0,U}(\tau_k)$ and $VB_{E0,L}(\tau_k)$.

As for spallings, obtaining results for second and subsequent intrusions is more difficult for two reasons. First, results are available for initial intrusions at only 350 and 1,000 years. Second, results are available for second intrusions but not for subsequent intrusions. The availability of results for initial intrusions at only 350 and 1,000 years is handled by extending these results to initial intrusions at other times on the basis of the assumption that elapsed time from the first to the second intrusion (that is, $\Delta\tau_{jk}$) is the primary determinant of the direct brine release for the second intrusion. Specifically, the following assignments are made:

$$VB_{E1,S}(\tau, \Delta\tau_{1k}) = VB_{E1,S}(\tau_1, \Delta\tau_{1k}) \quad (5)$$

for $100 \le \tau \le \tau_1 = 350$ years, and

$$VB_{E1,S}(\tau, \Delta\tau_{2k}) = VB_{E1,S}(\tau_2, \Delta\tau_{2k}) \quad (6)$$

for $\tau_2 = 1{,}000 \le \tau \le 10{,}000$ years. Similar assignments are also made for $VB_{E1,D}$, $VB_{E2,S}$ and $VB_{E2,D}$. The lack of results for more than two intrusions is handled by assuming that direct brine

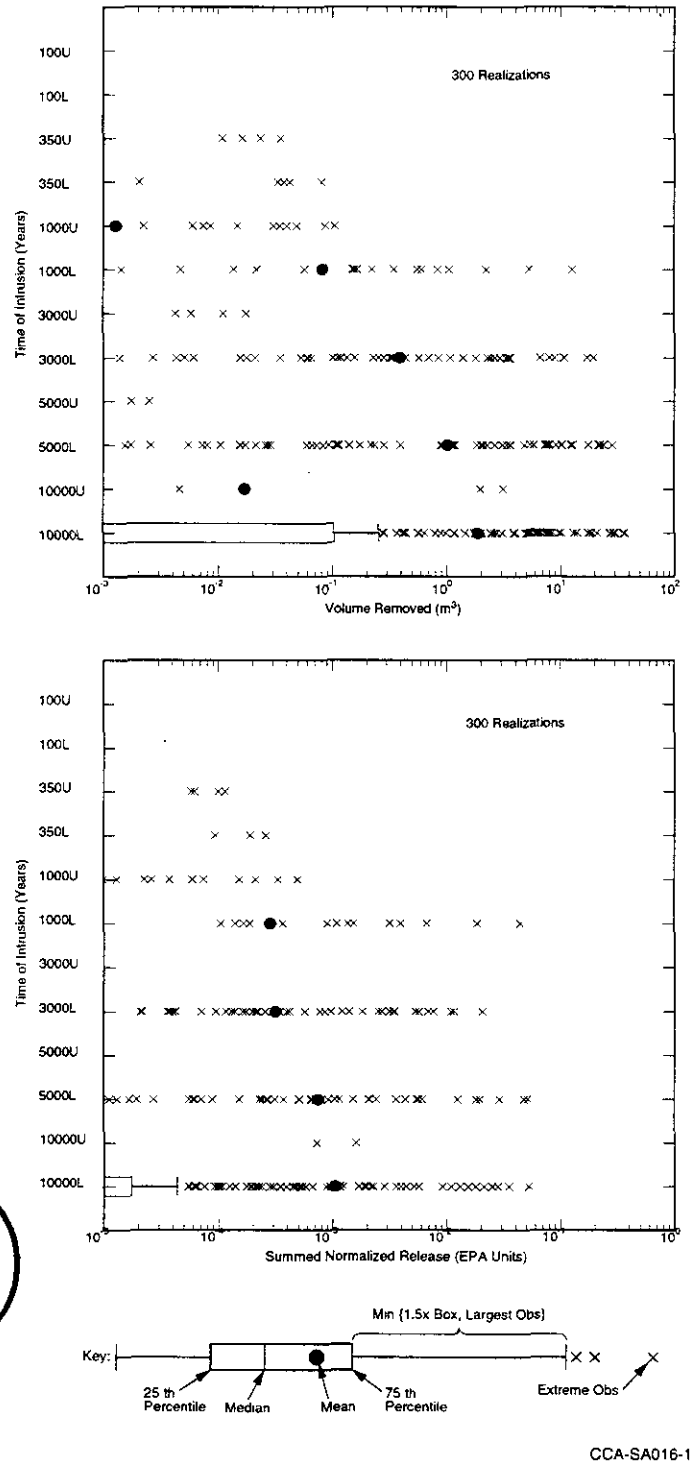

Figure SA-16. Distribution of Brine Release (cubic meters) and Summed Normalized Release (EPA units) from Direct Brine Release for a Single Drilling Intrusion into a Previously Unintruded Repository

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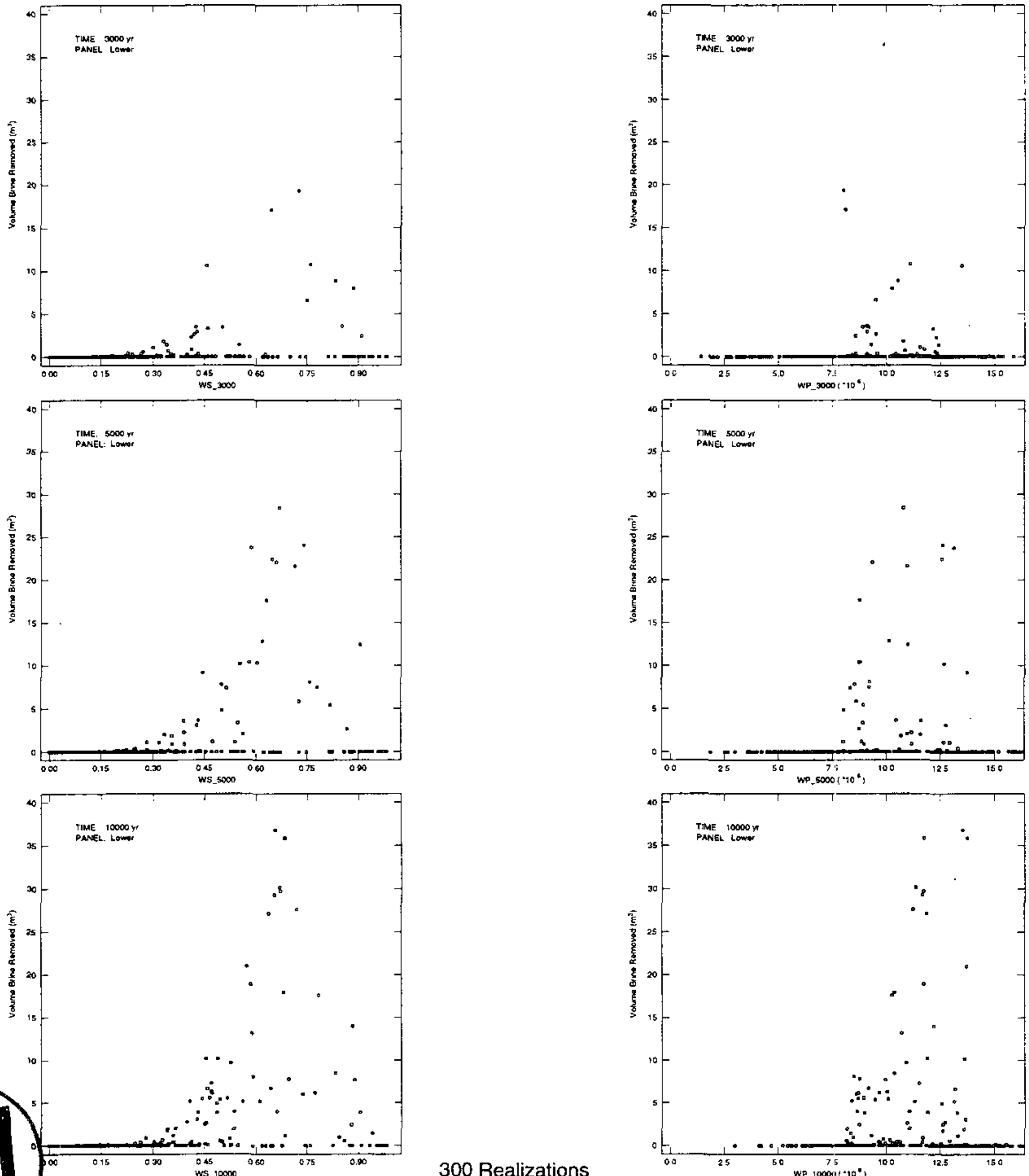

