6.4.13 Construction of a Single CCDF

Construction of a single CCDF requires combining the results of numerical simulations performed ~~for a given~~***using different*** set***s*** of ~~values of~~ subjective parameters ***values*** (~~that is,~~ ~~those determined~~***sets selected*** by LHS) with the probabilistic futures determined by random sampling ~~of~~ stochastic parameters (that is, those associated with intermittent drilling) (see Appendix ***PA, Section PA-3.0*** ~~CCDFGF, Section 2~~). ~~Because of t~~***T***he variety of sequences of events represented in a single CCDF and the impossibility of modeling the details of each future separately ***requires*** building a CCDF ~~necessarily involves~~***using*** methods ~~for the construction of~~ ***to construct*** consequences for any probabilistic future from a limited number of calculations for deterministic, idealized futures. Although this methodology is conceptually straightforward, the details of the process are highly dependent on model and system-specific considerations (see Appendix ***PA*** ~~CCDFGF~~, Section ***PA-6***4). Accordingly, insight gained from previous, preliminary ~~performance assessments~~***PAs*** as well as analysis of early results for this ~~performance assessment~~***PA*** ~~are~~ ~~used to~~ help configure the methodology used for CCDF construction.

Depending on the scenario into which probabilistic futures are classified, different techniques are used for estimating their consequences. The deterministically determined undisturbed performance scenario consequences require no special techniques for application to probabilistic futures. For E1, E2, and E1E2 scenarios, the CCDF construction methodology is primarily based on the principle of scaling, with some simplifying assumptions made for the E2 scenario. Scaling is ~~the estimation of~~ ***estimating the*** consequences of probabilistic futures based on consequence estimates from deterministic futures. The use of scaling and the building of a CCDF with it is discussed in this section. Note that all of the discussions in Section 6.4.13 are for one vector of ~~values for those~~ parameters ***values*** included in the subjective uncertainty analysis. In other words, this section addresses only stochastic variation resulting from uncertainty in the sequence of future events that may occur at the WIPP (see Section 6.1.2).

6.4.13.1 Constructing Consequences of the Undisturbed Performance Scenario

All probabilistic futures in which drilling intrusion and mining within the controlled area do not occur are included in the undisturbed performance scenario. Because there is no stochastic uncertainty for this scenario, all futures within a single LHS vector of undisturbed performance have the same releases to the accessible environment. The following major codes are used to estimate the consequences of undisturbed performance: BRAGFLO, NUTS, and, if actinides reach the Culebra, ~~SECOFL2D~~ ***MODFLOW-2000*** and SECOTP2D. To illustrate the flow of information for the undisturbed performance scenario, these codes and the connections between them are highlighted ~~on the diagram of PA codes~~ in ~~Figure 6-32~~***Figure 6-31***. For undisturbed performance, no special techniques are required to modify the results of the deterministic calculation to fit probabilistic futures. Therefore, for a single consequence ~~for~~ ***of*** undisturbed performance, BRAGFLO is executed once and NUTS is executed once. These calculations determine the release to the accessible environment ~~because of~~ ***from*** transport in the Salado or up the shaft to the surface. If any actinides reach the Culebra following these calculations, ~~SECOFL2D~~ ***MODFLOW-2000*** and SECOTP2D ~~are executed to~~ determine whether actinides released to the Culebra reach the lateral accessible environment. This information is sufficient to construct consequences for all probabilistic futures that have no intrusion events. This

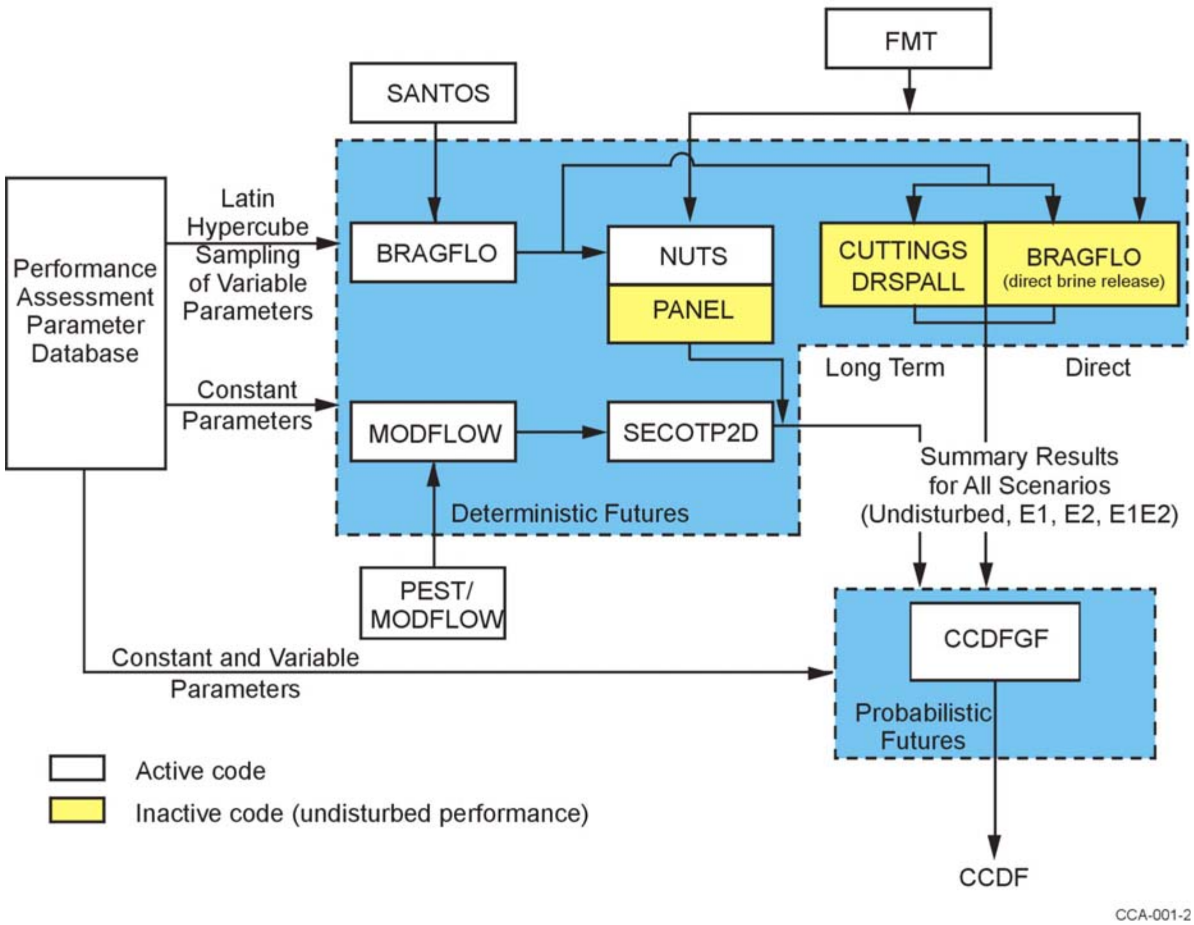


Figure ~~6-32~~*6-31*. Code Configuration for the ~~Undisturbed Performance~~*UP* Scenario

information is also used ~~as the basis for evaluations of~~ ***to evaluate*** compliance with 40 CFR § 191.15 and 40 CFR § 191.24, described in Chapter 8.0.

6.4.13.2 Scaling Methodology for Disturbed Performance Scenarios

Although 10,000 probabilistic futures are generated ~~for the construction of~~ ***to construct*** a CCDF, the major codes used in ~~performance assessment~~***PA*** are executed ~~many~~ ***far*** fewer times. The results of ~~the fewer~~ ***these*** calculations are used in part to construct the consequences of all of the probabilistic futures comprising a CCDF in a process called scaling.

The scaling methodology is simple, in concept. First, several simulations are performed with a code to develop a reference behavior for a particular event or process. Each simulation has a defined event occurring at a different time. Then, a large set of futures is developed probabilistically by random sampling. The behavior of the particular event or process in each of the probabilistically sampled futures is estimated by scaling ~~from~~ the results of the limited number of deterministic calculations. This scaling is generally simple linear interpolation. For events or processes involving radionuclides, however, scaling becomes more complicated***, since*** ~~as~~ it incorporates the effects of radioactive decay and ingrowth. Because scaling is generally less intensive computationally than ~~is~~ solving ***the*** matrix equations ~~of the type~~ encountered in many ~~performance assessment~~***PA*** codes, scaling is an efficient way to develop multiple probabilistic consequence estimates from a limited number of deterministic calculations. Without scaling, fewer futures would be possible, and resolution in the CCDF would be reduced.

For ~~an~~ example ~~of the application of scaling~~, assume that the process of interest is ~~of~~ actinides release***d*** to the surface during drilling. It is impossible to explicitly model the infinite possibilities present in a probabilistic conceptualization of the future. Thus, scaling is used. To develop a reference behavior for scaling, the CUTTINGS_S code is executed several times with different intrusion times. A probabilistic method is then used to develop a large number of possible, different future intrusion times. To estimate the release to the surface in probabilistic futures, scaling is used in which release at the times in the deterministic calculations closest to the probabilistic time of interest are used as reference points for scaling or interpolation.

