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Sandia National Laboratories

Waste Isolation Pilot Plant

Analysis Package for CCDFGF:

2009 Compliance Recertification Application

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1.0 Introduction

The Waste Isolation Pilot Plant (WIPP) is a deep geologic repository developed by the US Department of Energy (DOE) for the disposal of transuranic (TRU) radioactive waste. Containment of TRU waste at the WIPP is regulated by the U.S. Environmental Protection Agency (EPA) according to the regulations set forth in Title 40 of the Code of Federal Regulations (CFR), Parts 191 (EPA 1985) and 194 (EPA 1996). In December 2007 and January 2008, Sandia National Laboratories (SNL) completed a Performance Assessment (PA) of the WIPP. This PA supports the Compliance Recertification Application (CRA-2009) to be submitted by the DOE to the EPA to demonstrate continued compliance with the radiation protection regulations of 40 CFR 191 (EPA 1985) and 40 CFR 194 (EPA 1996). This new analysis has been termed the CRA-2009 Performance Assessment (CRA-2009 PA).

Analysis Plan AP-137 (Clayton 2008a) outlines the set of PA calculations required and identifies the changes that were made for the CRA-2009 PA. This analysis package documents the calculations performed by the code CCDFGF, included as part of the CRA-2009. This analysis package concludes that the potential releases are still predicted to be well within the regulatory limits.

2.0 Background

Analysis plan AP-137 (Clayton 2008a) explains the methodology used to calculate direct releases for the CRA-2004 PABC. As identified in AP-137, the conceptual models and inventory for transport via the Culebra are unaffected and thus the Culebra flow and transport results from the WIPP 2004 Compliance Recertification Application Performance Assessment Baseline Calculation (CRA-2004 PABC) were used for the CRA-2009 PA. The Culebra flow and transport results from the CRA-2004 PABC are documented in Lowry and Kanney (2005). Direct releases to the surface include cuttings and cavings releases, spallings releases, and direct brine releases (DBRs). The code CCDFGF assembles the release estimates from all other components of the WIPP PA system to generate cumulative complementary distribution functions (CCDFs) of releases (WIPP PA 2003). Releases are discussed and displayed in the form of CCDFs. The total release CCDFs and the major release mechanisms that comprise the total releases are investigated. The mathematical models, theory, design, and input and output file of the CCDFGF code will not be discussed here. They are discussed in the Design Document and User's Manual for CCDFGF (WIPP PA 2003).

Releases from the WIPP fall into two principal categories: (1) Direct releases, which may occur at the time of a drilling intrusion, and (2) Long-term releases, which may take place throughout the regulatory period. Direct releases are subdivided into three components: cuttings and cavings; spallings; and direct brine releases. Cuttings refers to a release of the waste material actually encountered by a drill bit as it passes through the waste and is brought to the surface by the drilling fluid. Cavings include material eroded from the walls of the waste and brought to the surface by the drilling fluid. Spallings accounts for additional material that may be brought to the surface through venting of repository gas pressure to the lower-pressure borehole. Direct brine releases are flows of brine from the repository to the surface during the few days while a borehole is assumed to be plugged.

Long-term releases include radionuclide transport in groundwater through the various geologic units to the land withdrawal boundary. The most transmissive unit is the Culebra. Radionuclides can be transported to the Culebra primarily by brine flow up boreholes. Other transport paths, such as through the shaft seals, or through the marker beds, have been demonstrated to be insignificant (Helton et al. 1998).

3.0 Methodology

The performance assessment methodology accommodates both stochastic and subjective uncertainty in its constituent models. Stochastic uncertainty pertains to unknowable future events such as intrusion times and locations that may affect repository performance and is treated by generating random sequences of future events. Subjective uncertainty concerns parameter values that are assumed to be constants and the constants' true values are uncertain because of a lack of knowledge about the system. An example of a subjectively uncertain parameter could be the permeability of a material. Subjective uncertainty is treated by sampling the parameter values from assigned distributions. One set of sampled values required to run a WIPP PA calculation is termed a vector. The performance assessment models are executed for three replicates of 100 vectors of possible parameter values; for each vector. The releases for each of 10,000 possible sequences of future events are tabulated for each of the 300 vectors, totaling 3,000,000 possible sequences.