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Figure SA-17. Scatterplots for Volume of Brine (cubic meters) Removed from Repository from Direct Brine Release Resulting from a Single Drilling Intrusion into a Previously Unintruded Repository that Passes through CH-TRU Waste in a Lower Waste Panel versus Brine Saturation and Pressure (pascals) in That Panel.

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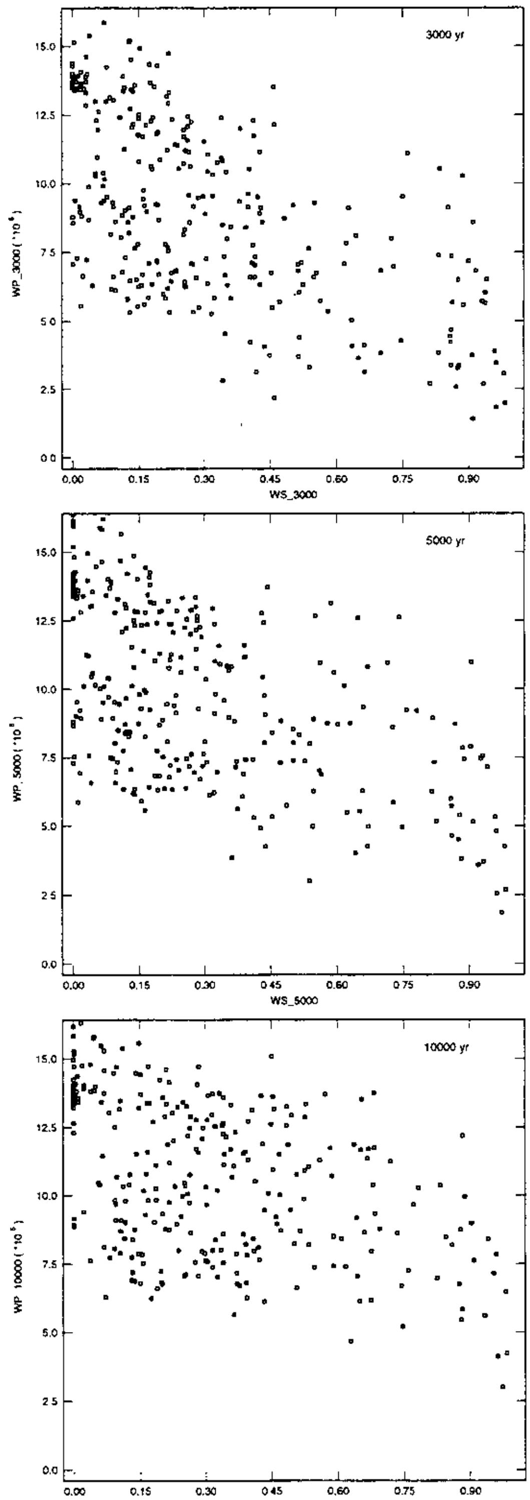

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Figure SA-18. Scatterplots for Brine Saturation versus Pressure (pascals) in Lower Waste Panels of Undisturbed Repository

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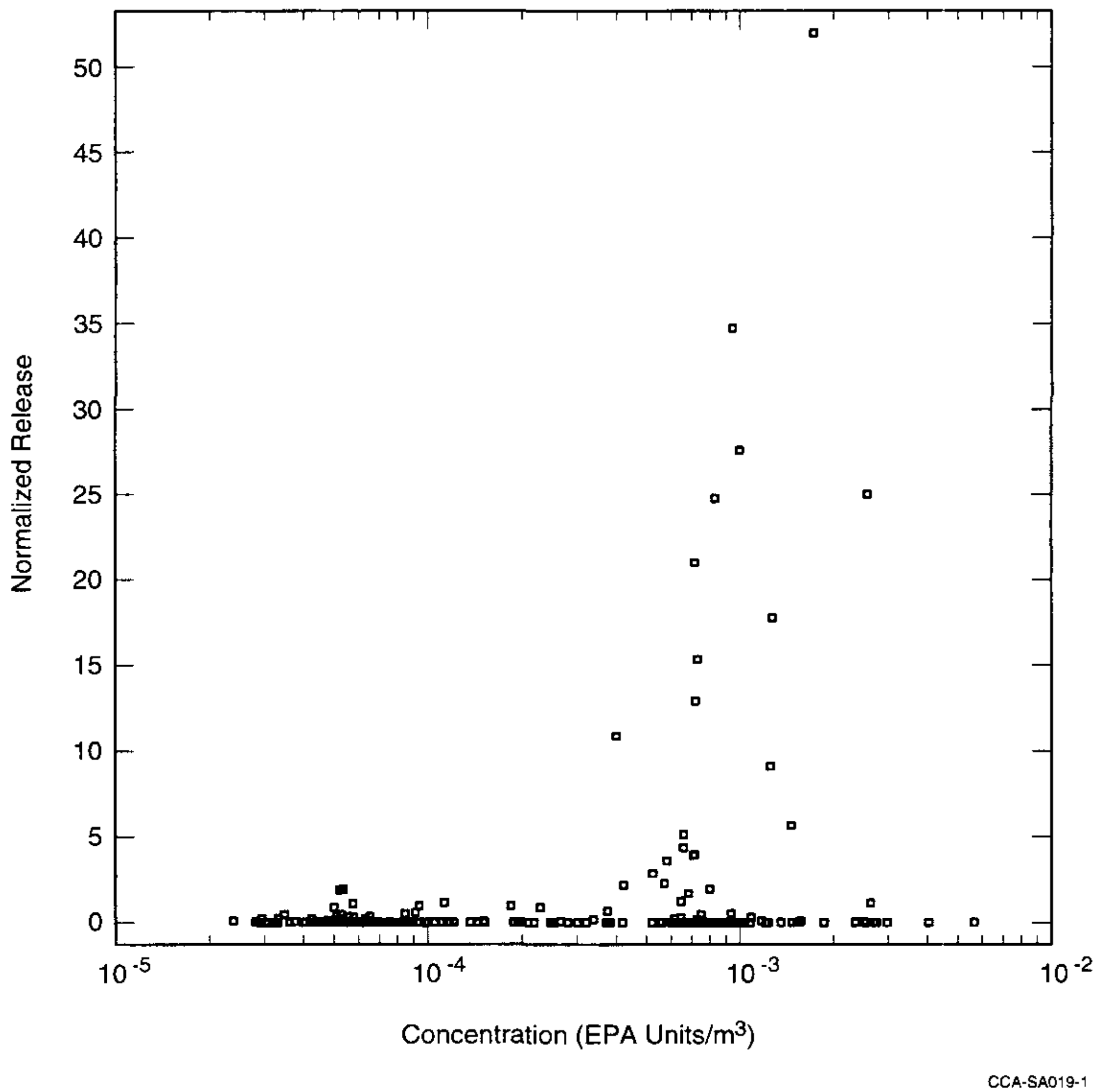