Scaling is used for all futures with intrusion boreholes. The times when various codes are executed to develop reference behavior, and how this reference behavior is used by other codes, is the subject of the next two sections. In presenting complete descriptions of the process for each scenario, there will be some duplication of discussion.

6.4.13.3 Estimating Long-Term Releases from the E1 Scenario

The E1 scenario is defined as a single penetration of a panel by a borehole that also intersects a brine reservoir. The code configuration with which the long-term consequences of E1 scenarios are estimated is illustrated in Figure ~~6-33~~***Figure 6-32***. For the E1 scenario, BRAGFLO is executed twice more for each CCDF (assuming the undisturbed performance run has already been executed), with the E1-type intrusion occurring at 350 years and 1,000 years. These three BRAGFLO calculations form the foundation for transport modeling that is used for scaling consequences to probabilistic futures.

Consistent with the BRAGFLO intrusion times, NUTS is executed with intrusions occurring at 350 and 1,000 years. These calculations form the basis for (1) estimating releases to the accessible environment via Salado interbeds, or to the surface; and (2) forming the actinide source term to the SECOTP2D code for Culebra transport. For computational efficiency, an intermediate scaling step is conducted prior to calculating the releases associated with probabilistic futures. In this intermediate step, NUTS reference conditions for Culebra releases by an intrusion at 100 years are calculated by using borehole flow from the 350-year intrusion. ~~and~~ NUTS reference conditions for intrusions at 3,000, 5,000, 7,000, and 9,000 years are calculated by using borehole flow from the 1,000-year calculation. Thus, ~~for the scaling of~~ ***to scale*** consequences of E1 intrusions in probabilistic futures, reference conditions calculated by NUTS are available for 100, 350, 1,000, 3,000, 5,000, 7,000, and 9,000 years postclosure.

Consistent with the BRAGFLO intrusion times, reference behavior for actinide transport in the Culebra is calculated by SECOTP2D for the E1 intrusion occurring at 350 and 1,000 years. Because the equations governing actinide transport and retardation in SECOTP2D are linear, scaling releases to probabilistic E1 penetrations occurring at other times is easily accomplished.

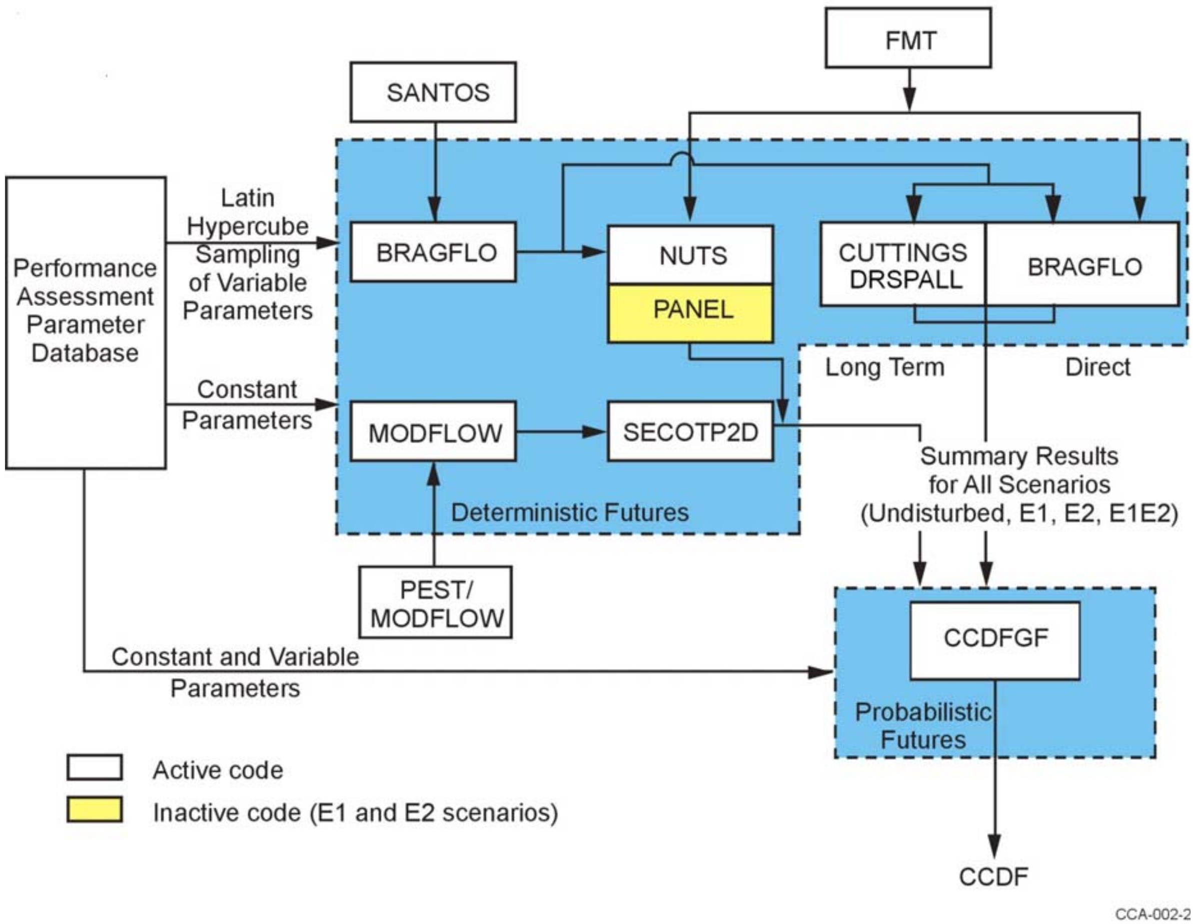


Figure ~~6-33~~*6-32*. Code Configuration for ~~Disturbed Performance~~*DP* Scenarios E1 and E2

6.4.13.4 Estimating Long-Term Releases from the E2 Scenario

The E2 scenario includes all futures with one or more exploratory borehole penetrations of a panel, none of which hits a brine reservoir. ~~Estimation of~~ ***Estimating*** long-term releases from the E2 scenario is slightly more complex than the ~~consequences of the~~ E1 scenario because the E2 scenario includes the possibility of multiple E2-type intrusions. The same codes used ~~in the construction of~~ ***to construct*** the E1 scenario consequences are used ~~for construction of~~ ***to construct*** the E2 scenario consequences. These are indicated in ~~Figure 6-34~~***Figure 6-33***.

As ~~is done for~~ ***with*** the E1 scenario, BRAGFLO is executed twice more for each CCDF (assuming the undisturbed performance run has already been executed), with the E2-type intrusion occurring at 350 years and 1,000 years. These three BRAGFLO calculations form the foundation for transport modeling ~~that is~~ used ~~for scaling~~ ***to scale*** consequences to probabilistic futures.

NUTS is executed with intrusions occurring at 350 and 1,000 years, consistent with the BRAGFLO times of intrusion. These calculations form the basis for (1) estimating releases to the accessible environment via Salado interbeds, or to the surface; and (2) forming the actinide