By regulation, performance assessment results are presented as a distribution of CCDFs of releases (EPA 1996). Each individual CCDF summarizes the likelihood of releases across all futures for one vector of parameter values. The uncertainty in parameter values result in a distribution of CCDFs.

To compare the distributions of CCDFs among replicates and to demonstrate sufficiency of the sample size, mean and percentile CCDFs are calculated. At each value for normalized release R on the abscissa, the CCDFs for a single replicate define 100 values for probability. The arithmetic mean of these 100 probabilities is the mean probability that release exceeds R; the curve defined by the mean probabilities for each value of R is the mean CCDF. The percentile CCDFs are calculated based on order statistics.

The overall mean CCDF is computed as the arithmetic mean of the three mean CCDFs from each replicate. A confidence interval is computed about the overall mean CCDF using the Student's t-distribution and the mean CCDFs from each replicate.

3.1 Code Version

No modifications have been made to the codes PRECCDFGF and CCDFGF since completion of the CRA-2004 PABC. PRECCDFGF version 1.01 and CCDFGF version 5.02 were used for the CRA-2009 PA.

3.2 Random Seed in the CCDFGF Control Files

One of the features that the CCDFGF control file controls is the random number generator in the code. Setting the random number seed in the control file determines the sequence of random numbers that CCDFGF uses. This sequence of numbers affects several stochastic parameters, such as the drilling location, depth, and type of plugging pattern, when CCDFGF simulates the drilling of boreholes at the surface of the WIPP repository.

For the CRA-2009 PA, the same random seeds for CCDFGF were used as in the CRA-2004 PABC (Kirchner 2008). This was done to allow a direct comparison of the results of the CRA-2009 PA to the CRA-2004 PABC.

3.3 Run Control

Run control for this analysis is documented in Long (2008).

4.0 Analysis and Results

This section presents total normalized releases for the CRA-2009 PA, followed by discussion of each of the four categories of releases that constitute the total release: cuttings and cavings, spallings, DBRs, and culebra transport releases. Within each following section, CRA-2009 PA results are compared with CRA-2004 PABC results.

4.1 Total Releases

Figure 4. 1, Figure 4. 2, and Figure 4. 3 show the CCDFs for total releases for replicates 1, 2, and 3 of the CRA-2009 PA, respectively. (In the figures, the releases (R) are shown in EPA units which are the unit of mearsure defined by regulation 40 CFR Part 191 Appendix A.) Total releases are calculated by totaling the releases from each release pathway: cuttings and cavings releases, spallings releases, DBRs, and culebra transport releases. Each CCDF lies below and to the left of the limits specified in 40 CFR § 191.13(a). Thus, the WIPP continues to comply with the containment requirements of 40 CFR Part 191.

Figure 4. 4 compares the mean, 90th, 50th, and 10th percentiles for each replicate's distribution of CCDFs for total releases. Figure 4. 4 shows that each replicate's distribution is quite similar, and shows qualitatively that the sample size of 100 in each replicate is sufficient to generate a stable distribution of outcomes. Figure 4. 5 shows 95 percent confidence intervals about the overall mean.

Figure 4. 6, Figure 4. 7, and Figure 4. 8 show the mean CCDFs for each component of total releases, for replicates 1, 2, and 3 of the CRA-2009 PA, respectively. For comparison, the mean CCDFs for each component of total releases for replicates 1, 2, and 3 from the CRA-2004 PABC are shown in Figure 4. 9, Figure 4. 10, and Figure 4. 11, respectively. (Only replicate 2 from each analysis have releases from the culebra larger than 10^{-6} EPA units.)

Two differences between the analyses are observed. The first is that mean DBRs releases for the CRA-2009 PA have increased slightly from the CRA-2004 PABC. For probabilities exceeding 0.01, cuttings and cavings are still the release mechanism that has the greatest impact on total releases. At low probabilities (<0.002), mean DBR releases still exceed all other mean releases. Further discussion of normalized DBRs follows in Section 4.4.

The second difference between the two analyses concerns the mean spallings CCDFs. The mean spallings releases for the CRA-2009 PA have increased slightly from the CRA-2004 PABC at all probabilities. Further discussion of spallings releases follows in Section 4.3.