Figure SA-19. Scatterplot for Normalized Release (EPA units) from Repository from Direct Brine Release Resulting from a Single Drilling Intrusion at 10,000 Years into a Previously Unintruded Repository that Passes through CH-TRU Waste in a Lower Waste Panel versus Radionuclide Concentration in EPA units per cubic meter at 10,000 Years

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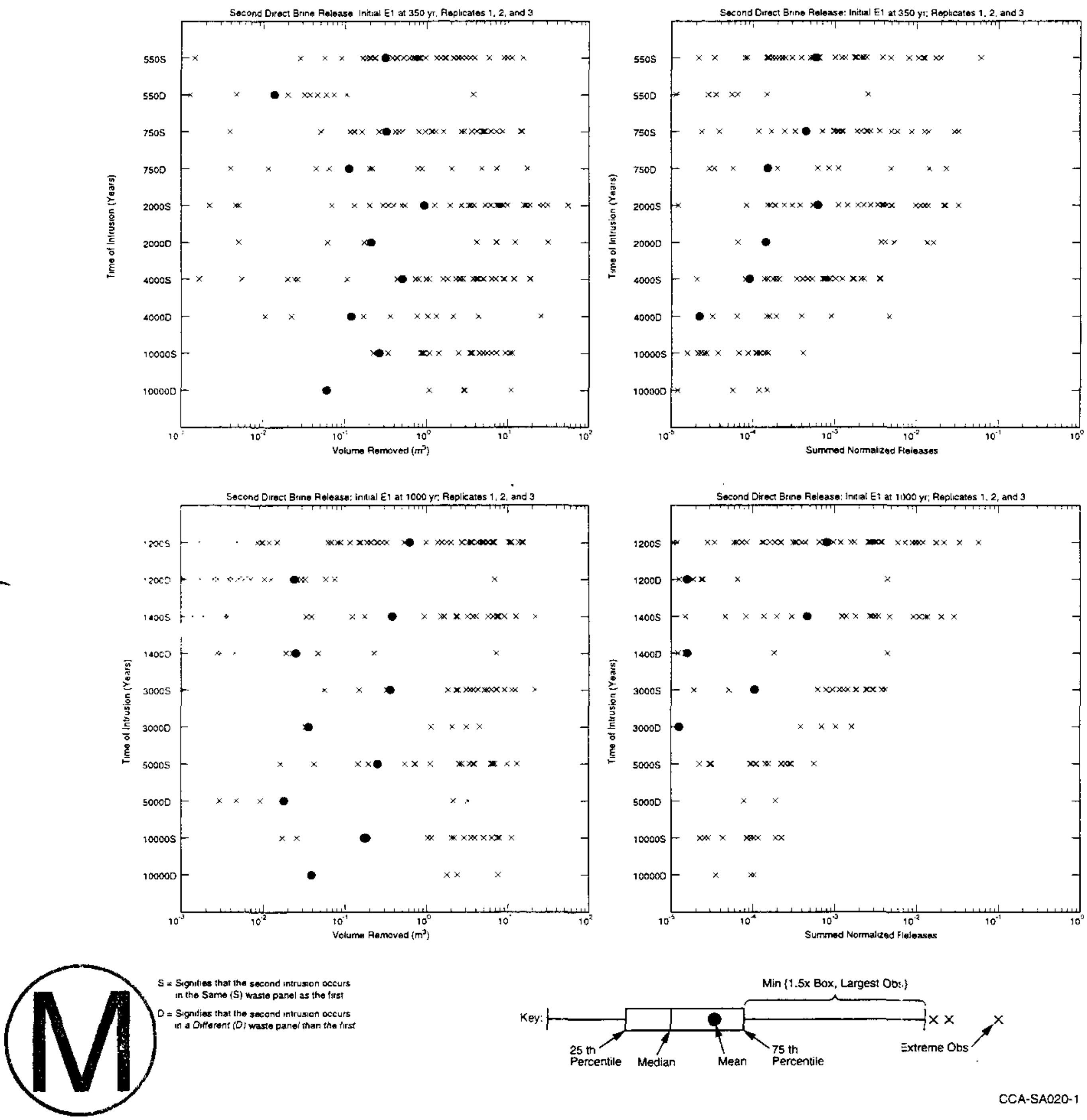

Figure SA-20. Distribution of Brine Release (cubic meters) and Summed Normalized Release (EPA units) from Direct Brine Release for the Second Drilling Intrusion into CH-TRU Waste after an Initial E1 Intrusion at 350 or 1,000 Years