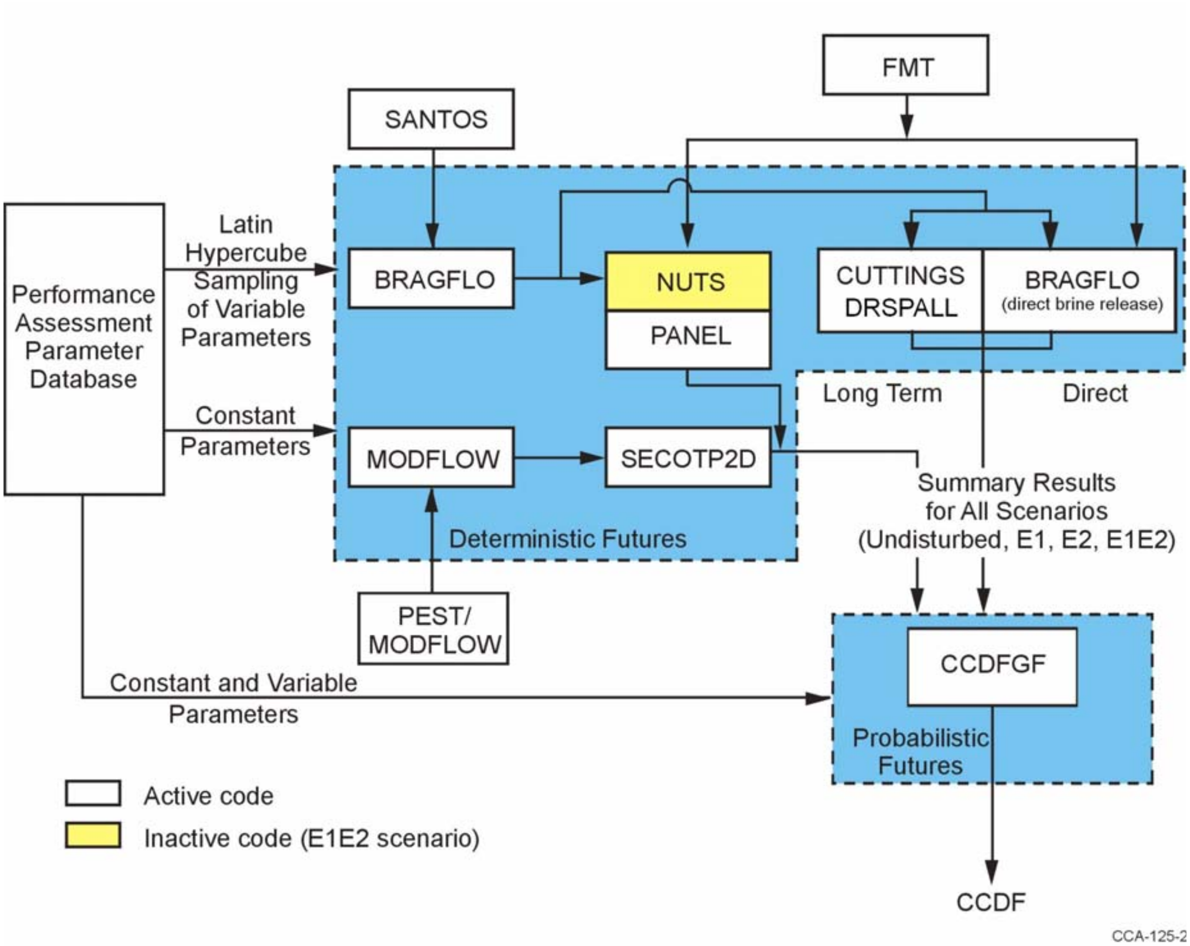


Figure ~~6-34~~*6-33*. Code Configuration for ~~Disturbed Performance~~*DP* Scenario E1E2

source term to the SECOTP2D code for Culebra transport. For computational efficiency, an intermediate scaling step is conducted prior to calculating the releases associated with probabilistic futures. In this intermediate step, NUTS reference conditions for Culebra release by an intrusion at 100 years ~~is~~ ***are*** estimated by scaling borehole flow from the 350-year intrusion**.**~~, and~~ NUTS reference conditions for intrusions at 3,000, 5,000, 7,000, and 9,000 years are estimated by scaling from the 1,000-year calculation. Thus, ~~for the scaling of~~ ***to scale*** consequences of E2 intrusions in probabilistic futures, reference conditions from ~~by~~ NUTS calculations are available for 100, 350, 1,000, 3,000, 5,000, 7,000, and 9,000 years.

Consistent with the BRAGFLO intrusion times, reference behavior for actinide transport in the Culebra is calculated by SECOTP2D for the E2 intrusion occurring at 350 and 1,000 years. Because the equations governing actinide transport and retardation in SECOTP2D are linear, scaling releases to probabilistic E2 penetrations occurring at other times is easily accomplished. For futures with two or more E2-type intrusions (and no E1-type intrusions), a simplifying assumption is made. The additional increment to the~~ source term to~~ Culebra***'s source term*** for the second and subsequent intrusions is assumed to be zero. This is considered reasonable because in the E2 scenario, the flux of brine to the Culebra is limited by the rate of flow from the

Salado to the waste panels, rather than by borehole properties. For second and subsequent E2 scenarios, only the direct releases to the surface are ~~therefore~~ considered in CCDF construction.

6.4.13.5 Estimating Long-Term Releases from the E1E2 Scenario

The E1E2 scenario is defined as multiple boreholes intersecting a single waste panel, at least one of which is an E1 penetration of a brine reservoir (Section 6.3.2.2.3). The DOE uses both scaling and simplification to develop the consequences of this scenario. Similar to the E1 and E2 scenarios, BRAGFLO and related computer codes are executed with a deterministic sequence of future events to develop reference behavior for the E1E2 consequences (see ~~Figure 6-34~~***Figure 6-33***). Scaling ~~is used to~~ estimate***s*** the consequences for events occurring at different times than those ~~used~~ in the BRAGFLO calculations. Simplifying assumptions are used to develop the consequences of E1E2 occurrences in different waste panels, or the consequences of a different sequence of future events leading to the E1E2 scenario, than assumed in the deterministic BRAGFLO calculation.

Reference behavior for brine flow to the Culebra in the E1E2 scenario is predicted by the BRAGFLO disposal system model. This is the same model used to predict brine flow to the Culebra for the E1 and E2 scenarios. The geometry of the grid used is the same as that depicted in Figures 6-14 through 6-16; however, different assumptions are used about the borehole development through time. Even though the E1E2 scenario includes at least two boreholes intersecting the panel, the model used included only one borehole column. As ~~will be~~ described ***below***, the assumptions used about the ~~manner in which~~ ***way*** brine mixes in the intruded panel are such that two boreholes are not needed to represent flow through the waste. The assumptions about the development of the borehole are related to the most likely (that is, most probable) sequence of events that gives rise to the E1E2 scenario.

~~Ninety-two percent of all deep boreholes are the E2 type(see Section 6.4.12.6). Therefore, it~~ ***It*** is most probable that the first borehole into any panel is an E2 borehole ***(see Section 6.4.12.6)***. In a BRAGFLO calculation after 1,000 years of undisturbed performance, the properties of the column of elements in BRAGFLO representing the borehole are changed. The changed properties represent the E2 borehole after the Rustler plug has degraded and silty sand fills the borehole. The period during which the plug is effective is not modeled to develop reference behavior for the E1E2 Culebra releases because relatively little happens in the disposal system ~~during the time that~~ ***when*** the Rustler plug is effective. Reference conditions are developed with the E1 intrusion that follows the initial E2 intrusion occurring after the 200 years ~~that~~ it takes Rustler plugs to degrade because it is more probable that a subsequent E1 intrusion occurs after the Rustler plug has degraded. It is assumed that the E1 intrusion occurs 1,000 years after the E2 borehole becomes filled with silty sand, at a simulation time of 2,000 years. At 2,000 years, the properties of the ~~section of the~~ borehole ***section*** below the repository horizon are changed to represent an open borehole (the E1 intrusion), allowing flow between the Castile brine reservoir and the repository. After another 200 years, the lower section is assumed to ~~become~~ fill~~ed~~ with silty sand; after another 1,000 years, the permeability of the lower section is decreased one order of magnitude because of salt creep. These changes are documented in ***Table 6-31*** ~~Table 6-29~~.

Table *6-31*~~6-29~~. Changes in BRAGFLO Borehole Properties in Developing Reference Behavior for the E1E2 Scenario

Time (years)	Borehole Portion	Properties
0 – 1,000	All	Undisturbed conditions
1,000 – 2,000	Above waste panel Below waste panel	Silty sand Undisturbed conditions
2,000 – 2,200	Above waste panel Below waste panel	Silty sand Open borehole between panel and Castile
2,200 – 3,200	Above waste panel Below waste panel	Silty sand Silty sand
3,200 – 10,000	Above waste panel Below waste panel	Silty sand Silty sand, permeability decreased 1 order of magnitude

Thus, above the waste panel, the E1E2 borehole evolves as an E2 borehole from 1,000 years to 10,000 years. Below the waste panel, the borehole evolves as an E1 borehole from 2,000 to 10,000 years. At 2,200 years, there will be two boreholes above the waste panels with silty-sand properties. The assumption about upper borehole permeability most consistent with ~~the assumption made for~~ ***that for*** this scenario of complete mixing in the panel (discussed below) is that the upper portion of the E1 borehole is relatively impermeable and all flow ~~that might occur through it~~ is diverted to the E2 borehole. Therefore, the permeability of the upper borehole remains that of the E2 borehole at 2,200 years.

The concentration of actinides in liquid moving up the borehole assumes homogeneous mixing within the panel and is calculated with the code PANEL. PANEL is a mixing-cell model that sums BRAGFLO fluxes into the waste panel from the boreholes and Salado as inputs to the cell and subtracts the flow up the borehole as a depletion from the model. Brine moving up the borehole is assumed to be at its greatest possible actinide concentration according to the dissolved and colloidal actinide source term models (Sections 6.4.3.5 and 6.4.3.6). In PANEL calculations, all actinides that enter the borehole are conservatively assumed to reach the Culebra.

Random sampling of future events can produce different timing of borehole penetrations. From the time the E2 borehole penetrates until the E1 borehole penetrates, the consequences are determined as they are in the E2 scenario. When the E1 is drilled, completing the E1E2 configuration, the consequences are assumed to be similar to ~~the consequences~~ ***those*** modeled after the E1 penetration for the reference calculation, accounting for radionuclide decay and ingrowth.

Random***ly*** sampling ~~of~~ future events can also produce a different sequence of borehole types. In a randomly sampled future with many E2 intrusions into a waste panel prior to the E1, the consequences are determined as they are for the E2 scenario until the E1 occurs, at which time the E1E2 consequences are used. In a randomly sampled future with the sequence E1 then E2, the consequences are assumed to be similar to an E1 event until the E2 is drilled, whereupon the consequences are assumed to be similar to the E1E2 event following the E1 drilling. In a randomly sampled future with two E1 boreholes, the consequences are assumed to be similar to an E1 borehole until the second E1 is drilled, at which time the consequences are assumed to be similar to the E1E2 behavior.

For computational simplicity, the E1E2 calculations are scaled to E1 intrusions following a prior E2 intrusion occurring at 100, 350, 3,000, 5,000, 7,000, and 9,000 years, similar to the treatment of the E1 and E2 reference conditions.