Figure 4. 12 provides an additional comparison between the CRA-2009 PA and CRA-2004 PABC. At all probabilities, the overall mean CCDFs for total normalized releases from the two analyses are very similar. A small increase is noticeable because of a change in the drilling rate parameter (Clayton 2008a) and the increase in the DBR and Spallings releases.

Table 4. 1 lists the overall mean total release at probabilities of 0.1 and 0.001 for the CRA-2004 PABC and the CRA-2009 PA. Mean total releases increased around 10^{-1} EPA units at probabilities of 0.1 and of 0.001 for the CRA-2009 PA compared to the CRA-2004 PABC (Table 4. 1). Similarly CRA-2009 PA showed increases compared to the CRA-2004 PABC in the 90th percentile CCDFs for total releases. These increases in the total releases 90th percentile CCDF are on the order of 10^{-2} EPA units at a probability of 0.1 and on the order of 10^{-1} EPA units a probability of 0.001. These increases in the total releases are primarily a result of the increases in the DBR and Spallings releases, discussed in Sections 4.3 and 4.4.

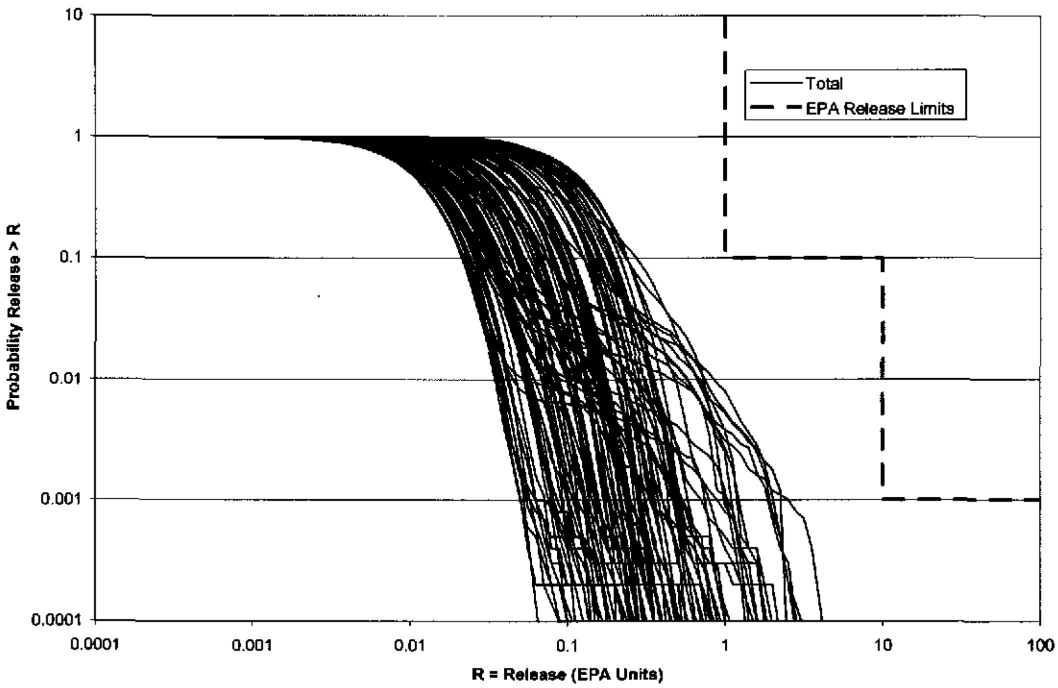

Figure 4. 1. Total Normalized Releases: Replicate 1 of the CRA-2009 PA

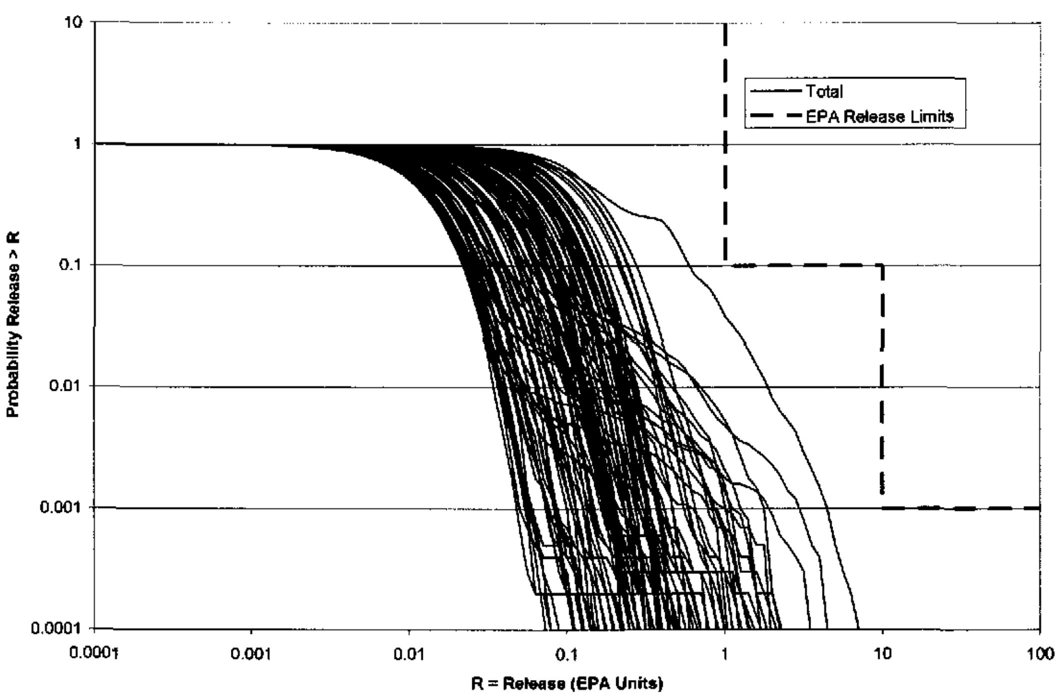

Figure 4. 2. Total Normalized Releases: Replicate 2 of the CRA-2009 PA

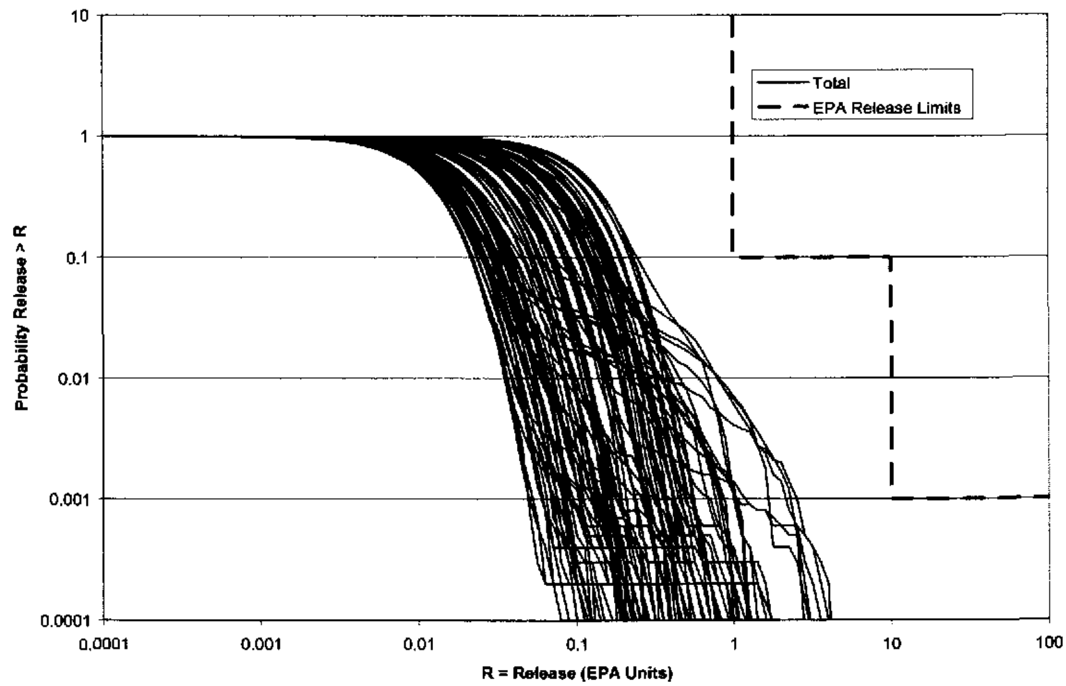

Figure 4. 3. Total Normalized Releases: Replicate 3 of the CRA-2009 PA

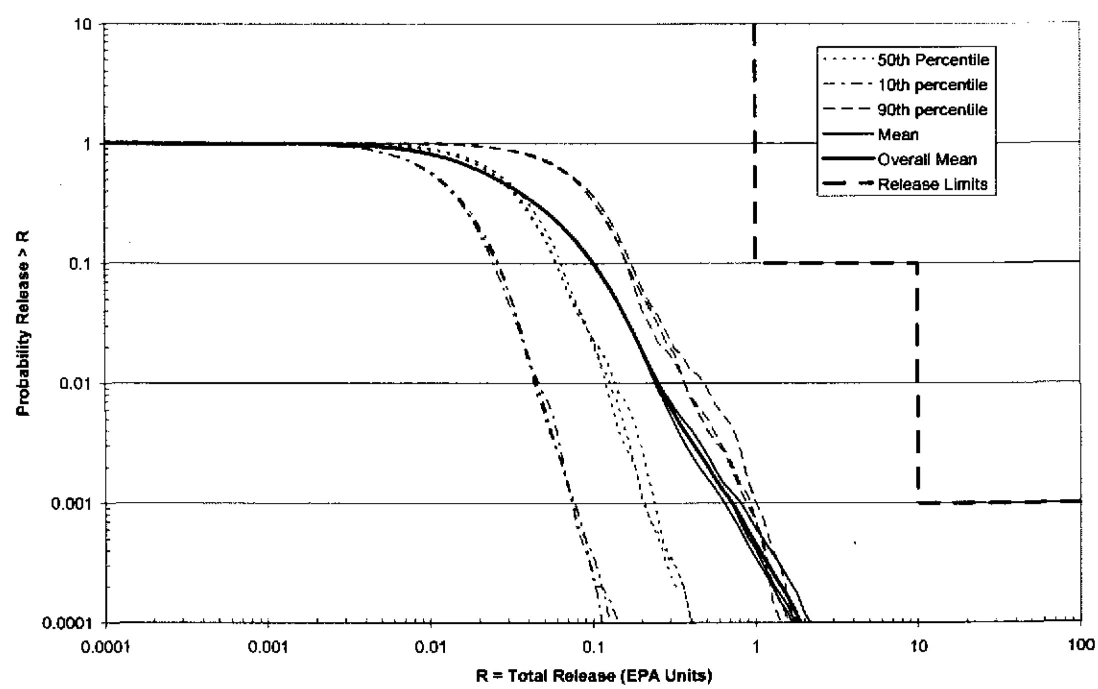

Figure 4. 4. Mean and Percentile CCDFs for Total Normalized Releases: All Replicates of the CRA-2009 PA