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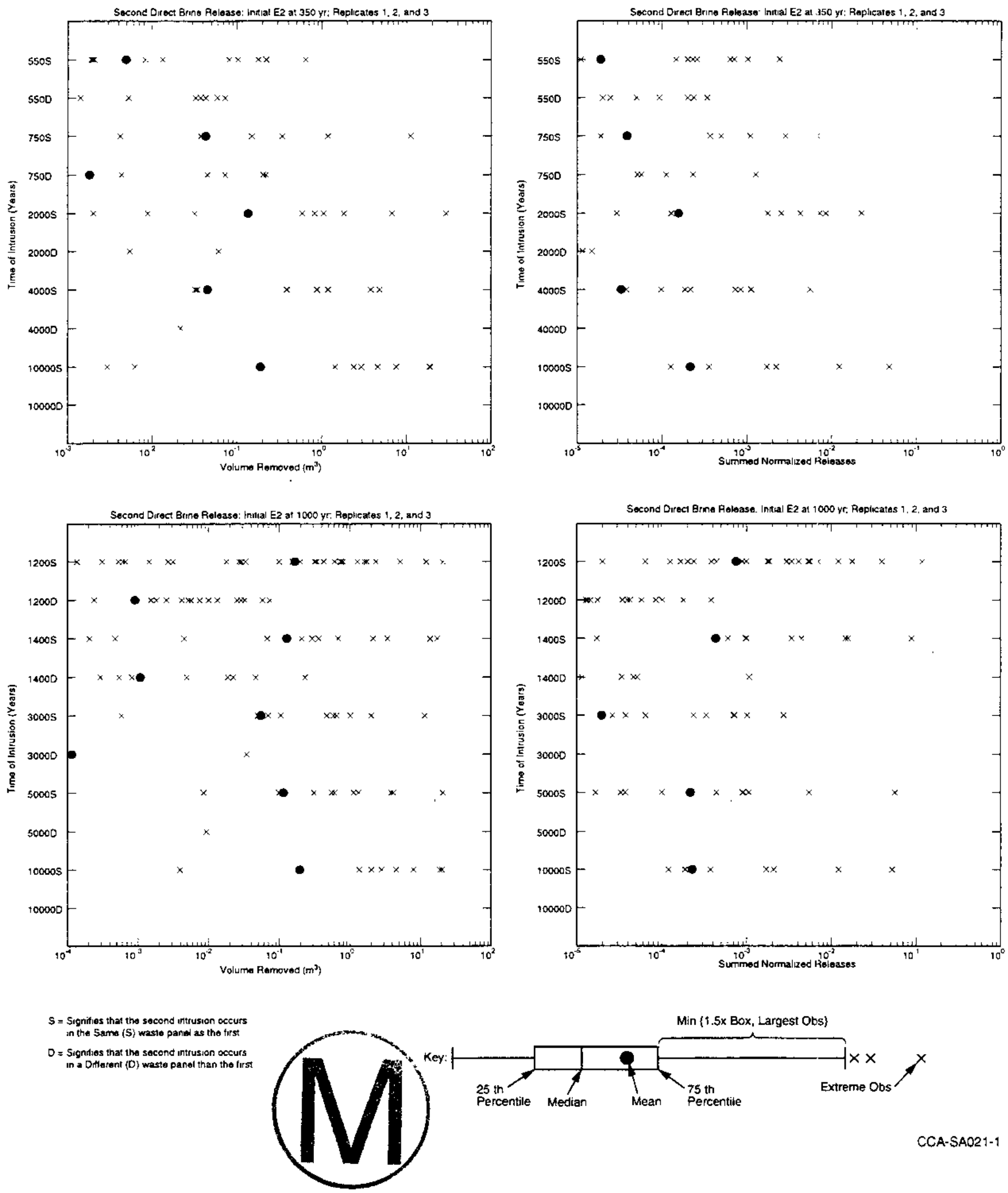

Figure SA-21. Distribution of Brine Release (cubic meters) and Summed Normalized Release (EPA units) from Direct Brine Release for the Second Drilling Intrusion into CH-TRU Waste after an Initial E2 Intrusion at 350 or 1,000 Years

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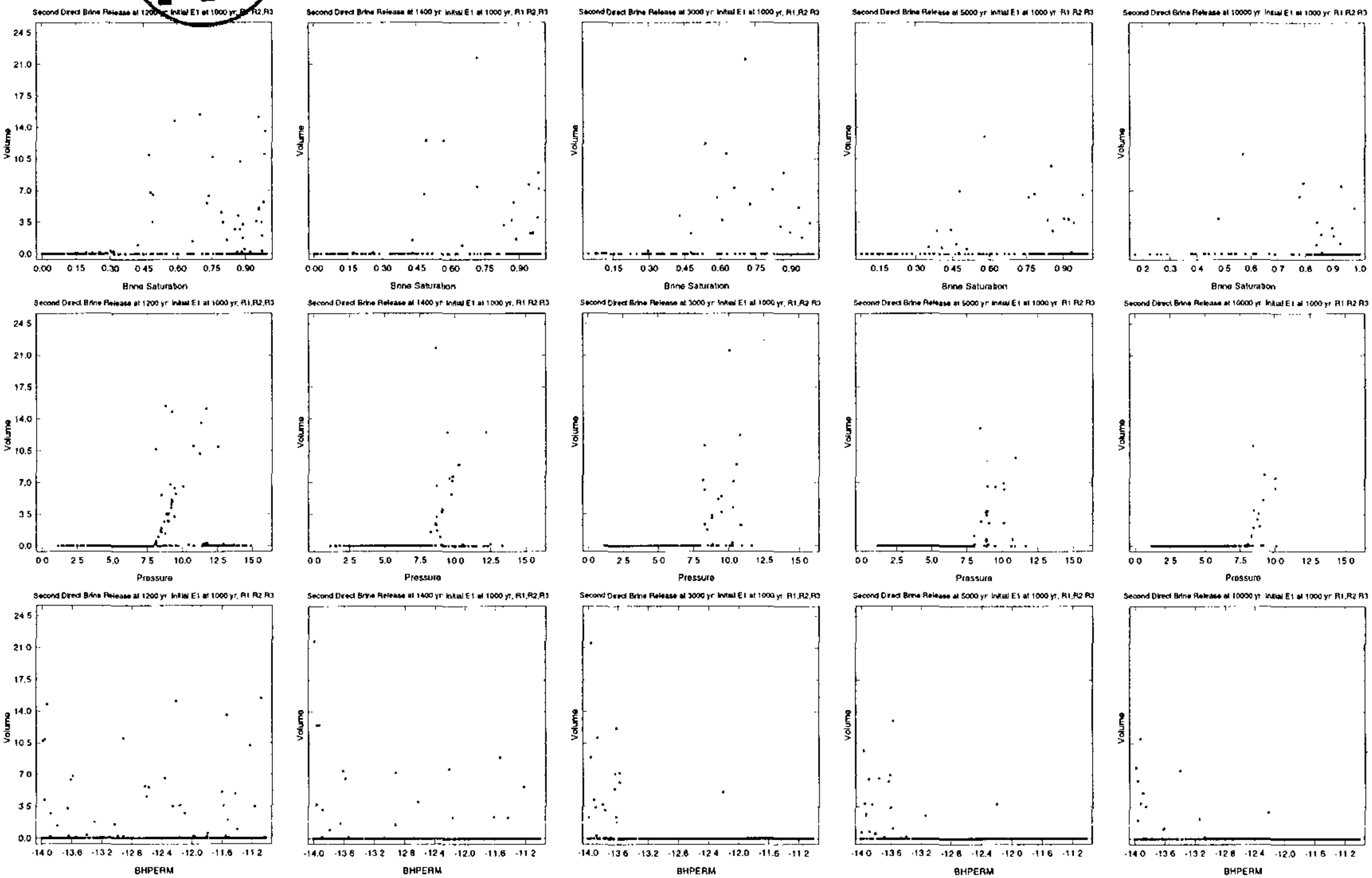