6.4.13.6 Multiple Scenario Occurrences

For long-term brine flow into the Culebra, scenario occurrences are effectively defined at the panel scale for this ~~performance assessment~~***PA***. It was recognized in preliminary analysis of BRAGFLO results for this analysis that liquid flow between the separate panel and the ~~two~~ rest of the repository ***sections*** is slow enough that the panel is effectively independent from the rest of the repository. Gas flow does occur, and for this reason, calculations of direct release to the surface are performed at the repository scale. For long-term brine flow to the Culebra, it is considered more reasonable, based on BRAGFLO results, to assume independent panel behavior in developing the CCDF ~~rather~~ than an interconnected repository.

It is very important to distinguish between model results and model assumptions on this point. For disposal system performance, the DOE is not assuming that panel closures isolate panels from one another. Rather, the DOE has assigned reasonable properties to the panel closures as input to the BRAGFLO calculations and has found that ~~the assignment of these reasonable properties~~ ***they*** result~~s~~ in limited liquid flow through ~~them~~ ***the panel closures***. Because simplification and scaling must be used to develop CCDFs, the DOE has to assume either that the repository is well interconnected or that the panels behave fairly independently. Based on model results for this analysis, the DOE has established that it is more reasonable in constructing a CCDF to assume that brine does not flow between panels. This ~~is a~~ simplification of ~~results of the~~ detailed modeling ***results*** conducted in BRAGFLO ***is*** necessary for CCDF construction. It is not an assumption used in developing conceptual models of disposal system performance. This assumption does affect how scenario consequences are developed.

There are ten panels in the repository and the possibility of many intrusions. If panels behave independently, as they are assumed to in developing consequences of long-term brine flow in the CCDF, it is possible for different configurations of boreholes (scenarios) to occur in different panels. For example, an E1E2 type situation might occur in one panel, an E2 situation in a different panel, and an E1 situation in a third panel. In this example, there are essentially three scenario types occurring. For long-term release, the repository behaves as ten small modules (each comprising one panel), and a different borehole scenario can develop in each of those ten modules. Long-term releases in CCDF construction are based on the premise that releases from each of these modules are independent and that the cumulative release from the repository is equal to the sum of the cumulative releases from the different modules.

6.4.13.7 Estimating Releases During Drilling for All Scenarios

The reference behavior for cuttings and cavings from the first intrusion into a pressurized repository, regardless of whether it is an E1 or E2 intrusion, is established by calculations performed in the CUTTINGS_S code. Cavings releases are also dependent on the effective shear resistance to erosion ***and the angular velocity of the drill string*** (Appendix PA***, Section PA-4.5*** ~~R, Parameter 33~~). The effects of radioactive decay are captured by calculating reference behavior for cuttings and cavings by the CUTTINGS_S code at 100, 125, 175, 350, 1,000, 3,000, 5,000, 7,500, and 10,000 years.

Spall and direct brine releases during drilling are also dependent on pressure conditions in the repository, and reference releases are calculated by CUTTINGS_S for spall and ~~by~~ BRAGFLO~~_DBR~~ ***(direct brine release)*** at 100, 350, 1,000, 3000, 5,000, and 10,000 years for intrusions into ~~up-dip and down-dip (that is, northern and southern)~~ ***lower, middle, and upper*** panels ***(Appendix PA, Section PA-4.7)***. ~~Spall releases are also dependent on thewaste particle diameter(Appendix PAR, Parameter 32).~~

Radionuclide releases from the processes in the CUTTINGS_S code and direct brine release for intrusions occurring at intermediate times are scaled from the closest calculated releases, correcting for radioactive decay (see Section 6.4.12.3 and ~~Figure 6-28~~***Figure 6-27***). The cuttings and cavings portion of the CUTTINGS_S releases are further adjusted to account for the distribution of CH- and RH-TRU waste streams (see Sections 6.4.12.3 and 6.4.12.4). The processes of spallings and direct brine release are assumed to involve a large enough volume of waste that it is reasonable to use homogeneous waste with average activity to estimate releases.

For multiple-intrusion scenarios, the pressure in the repository at the time of the second and subsequent intrusions may be quite different from ~~the pressure~~ ***that*** at the time of the first intrusion. This is expected because of the assumptions of relatively-permeable boreholes adopted in ~~performance assessment~~***PA***. Therefore, estimates of drilling releases to the accessible environment need to be formed for penetrations of a previously intruded repository. The reference behavior for these ~~for~~ subsequent intrusion~~s~~ releases is calculated by the CUTTINGS_S code from BRAGFLO histories with E1- and E2-type intrusions at 350 and 1,000 years. Repository conditions ~~from the calculations of~~ ***calculated for*** the effects of a subsequent E1-type penetration are used in consequence analysis for both E1- and E2-type intrusions that follow an E1 intrusion. Conditions from the subsequent E2 calculations are used for intrusions that follow E2 intrusions only. E1 conditions are used for multiple combinations of boreholes that include at least one E1 intrusion, ~~based on the assumption~~ ***assuming*** that repository conditions will be dominated by Castile brine if any borehole connects to a brine reservoir. For futures in which more than two E2-type intrusions occur (and no E1-type intrusions occur), third and subsequent spall and direct brine releases are assumed to be the same as for the second release.

For both E1 and E2 conditions following a 350-year intrusion, spall and direct brine release calculations are performed at 550, 750, 2,000, 4,000, and 10,000 years. For the 1,000-year E1 and E2 intrusions, spall and direct brine release calculations are performed at 1,200, 1,400, 3,000, 5,000, and 10,000 years. Because the subsequent intrusion may penetrate either a previously-intruded panel or an unintruded panel, these calculations are done twice, once with initial conditions drawn from the previously-intruded panel in BRAGFLO, and once with conditions drawn from the BRAGFLO subsequent intrusion of the waste-disposal region. As ~~is done for~~ ***with*** the first intrusion into a previously undisturbed repository, radionuclide releases from spall and direct brine release for intrusions occurring at intermediate times are scaled from the closest calculated releases, correcting for radioactive decay.

After flow through the repository has occurred for some time, ~~such~~ as ~~may occur~~ in an E1E2 scenario, portions of the repository may be depleted of actinides. In the estimate of releases during drilling, however, the possibility is not ~~accounted for~~ ***considered*** that random drilling might penetrate portions of the repository ~~that have been~~ ***already*** depleted of actinides ~~as a consequence of~~ ***from*** processes initiated by previous drilling. This is conservative because it tends to overestimate releases during drilling.

6.4.13.8 Estimating Releases in the Culebra and the Impact of the Mining Scenario

Ten thousand-year ~~SECOFL2D and~~ SECOTP2D calculations are performed with Culebra transmissivity fields reflecting undisturbed performance (no future mining within the Land Withdrawal Area) and disturbed performance (see Section 6.4.6.2.3). These calculations are performed with a unit source term of one kilogram of the actinide species of interest at 100 years. Because transport as modeled is a linear process, scaling is used to estimate the consequences of time-variable concentrations and different times of intrusion (see Appendix ***PA, Section PA-6.8.7*** ~~CCDFGF, Section 4.9~~). As well, mining may occur at random times in the future. The effect of mining on releases in the Culebra is determined in the following manner.

Boreholes intersecting the repository may provide a source of actinides to the Culebra with concentrations that vary through time. Until mining occurs, the transport behavior of actinides from these borehole sources is estimated by scaling the results of the undisturbed performance Culebra transport calculations. All actinides introduced into the Culebra by the time of mining are transported exclusively in the undisturbed performance flow fields. In other words, actinides in transit in the Culebra when mining occurs are not assumed to be affected ~~by it~~ and continue to be transported in the undisturbed flow field. Once mining occurs (~~it is~~ assumed to ~~occur~~ ***be*** instantaneous~~ly~~), the transport behavior of all actinides subsequently introduced into the Culebra is estimated by scaling the results of the disturbed performance flow fields.

6.4.13.9 Final Construction of a Single CCDF

After consequences for all of the sampled probabilistic futures ~~have been~~ ***are*** estimated by the methodologies presented in the preceding sections, the information necessary to plot the CCDF associated with the probabilistic futures and the particular LHS vector is available.

The sequences of future events used in this ~~performance assessment~~***PA*** were generated by random sampling. Thus, each sampled future is assigned an equal weight of occurrence ~~for the construction of~~ ***to construct*** a CCDF. Each sequence of future events is assigned a weight of 1/10,000 of occurrence because 10,000 futures are used for each CCDF. Before plotting, an additional step is performed in which the weights of futures with similar consequences are summed. The first step in the plotting process is to order the grouped futures according to normalized release, as discussed in Section 6.1.1, from lowest normalized release to highest. Following this ~~ordering~~, the CCDF can be plotted by summing, for a given value of EPA normalized release, the probabilities of all futures whose normalized release exceeds the given value, ***and*** where the probabilities are assumed to be equal to the weights. Because the releases **cS** have been ordered so that $cS_i \le cS_{i+1}$ for i=1 …, nS-1, the probability that **cS** exceeds a specific consequence value x is determined by the summation routine (duplicated from Section 6.1.1)

$$F(x) = \sum_{j=i}^{nS} pS_j, \qquad (~~14~~ \textbf{\textit{6.18}})$$

where i is the smallest integer, ~~such so~~ that $cS_i > x$. This completes an analysis of stochastic uncertainty for a particular vector of variable values from the LHS sampling.