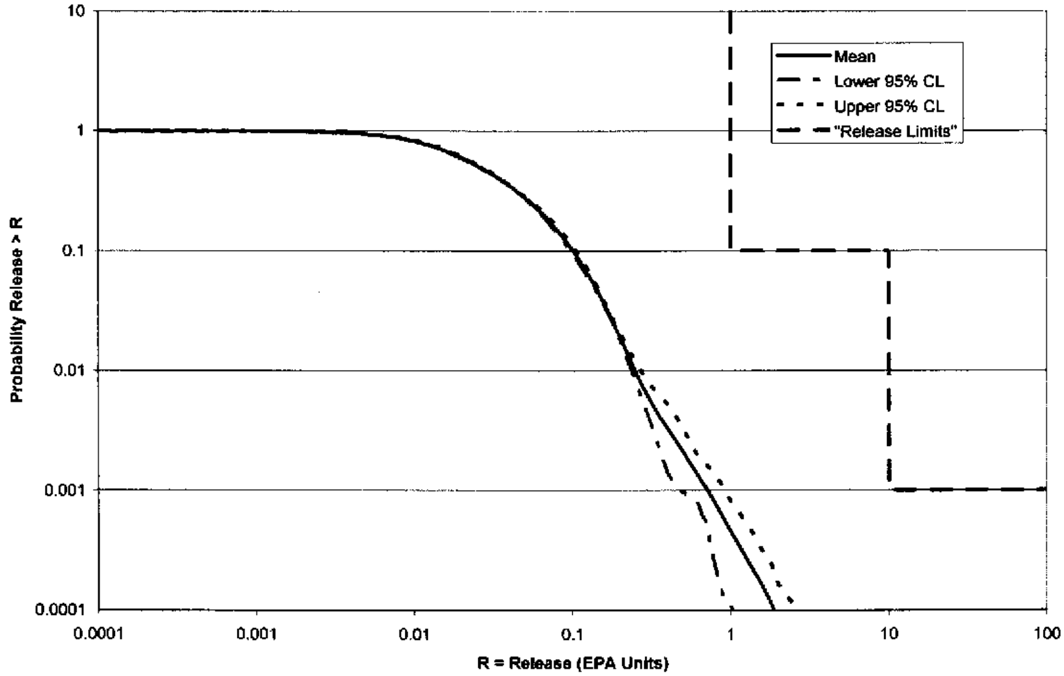

Figure 4. 5. Confidence Interval on Overall Mean CCDF for Total Normalized Releases: CRA-2009 PA

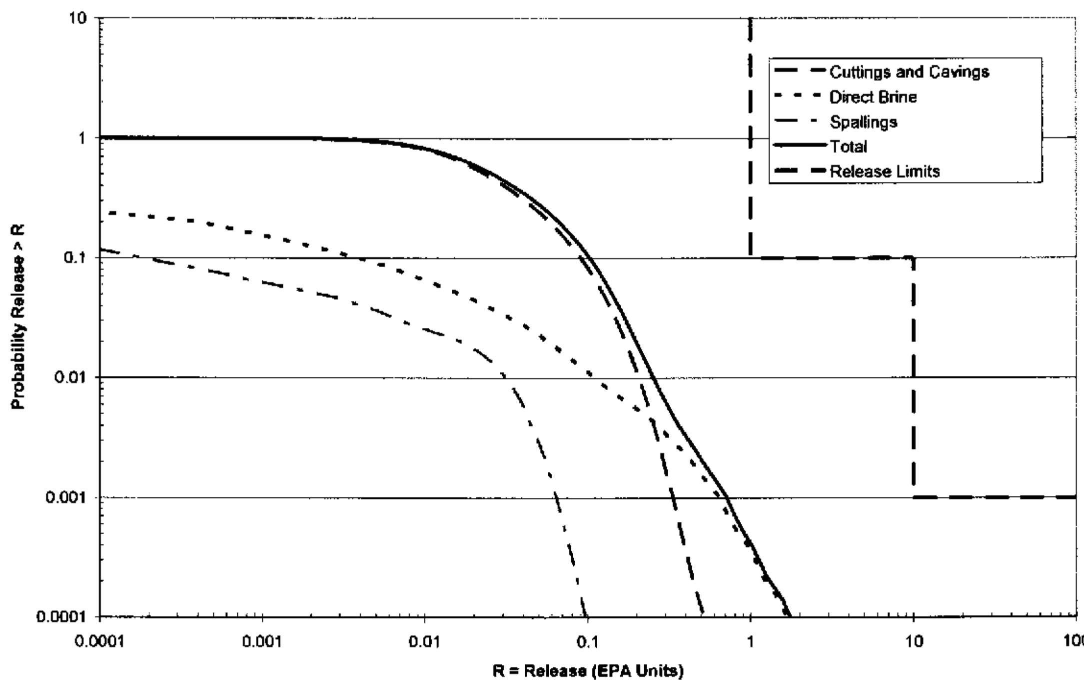

Figure 4. 6. Mean CCDFs for Components of Total Normalized Releases: Replicate 1 of CRA-2009 PA