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Figure SA-22. Scatterplots for Volume of Brine (cubic meters) Removed from Repository Due to Direct Brine Release Resulting from Second Drilling Intrusion into CH-TRU Waste in Same Waste Panel as an Initial E1 Intrusion versus Brine Saturation, Pressure (pascals) and Borehole Permeability (square meters, *BHPERM*)

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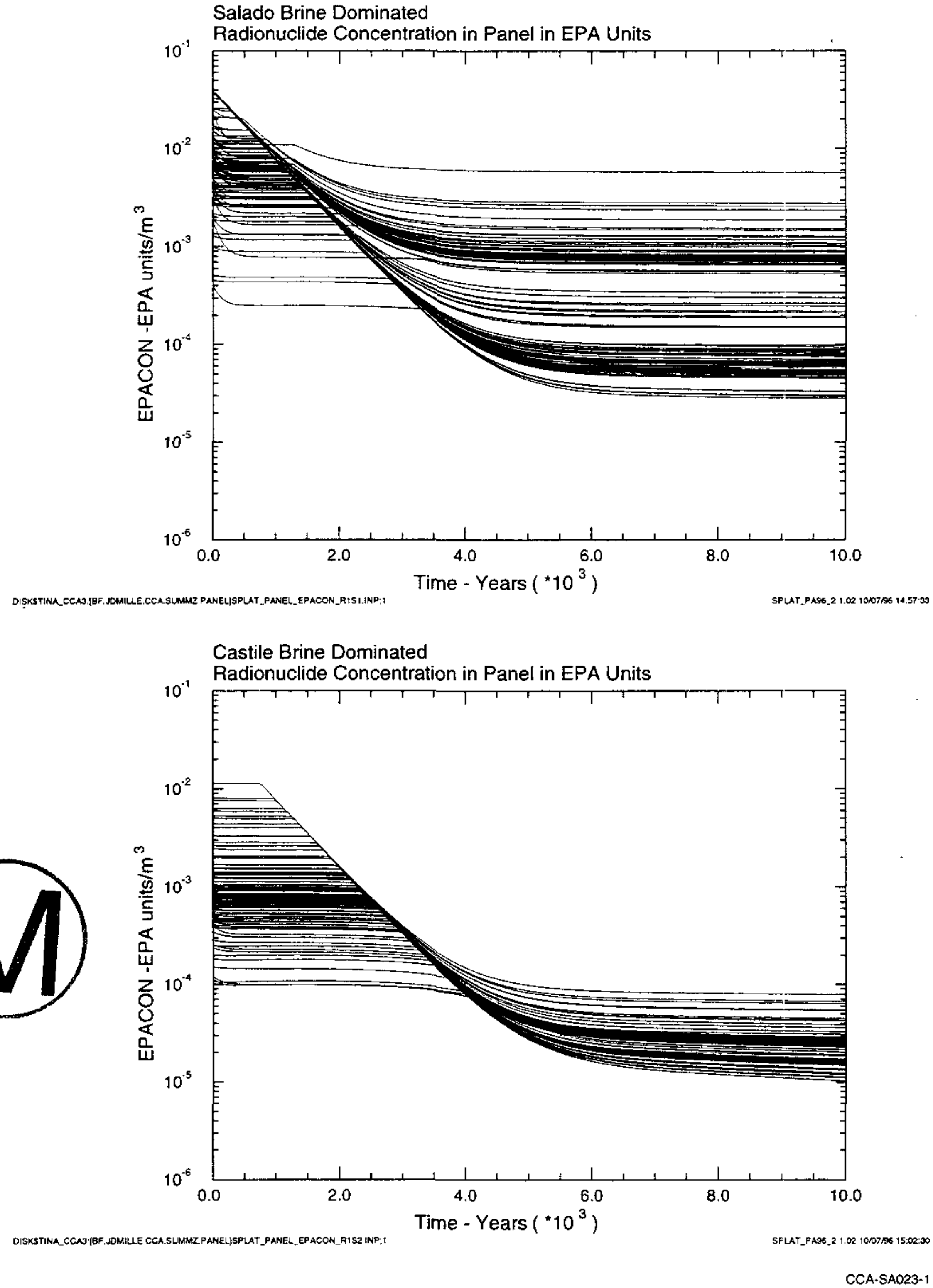

Figure SA-23. Radionuclide Concentration (EPA units per cubic meter) in Repository

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Table SA-4. Results Available for Use in CCDF Construction for Direct Brine Releases