6.4.14 CCDF Family

The process of CCDF construction described in Section 6.4.13 is repeated once for each vector of ~~values of~~ subjectively uncertain variable~~s~~ ***values*** created by LHS. This process yields a family of CCDFs ~~such as~~ ***like*** those presented in Section 6.5. This family of CCDFs provides a complete display of both stochastic and subjective uncertainty~~,~~ as discussed in Section 6.1.2.

6.5 Performance Assessment Results

This section contains results of the ***recertification*** ~~performance assessment~~***PA*** and demonstrates that the WIPP continues to comply with the quantitative containment requirements in 40 CFR § 191.13(a). See Section 6.1 for a discussion of the containment requirements. Criteria for presenting the results of ~~performance assessments~~***PAs*** are provided by the EPA in 40 CFR § 194.34, and are discussed in Section 6.1.3. These criteria are also summarized here for clarity.

This CRA-2004 PA is different than the original certification PA in the CCA because it includes additional information, changes and new data required by 40 CFR § 194.15 recertification application requirements. Section 6.0 details the changes and new information included in this PA. The results of this recertification PA conclude that the repository continues to comply with the disposal standards.

Additional detail about the results of the ***CRA-2004 PA*** is contained in Appendix ~~SA~~ ***PA, Section PA-9.0***, which describes sensitivity analyses conducted as the final step in the Monte Carlo analysis. These sensitivity analyses indicate the relative importance of each of the sampled parameters in terms of their contribution to uncertainty in the estimate of disposal system performance. Analyses also examine the sensitivity of intermediate performance measures to the sampled parameters. Examples of such intermediate performance measures include the quantity of radionuclides released to the accessible environment by any one mechanism (for example, cuttings or direct brine releases), and other model results that describe conditions of interest such as disposal region pressure.

6.5.1 Demonstrating Convergence of the Mean CCDF

As discussed in Sections 6.4.13 and 6.4.14, individual CCDFs for the WIPP are constructed by estimating cumulative radionuclide releases to the accessible environment for 10,000 different possible futures. Each CCDF is calculated for a single LHS vector of input parameters and is conditional on the occurrence of that particular combination of parameter values. Multiple realizations of the ~~performance assessment~~***PA*** calculations yield a family of CCDFs in which each individual CCDF is generated from a different LHS vector. Families of CCDFs calculated for the WIPP ~~performance assessment~~***PA*** are based on 100 LHS vectors drawn from distributions of values for ***64***~~57~~ imprecisely known parameters. As discussed in Section 6.1.2, mean and percentile CCDFs are constructed from families and provide summary measures of disposal system performance.

Criteria provided by the EPA in 40 CFR Part 194.34 address the statistical interpretation of CCDFs:

> The number of CCDFs generated shall be large enough such that, at cumulative releases of 1 and 10, the maximum CCDF generated exceeds the 99th percentile of the population of CCDFs with at least a 0.95 probability. Values of cumulative release shall be calculated according to Note 6 of Table 1, Appendix A of Part 191 of this chapter. (40 CFR § 194.34(d))

> Any compliance application shall provide information which demonstrates that there is at least a 95 percent level of statistical confidence that the mean of the population of CCDFs meets the containment requirements of § 191.13 of this chapter. (40 CFR § 194.34(f))

Information provided by the EPA in the Background Information Document for 40 CFR Part 194 clarifies the intent of these criteria.

In 40 CFR ~~p~~***P***art 194, EPA decided that the statistical portion of the determination of compliance with 40 CFR ~~p~~***P***art 191 will be based on the sample mean. The LHS sample sizes should be demonstrated operationally (approximately 300 when 50 variables are considered) to improve (reduce the size of) the confidence interval for the estimated mean. The underlying principle is to show convergence of the mean. (EPA 1996b, 8-41)

The DOE has chosen to demonstrate convergence of the mean and to address the associated criteria of 40 CFR Part 194 using an operational approach of multiple replication as proposed by Iman (1982). The complete set of ~~performance assessment~~***PA*** calculations was repeated three times with all aspects of the analysis identical except for the random seed used to initiate the LHS procedure. Thus, ~~performance assessment~~***PA*** results are available for three replicates, each based on an independent set of 100 LHS vectors drawn from identical CCDFs for imprecisely known parameters and propagated through an identical modeling system. This technique of multiple replication allows evaluation of the adequacy of the sample size chosen in the Monte Carlo analysis and provides a suitable measure of confidence in the estimate of the mean CCDF used to demonstrate compliance with 40 CFR § 191.13(a).

6.5.2 Complementary Cumulative Distribution Functions for the WIPP

Families of CCDFs for each of the three replicates are shown in Figures ~~6-35, 6-36, and 6-37~~***6-36, 6-37, and 6-38***. Each figure contains 100 CCDFs. These figures address the criterion stated in 40 CFR § 194.34(e):

> Any compliance application shall display the full range of CCDFs generated.

Figures ~~6-35~~***6-34*** through ~~6-37~~***6-36*** show that all 300 CCDFs lie below and to the left of the limits specified in 40 CFR § 191.13(a). They also show qualitatively that the three replicates yield very similar results. Quantitative verification of the similarity of the three replicates is demonstrated in ~~Figure 6-38~~***Figure 6-37***, which shows the mean CCDFs calculated for each of the three replicates, together with an overall mean CCDF that is the arithmetic mean of the three individual mean CCDFs. ~~Figure 6-38~~***Figure 6-37*** demonstrates two key points. First, the

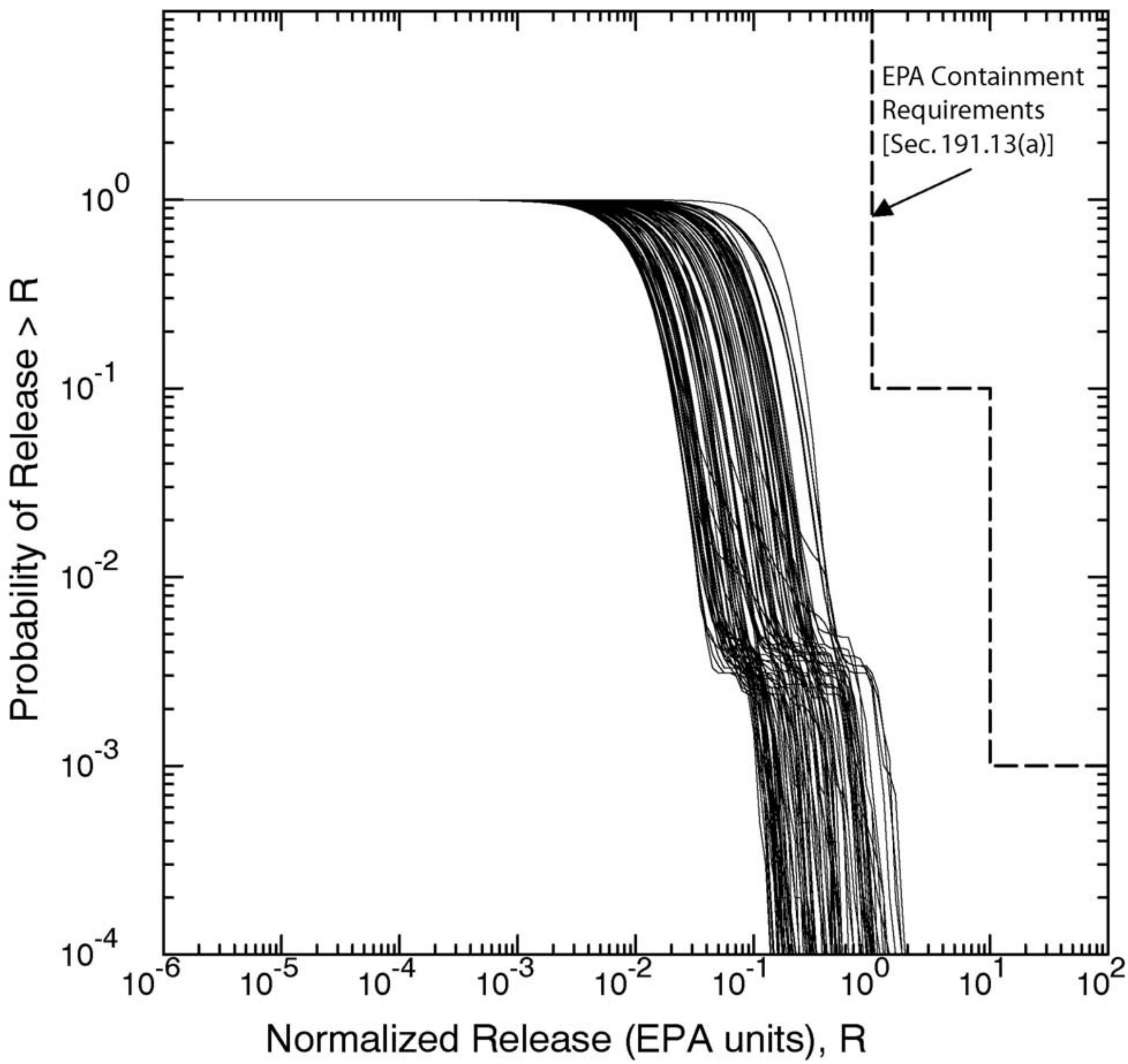


Figure *6-34*~~6-35~~. Distribution of CCDFs for Normalized Radionuclide Releases to the Accessible Environment from the WIPP, Replicate 1.