$C_{E0}(\tau_k)$	=	concentration (EPA units per cubic meter) in brine in the repository under undisturbed conditions at time τ_k, where τ_k, $k = 1, 2, \ldots, 9$, corresponds to 100, 125, 175, 350, 1,000, 3,000, 5,000, 7,500, and 10,000 years. Based on solubilities and chemical conditions for repository dominated by Salado brine; see upper frame, Figure SA-23.
$C_{E1}(\tau_k)$	=	concentration (EPA units per cubic meter) in brine in the repository subsequent to an E1 intrusion at time τ_k, where τ_k, $k = 1, 2, \ldots, 9$, corresponds to 100, 125, 175, 350, 1,000, 3,000, 5,000, 7,500, and 10,000 years. Based on solubilities and chemical conditions for repository dominated by Castile brine; see lower frame, Figure SA-23.
$VB_{E0,U}(\tau_k)$	=	volume (cubic meters) of brine released by a drilling intrusion into a previously unintruded repository at time τ_k that encounters CH-TRU waste in an upper waste panel, where τ_k, $k = 1, 2, \ldots, 6$, corresponds to 100, 350, 1,000, 3,000, 5,000, and 10,000 years, respectively. See Figure SA-16.
$VB_{E0,L}(\tau_k)$	=	Same as $VB_{E0,U}(\tau_k)$ but for intrusion into a lower waste panel. See Figure SA-16.
$VB_{E1,S}(\tau_j, \Delta\tau_{jk})$	=	volume (cubic meters) of brine released by second drilling intrusion at time $\tau_j + \Delta\tau_{jk}$ into the same waste panel penetrated by an initial E1 intrusion at time τ_j, where τ_j, $j = 1, 2$, corresponds to 350 and 1,000 years; $\tau_1 + \Delta\tau_{1k}$, $k = 1, 2, \ldots, 7$, corresponds to 350, 550, 750, 2,000, 4,000, 10,000, and 10,250 years (that is, $\Delta\tau_{1k} = 0$, 200, 400, 1,650, 3,650, 9,650, 9,900 years), results for $k = 2, 3, \ldots, 6$ are summarized in Figure SA-20, $VB_{E1,S}(\tau_1, \Delta\tau_{11}) = VB_{E1,S}(\tau_1, \Delta\tau_{12})$ (that is, $VB_{E1,S}(350, 0) = VB_{E1,S}(350, 200)$), and $VB_{E1,S}(\tau_1, \Delta\tau_{16}) = VB_{E1,S}(\tau_1, \Delta\tau_{17})$ (that is, $VB_{E1,S}(350, 9{,}650) = VB_{E1,S}(350, 990)$); and $\tau_2 + \Delta\tau_{2k}$, $k = 1, 2, \ldots, 6$, corresponds to 1,000, 1,200, 1,400, 3,000, 5,000 and 10,000 years (that is, $\Delta\tau_{2k} = 0$, 200, 400, 1,000, 4,000, 9,000 yr), results for $k = 2, 3, \ldots, 6$ are summarized in Figure SA-21, and $VB_{E1,S}(\tau_2, \Delta\tau_{21}) = VB_{E1,S}(\tau_2, \Delta\tau_{22})$ (that is, $VB_{E1,S}(1{,}000, 0) = VB_{E1,S}(1{,}000, 200)$). The assignments $VB_{E1,S}(350, 0) = VB_{E1,S}(350, 200)$ and $VB_{E1,S}(1{,}000, 0) = VB_{E1,S}(1{,}000, 200)$ are made to bracket the time period between the occurrence of the first drilling intrusion and the failure of the plug at the Rustler and Salado interface; the assignment $VB_{E1,S}(350, 9{,}650) = VB_{E1,S}(350, 9{,}900)$ is made to facilitate the use of $VB_{E1,S}(\tau_1, \Delta\tau_{1k})$ for initial intrusions before $\tau_1 = 350$ years.
$VB_{E1,D}(\tau_j, \Delta\tau_{jk})$	=	same as $VB_{E1,S}(\tau_j, \Delta\tau_{jk})$ but for intrusion into different waste panel. See Figure SA-20.
$VB_{E2,S}(\tau_j, \Delta\tau_{jk})$	=	same as $VB_{E1,S}(\tau_j, \Delta\tau_{jk})$ but for initial E2 intrusion. See Figure SA-21.
$VB_{E2,D}(\tau_j, \Delta\tau_{jk})$	=	same as $VB_{E1,D}(\tau_j, \Delta\tau_{jk})$ but for initial E2 intrusion. See Figure SA-21.

releases for third and subsequent intrusions can be estimated by ignoring intermediate intrusions and treating the initial intrusion and the particular subsequent intrusion under consideration as if they were the only two intrusions in existence (Table SA-5).

For each LHS element, nS = 10,000 futures are randomly selected and the corresponding direct brine releases are determined as shown in Table SA-5. The resultant CCDFs for direct brine releases to the accessible environment are then constructed (Figure SA-24). All the CCDFs fall below the boundary line specified in 40 CFR § 191.13(a). Overall, the CCDFs tend to be farther from the boundary line and also more scattered than the CCDFs for cuttings/cavings and spallings (Figures SA-5 and SA-13), with 48 out of 100 CCDFs being degenerate (that is, having no nonzero releases) for the first replicate.

The primary determinants of the uncertainty in the CCDFs in Figure SA-24 are the pressure and brine saturation conditions in the repository, with no direct brine releases taking place for low brine saturation (Figure SA-17) and also no releases taking place for low pressures (Figure SA-17).

To provide additional perspective, CCDFs for volume of brine released directly (that is, the quantity obtained from Table SA-5 when C_{E0} and C_{E1} are set to 1) can also be constructed (Figure SA-25). Similarly to cuttings/cavings and spallings, the release of more than 353 cubic feet (10 cubic meters) of brine over 10,000 years is unlikely.

The direct brine releases for individual futures were constructed with the assumption that each intrusion could result in a direct brine release (Table SA-5). However, releases after the first intrusion occur only if the pressure in the repository remains above approximately 8 megapascals (Figure SA-21). The pressure in the repository subsequent to an intrusion is dependent on the borehole permeability. In turn, this means that the occurrence of direct brine releases subsequent to an initial intrusion is also dependent on borehole permeability (Figure SA-21). In the present analysis, there is no variation in the permeabilities among boreholes above the repository horizon for plugging patterns 2 and 3; specifically, all boreholes for a given LHS element are assumed to have the same permeability. As the repository rapidly drops below 8 megapascals, unless a borehole has a very low permeability, it is probably unreasonable to assume that the pressure in the repository after multiple intrusions has the same value as after a single intrusion. Rather, once a higher permeability borehole occurs, the pressure would drop below 8 megapascals and no additional direct brine releases would take place. Inclusion of this depressurization mechanism in the analysis would substantially reduce the direct brine releases (Figure SA-26).

SA.9 Summary of Sensitivity Analyses for Total Releases

As shown in Figure 6-41 of Chapter 6.0 and discussed in Section 6.5.3, the location of the mean CCDF is dominated by releases resulting from two mechanisms: (1) cuttings and cavings, and (2) spallings. Direct brine releases are unimportant in contributing to the location of the mean CCDF, and releases from subsurface groundwater transport make essentially no contribution to

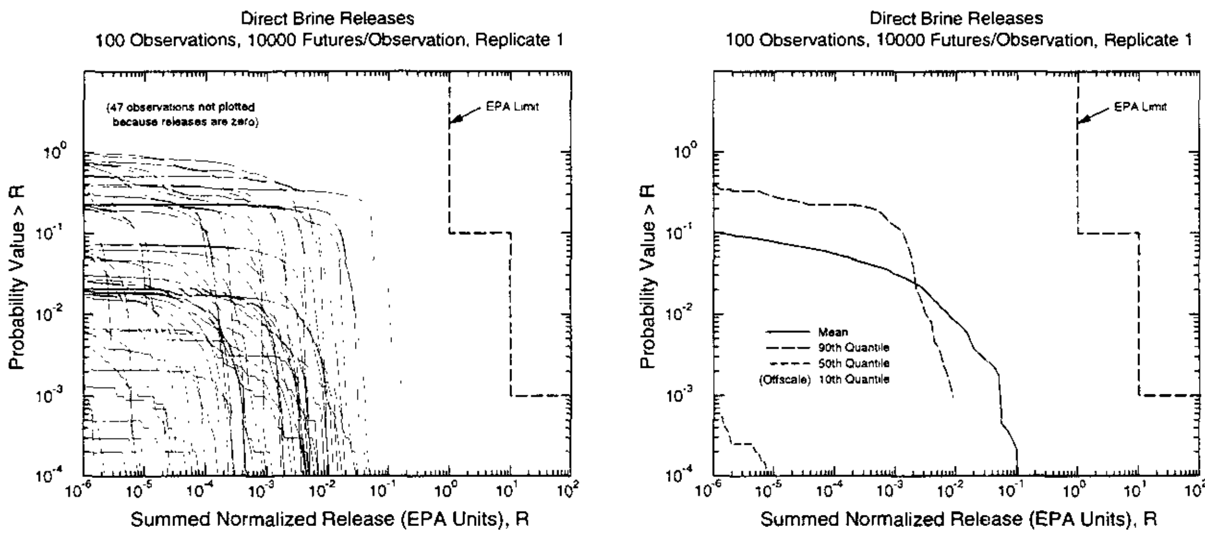

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Figure SA-24. Distribution of CCDFs for Summed Normalized Release to Accessible Environment over 10,000 Years due to Direct Brine Release

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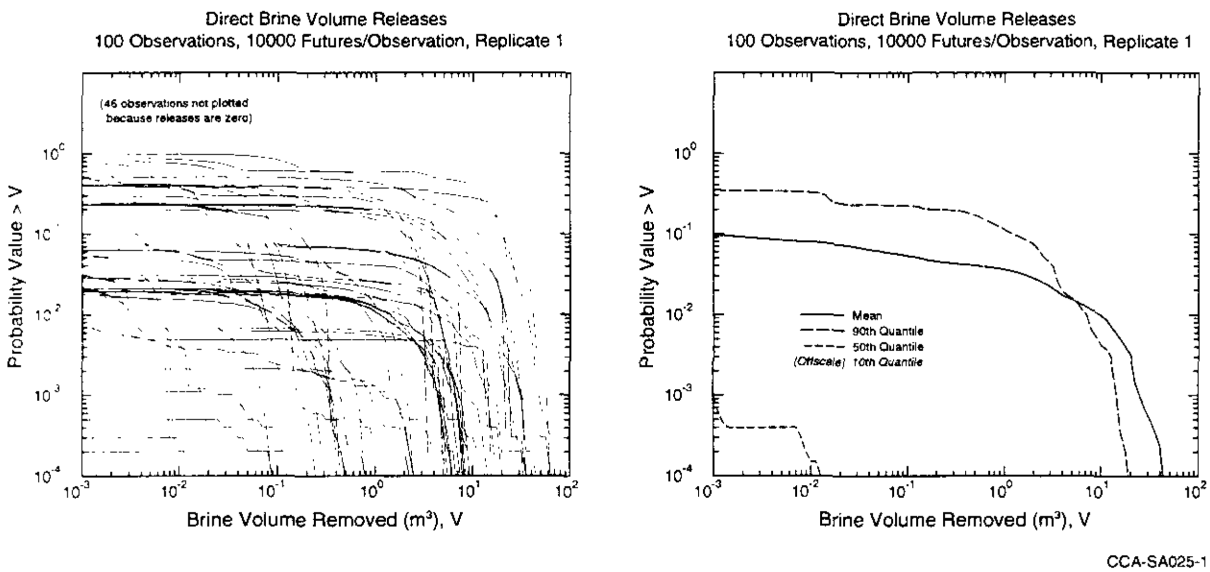

Figure SA-25. Distribution of CCDFs for Volume of Brine (cubic meters) Removed to Accessible Environment over 10,000 Years due to Direct Brine Release

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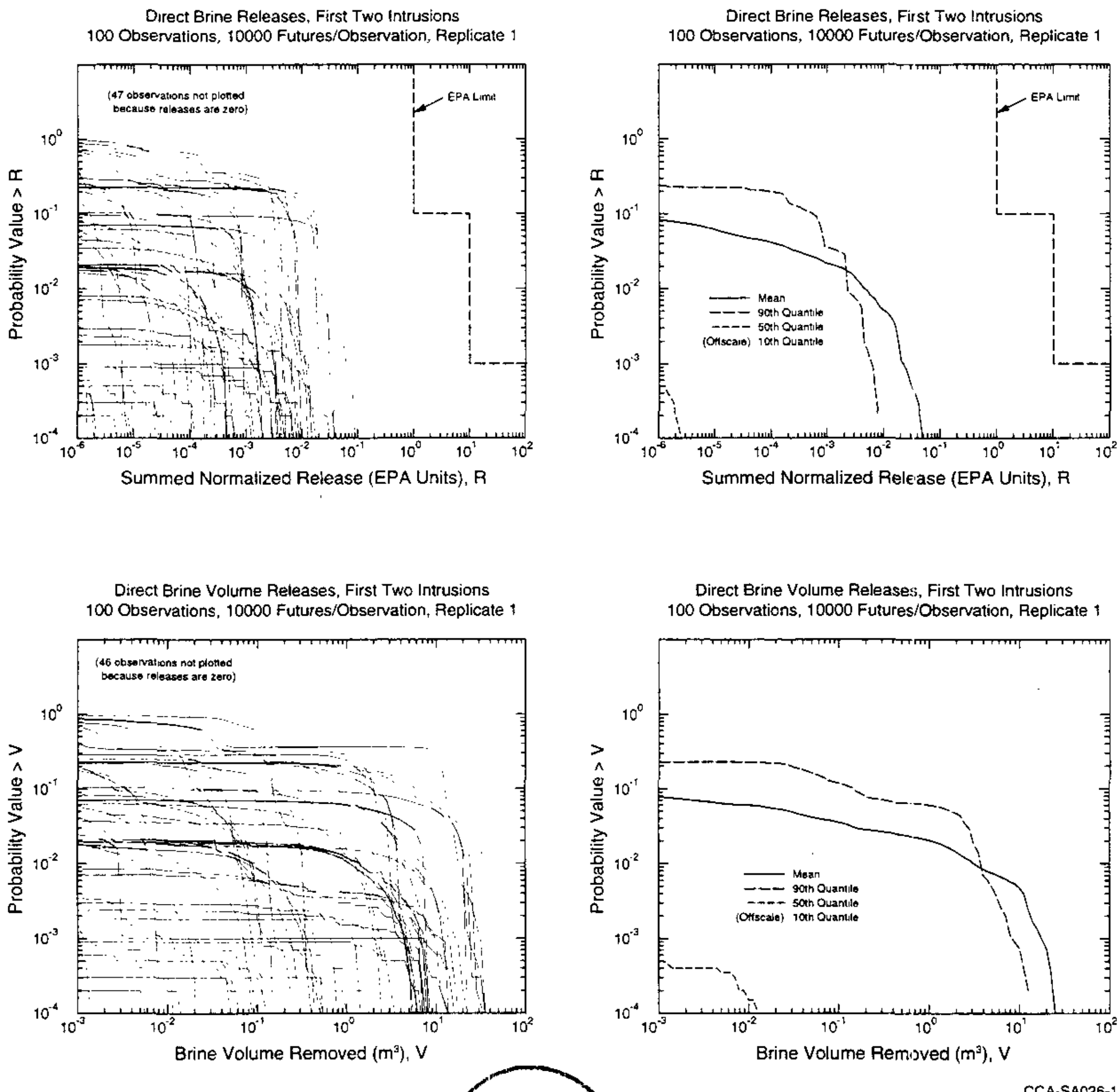