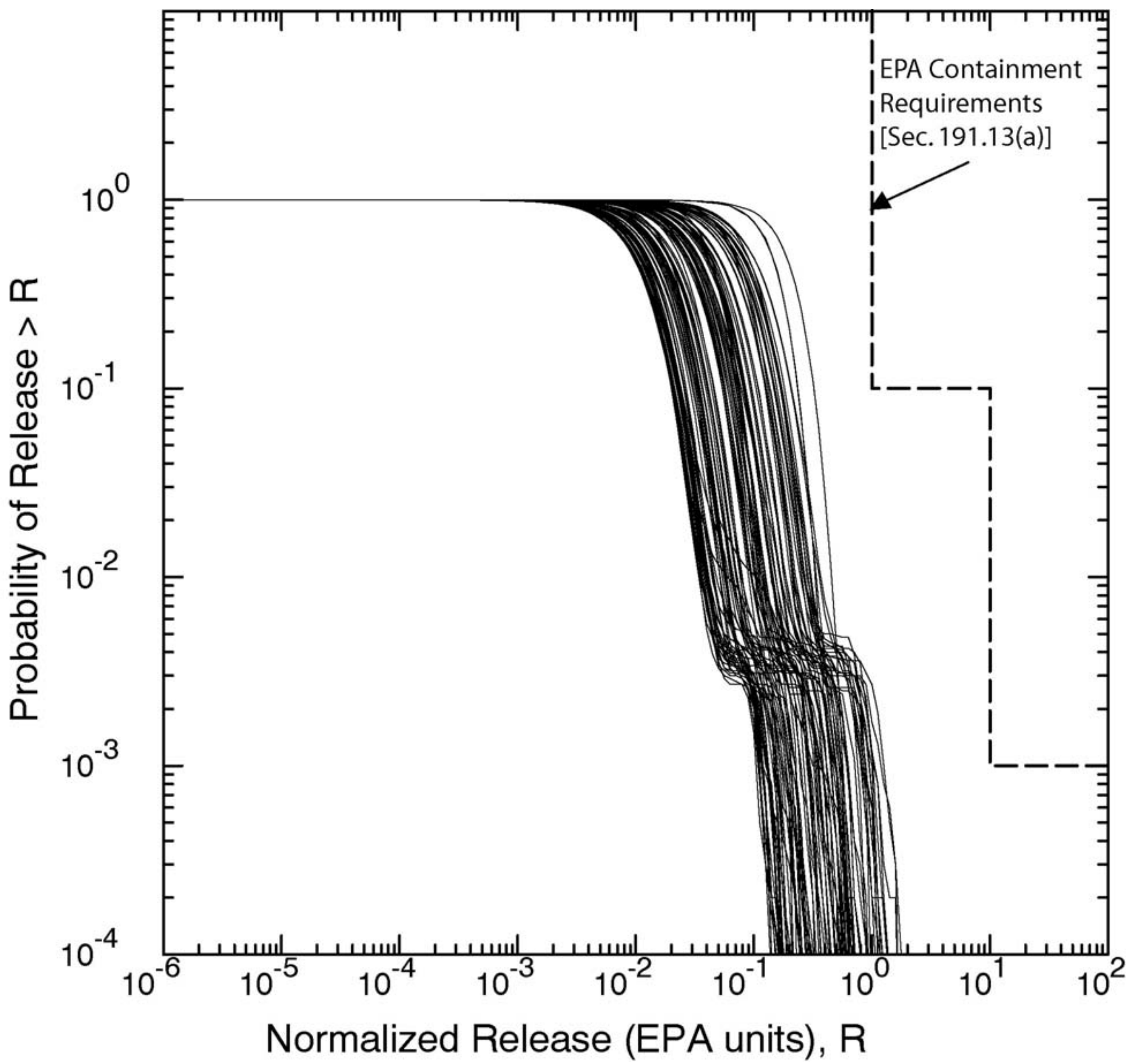


Figure *6-35*~~6-36~~. Distribution of CCDFs for Normalized Radionuclide Releases to the Accessible Environment from the WIPP, Replicate 2.

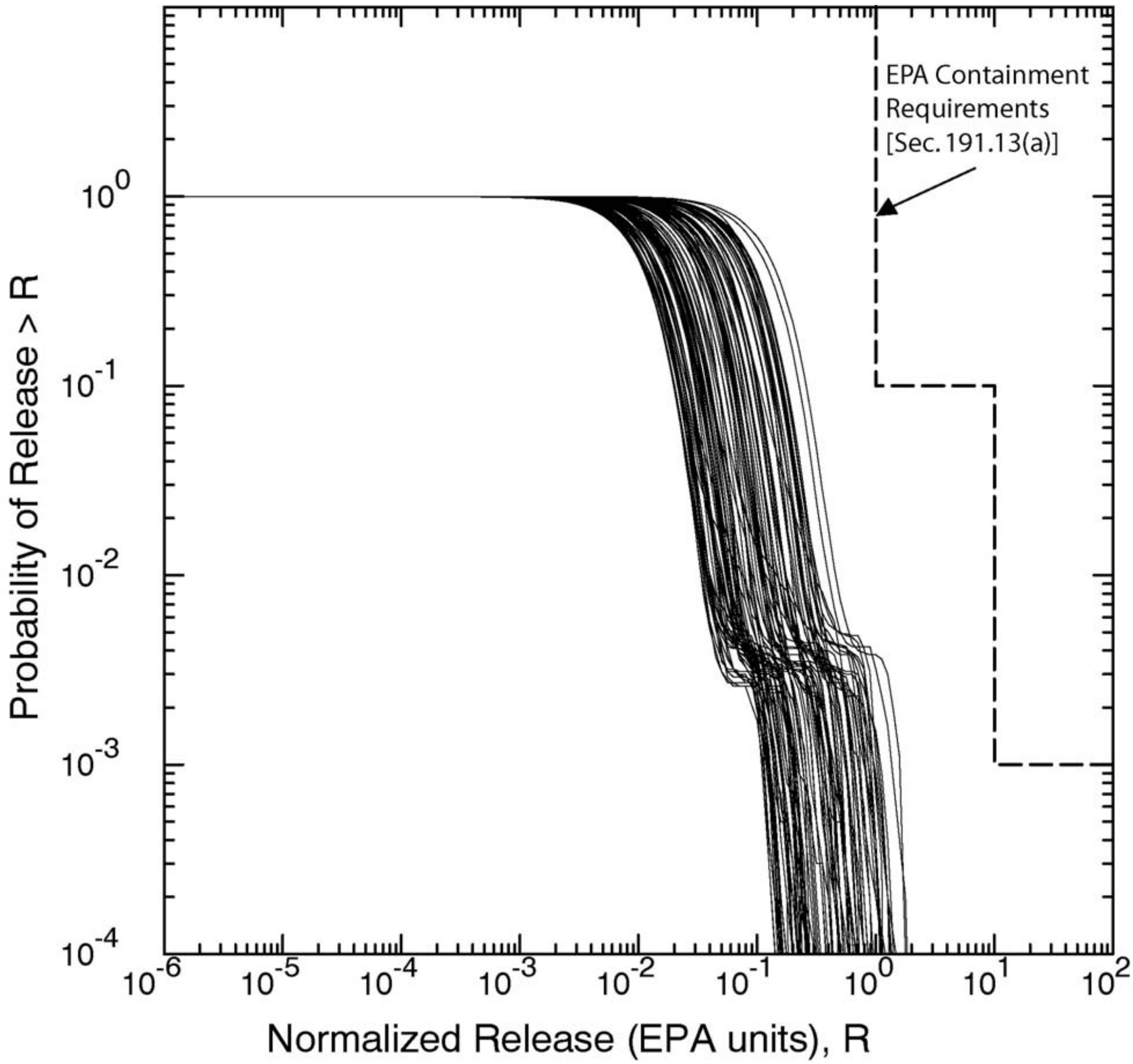
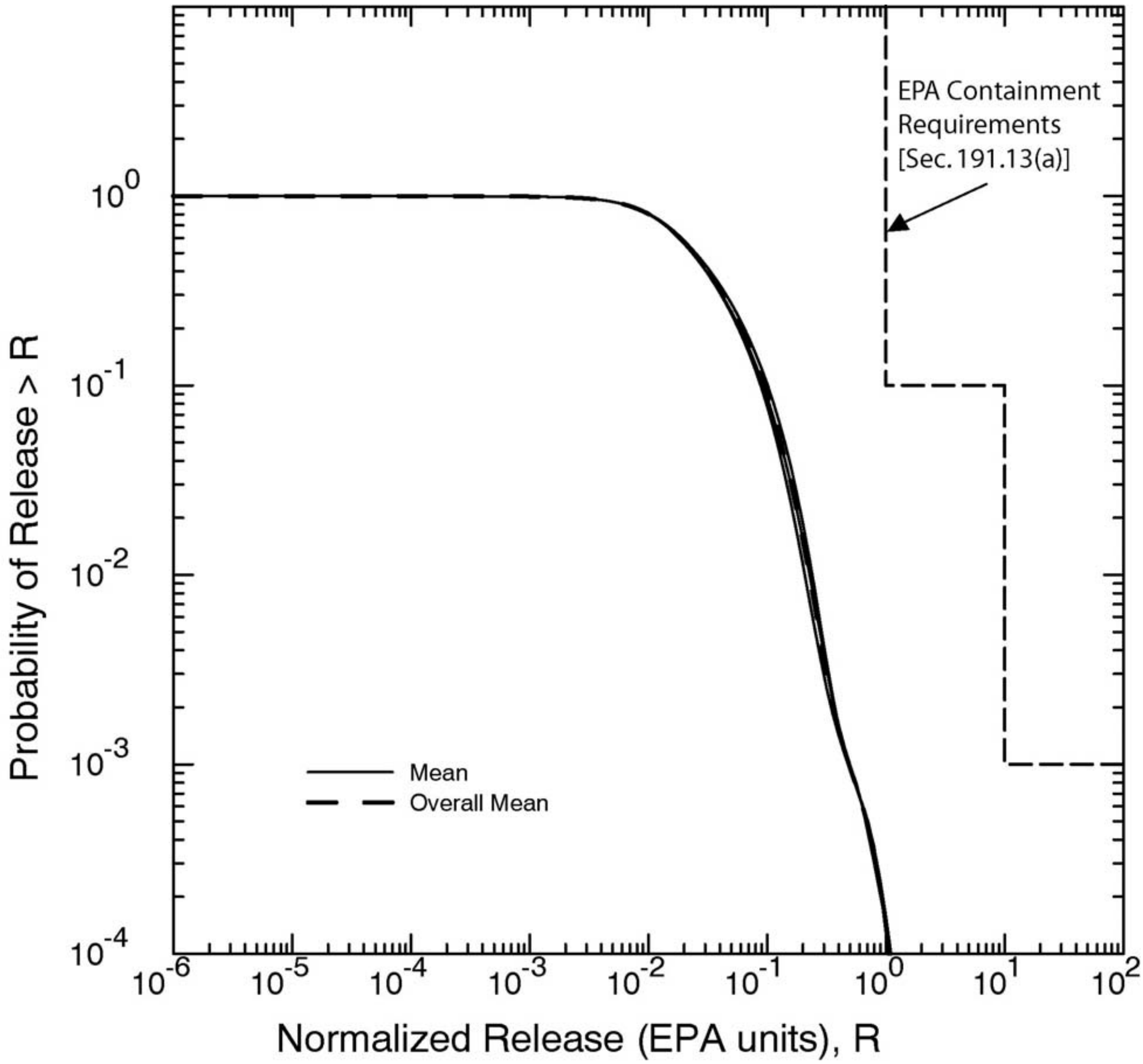


Figure *6-36*~~6-37~~. Distribution of CCDFs for Normalized Radionuclide Releases to the Accessible Environment from the WIPP, Replicate 3

overall mean CCDF lies entirely below ~~and to the left of~~the limits specified in 40 CFR § 191.13(a). Thus, the WIPP is in compliance with the containment requirements of 40 CFR Part 191. Second, the sample size of 100 in each replicate is sufficient to generate a stable distribution of outcomes. Within the region of regulatory interest (that is, at probabilities greater than $10^{-3}/10^{4}$ yr), the mean CCDFs from each replicate are essentially indistinguishable from the overall mean at the resolution of the figure. ~~Figure 6-39~~***Figure 6-38*** provides quantitative confirmation of the sufficiency of the sample size, by displaying the overall mean together with the 0.95 confidence interval of the Student's t-distribution estimated from the individual means of the three independent replicates (Iman 1982), as shown in ~~Figure 3-38~~***Figure 6-37***.

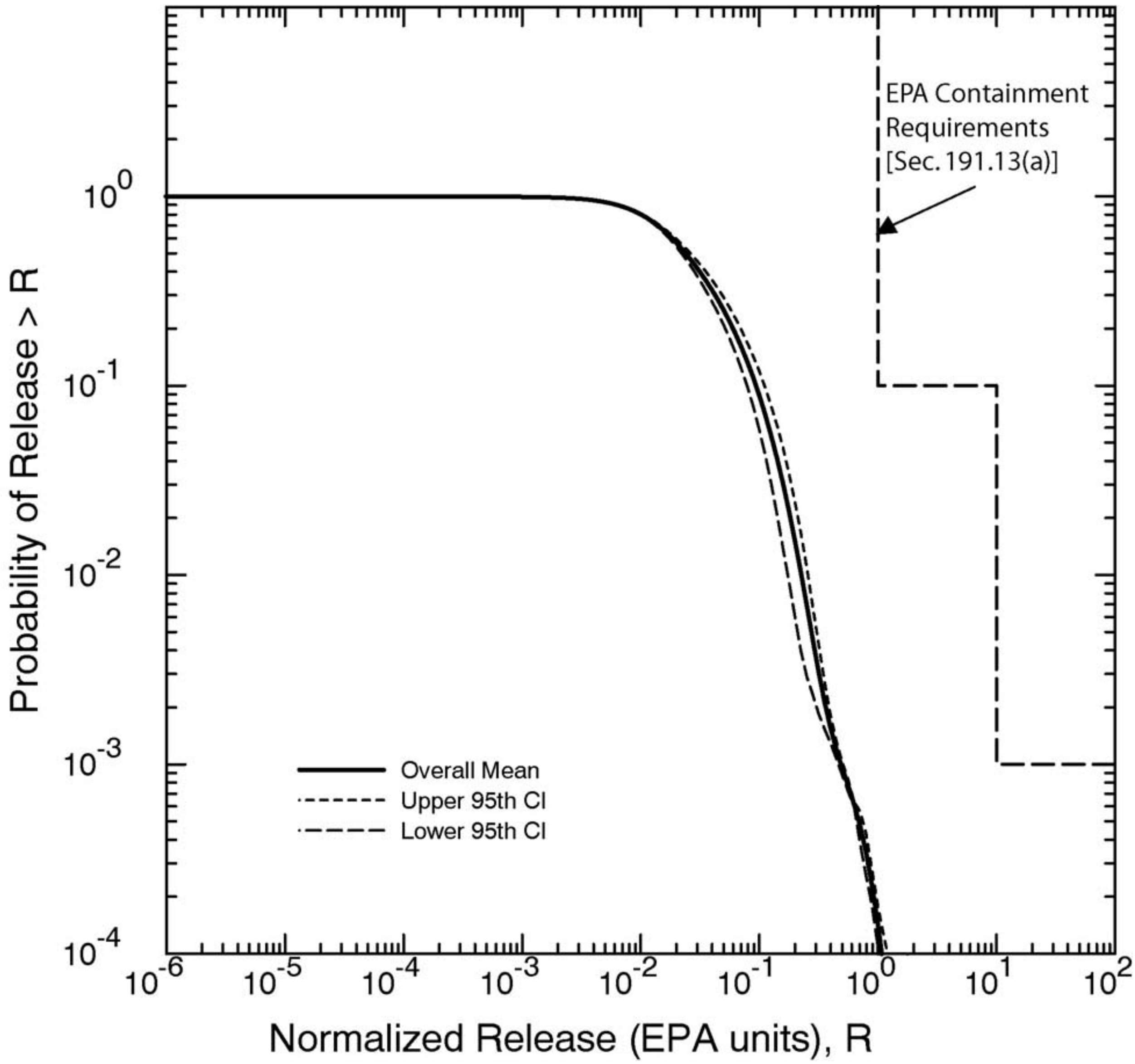
~~Figure 6-40~~***Figure 6-1*** provides additional summary information about the distributions of CCDFs resulting from the three replicates. This figure shows CCDFs representing the mean,



Note: Four CCDFs are shown, including three individual mean CCDFs calculated for each of the three distributions of CCDFs calculated for the three replicates and shown in Figures ~~6-35, 6-36, 6-37~~***6-34, 6-35, 6-36***, and an overall mean CCDF that is the arithmetic mean of the three individual mean CCDFs."

Figure *6-37*~~6-38~~. Mean CCDFs for Normalized Radionuclide Releases to the Accessible Environment

median, and 10th and 90th percentile CCDFs from each replicate, together with the overall mean. Note that for each type of CCDF (for example, the 10th percentile), curves from each replicate overlie closely. This provides quantitative verification of the qualitative observation that distributions from each replicate appear similar. ~~Note also that the mean CCDFs lie to the right of the 90th percentileCCDFs at probabilities less than approximately $10^{-2}/10^{4}$ yr. This is a result of the strongly skewed distribution, with the location of the mean being dominated by the relatively small number of CCDFs associated with the largest normalized releases.~~



Note: The overall mean CCDF shown in Figure ~~6-38~~*6-37* is repeated together with the 0.95 confidence interval of the Student-t distribution estimated from the three individual mean CCFDs.