Figure SA-26. Distributions of CCDFs for Summed Normalized Release to Accessible Environment and Volume of Brine (cubic meters) Removed to Accessible Environment over 10,000 Years due to Direct Brine Releases with the Assumption that Direct Brine Releases Will Occur Only for the First Two Drilling Intrusions into the Repository

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Table SA-5. Determination of Direct Brine Release $f_{BL}(\mathbf{x}_{st})$ for an Arbitrary Future $\mathbf{x}_{st}$ of Form in Equation 1

Release rBL_i for intrusion into pressurized repository at time t_i (that is, $i = 1$ or $\tilde{b}_j = 0$[a] for $j = 1, 2, \ldots, i-1$):

$rBL_i = 0$	if intrusion penetrates RH-TRU waste or no waste
$= C_{E0}(t_i)^{b} VB_{E0,U}(t_i)$	if l_i in upper waste panel
$= C_{E0}(t_i)\, VB_{E0,L}(t_i)$	if l_i in upper waste panel.

Release rBL_i for intrusion into a depressurized repository at time t_i with no E1 intrusion in first $i - 1$ intrusions (that is, $\tilde{b}_k = 0$ for $k = 1, 2, \ldots, j-1$, $\tilde{b}_j = 2$, $\tilde{b}_k \neq 1$ for $k = j+1, j+2, \ldots, i-1$):

$rBL_i = 0$	if intrusion penetrates RH-TRU waste or no waste
$= C_{E0}(t_i)\, VB_{E2,S}(t_j, t_i - t_j)^{c}$	if l_j, l_i in same waste panel
$= C_{E0}(t_i)\, VB_{E2,D}(t_j, t_i - t_j)$	if l_j, l_i in different waste panels.

Release rBL_i for intrusion into a depressurized repository at time t_i with first E1 intrusion at time $t_j < t_i$ (that is, $\tilde{b}_k \neq 1$ for $k = 1, 2, \ldots, j-1$, $\tilde{b}_j = 1$):

$rBL_i = 0$	if intrusion penetrates RH-TRU waste or no waste
$= C_{E1}(t_i)\, VB_{E1,S}(t_j, t_i - t_j)$	if l_j, l_i in same waste panel
$= C_{E1}(t_i)\, VB_{E1,D}(t_j, t_i - t_j)$	if l_j, l_i in different waste panels.

Spallings release $f_{BL}(\mathbf{x}_{st})$:

$$f_{BL}(\mathbf{x}_{st}) = \sum_{i=1}^{n} rBL_i$$

[a] See Table SA-3 for definition of $\tilde{b}_j = 0, 1, 2$.

[b] Here and elsewhere, appearance of an undefined time implies interpolation between defined times in Table SA-4.

[c] Here and elsewhere, appearance of two undefined times implies two-dimensional interpolation between defined times in Table SA-4.

the total normalized release. The location of the mean CCDF is therefore sensitive only to uncertainty associated with the models and parameters used to estimate releases resulting from cuttings, cavings, and spallings. The relative sensitivity of the distribution of CCDFs to uncertainty in values for sampled parameters is discussed in this section and summarized in Table SA-6. Results are conditional on the conceptual models used in the analysis, the parameters selected for sampling, and the distributions assigned to those parameter values.

Table SA-6. Relative Importance of Sampled Parameters with Respect to Uncertainty in the Distribution of CCDFs for Total Releases. Results are conditional on the conceptual models used in the analysis, the parameters selected for sampling, and the distributions assigned to those parameter values. The order of individual parameters within categories is not significant.

Important parameters

- Waste erosion shear strength
- Waste particle diameter
- Probability of microbial degradation
- Borehole permeability

Less important parameters

- Parameters not listed above that contribute to uncertainty in repository pressure

Parameters that have little or no effect on the location of the mean CCDF

- Parameters related to radionuclide concentration in brine
- Shaft parameters
- Parameters related to flow and transport in the Culebra

SA.9.1 Sensitivity of Total Releases to Sampled Parameters Affecting Cuttings and Cavings

As discussed in Sections SA.2 and SA.3, the erosion shear strength of the waste, *TAUFAIL*, is the only parameter varied in the LHS that affects cuttings and cavings releases. This parameter accounts for all uncertainty in the distribution of CCDFs for cuttings and cavings, and is therefore an important parameter with respect to determining the distribution of the CCDFs for total releases.

SA.9.2 Sensitivity of Total Releases to Sampled Parameters Affecting Spallings

As discussed in Sections SA.3 and SA.4, releases resulting from spallings are sensitive to the particle diameter size of the waste, *PARTDIA*, and to the pressure in the repository at the time of intrusion. Releases are sensitive to repository pressure because spalling occurs only if pressure in the waste is greater than 8 megapascals, which is the approximate pressure that would exist at the repository depth in a hydrostatic column of drilling fluid within a borehole. Numerous parameters varied in the LHS have the potential to affect repository pressure. The most important of these is the pointer variable *PROBDEG* used to determine whether microbial degradation occurs in the realization and whether it involves cellulosics or cellulosics plus rubbers and plastics. Repository pressures above 8 megapascals are more likely to occur in those realizations in which microbial degradation occurs. Repository pressures above 8 megapascals are also more likely to occur for second and subsequent intrusions if the sampled value for borehole permeability in the earlier intrusions is small, allowing the rate of gas generation to exceed the rate at which gas flows up the borehole.

SA.9.3 Sensitivity of Total Releases to Sampled Parameters Affecting Direct Brine Releases

Total releases are not sensitive to variability in parameters that affect direct brine releases, except to the extent that such parameters also affect spalling releases. Like spalling releases, direct brine releases occur only if the repository pressure at the time of intrusion is greater than 8 megapascals. Parameters that may be important with respect to direct brine releases, because of their effect on pressure, may also be important with respect to total releases because of their analogous impact on spallings.

SA.9.4 Sensitivity of Total Releases to Sampled Parameters Affecting Groundwater Releases

Total releases are not sensitive to uncertainty in parameters that affect groundwater releases, except to the extent that such parameters also affect spalling releases. For example, total releases are insensitive to uncertainty in all sampled parameters that describe flow and transport in the Culebra.

REFERENCES

Fox, R.W., and McDonald, A.T. 1973. *Introduction to Fluid Mechanics*. Wiley, New York, NY.