Figure *6-38*~~6-39~~. Confidence Levels for the Mean CCDF

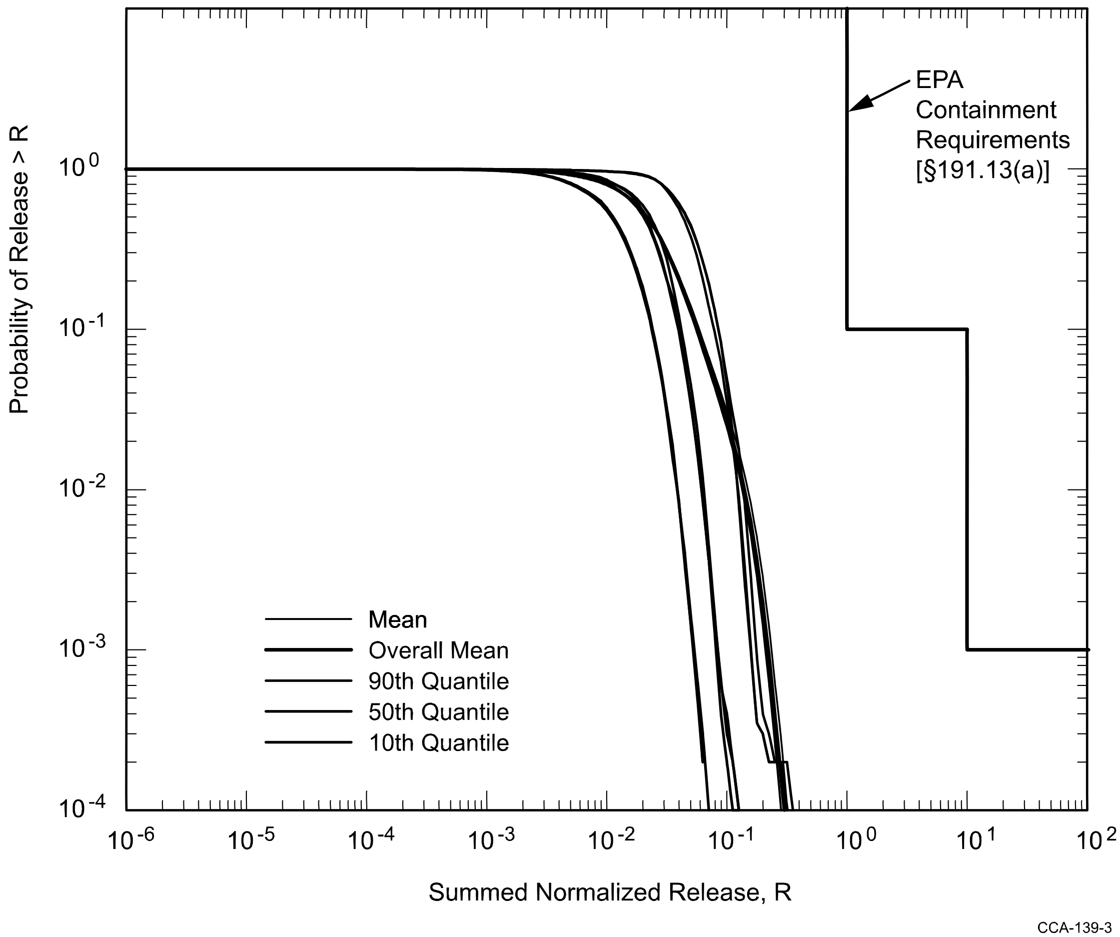
6.5.3 Release Modes Contributing to the Total Radionuclide Release

Radionuclide releases to the accessible environment can be grouped into four categories according to their mode of release:

(1) cuttings and cavings releases,

(2) spallings releases,

(3) releases resulting from the direct release of brine at the surface during drilling, and



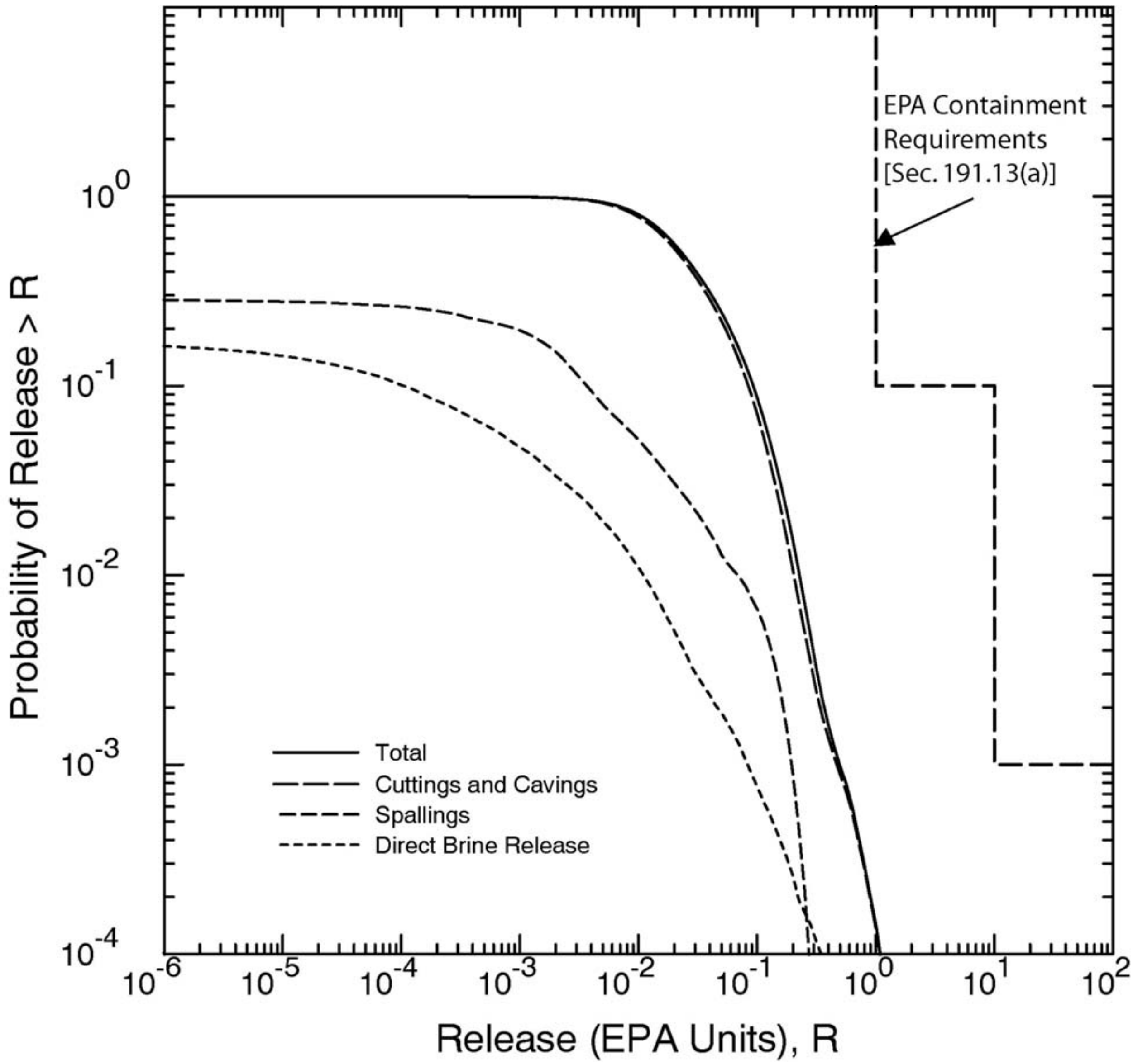
Note: Mean, median, and 10th and 90th percentile CCDFs are shown together with the overall mean. These CCDFs are based on the distributions of CCDFs shown in Figures 6-35, 6-36, and 6-37.

~~Figure 6-40. Summary CCDFs for Replicates 1, 2, and 3~~

(4) releases in the subsurface following transport in groundwater.

Each of these four modes has the potential to contribute to the total quantity of radionuclides released from the repository, and therefore each has the potential to affect the position of the mean CCDF.

Figure ~~6-41~~***6-39*** provides a display of the relative contribution of each mode to the total release. Releases for each of the three replicates are similar, and results are shown for replicate 1 only for simplicity. Mean CCDFs are shown for the total normalized release (this curve is also shown in Figure ~~6-40~~***6-1*** and is the mean of the family shown in Figure ~~6-35~~***6-34***) and for the normalized releases resulting from cuttings and cavings, spallings, and direct brine release. The mean CCDF for subsurface releases resulting from groundwater transport is not shown because those releases were less than 10^{-6} EPA units and the CCDF cannot be shown at the scale of this figure. Releases from cuttings and cavings are shown to be the most important contributors to the location of mean CCDF, with spallings also making a small contribution. Direct brine releases



Note: Mean CCDFs are shown for the total normalized release (this curve is also shown in Figure ~~6-40~~***6-1*** and is the mean of the family shown in Figure ~~6-35~~***6-34***) and for the normalized releases resulting from cuttings and cavings, spallings, and direct brine release. The mean CCDF for subsurface releases resulting from groundwater transport is not shown because those releases were less that 10-6 EPA units and the CCDF cannot be shown at the scale of this figure.

Figure *6-39*~~6-41~~. Mean CCDFs for Specific Release Modes, Replicate 1

are less important, and have very little effect on the location of the mean CCDF. Subsurface groundwater releases are not important, and have essentially no effect on the mean CCDF. See Appendix PA, ***Section PA-9.0***~~SA~~ for additional discussion of the relative importance of the release modes.