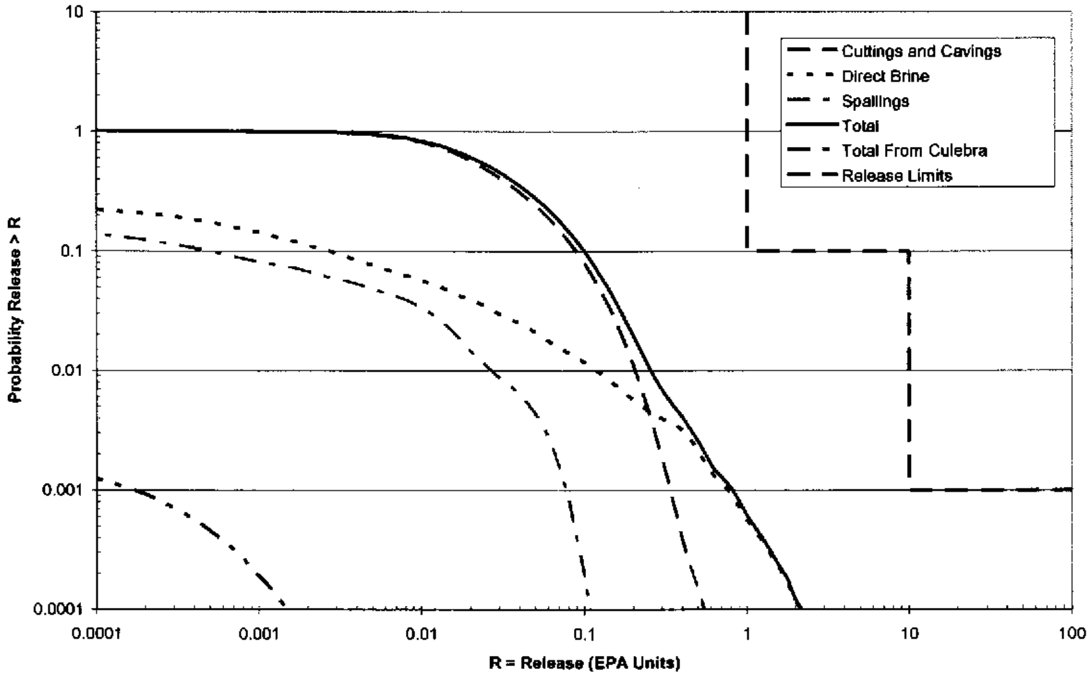

Figure 4. 7. Mean CCDFs for Components of Total Normalized Releases: Replicate 2 of CRA-2009 PA

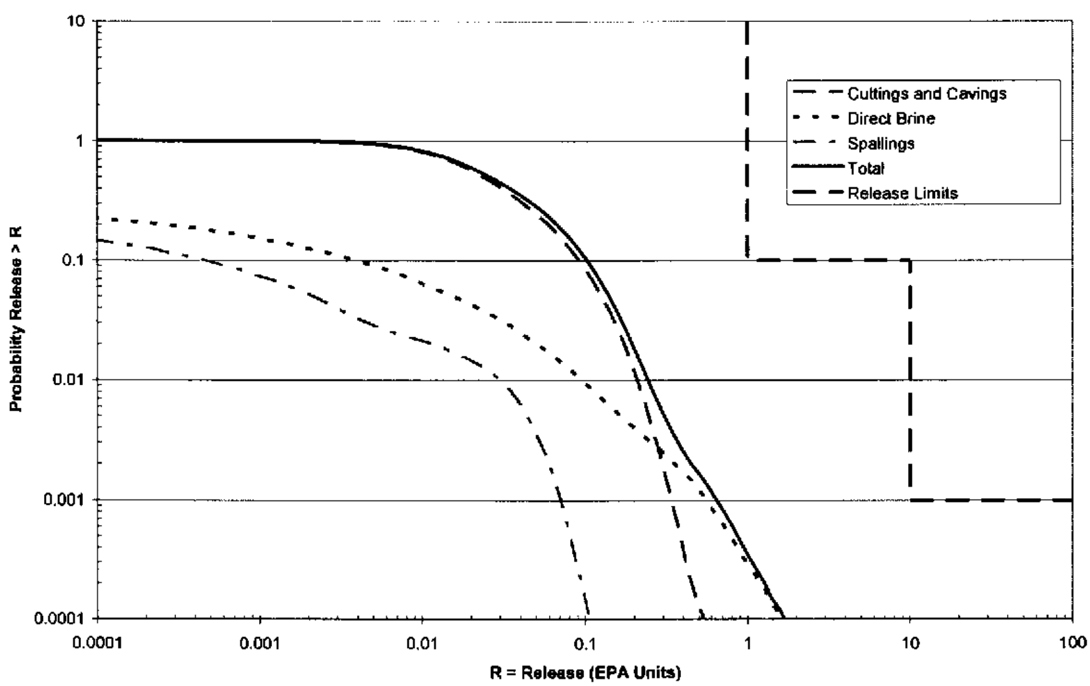

Figure 4. 8. Mean CCDFs for Components of Total Normalized Releases: Replicate 3 of CRA-2009 PA

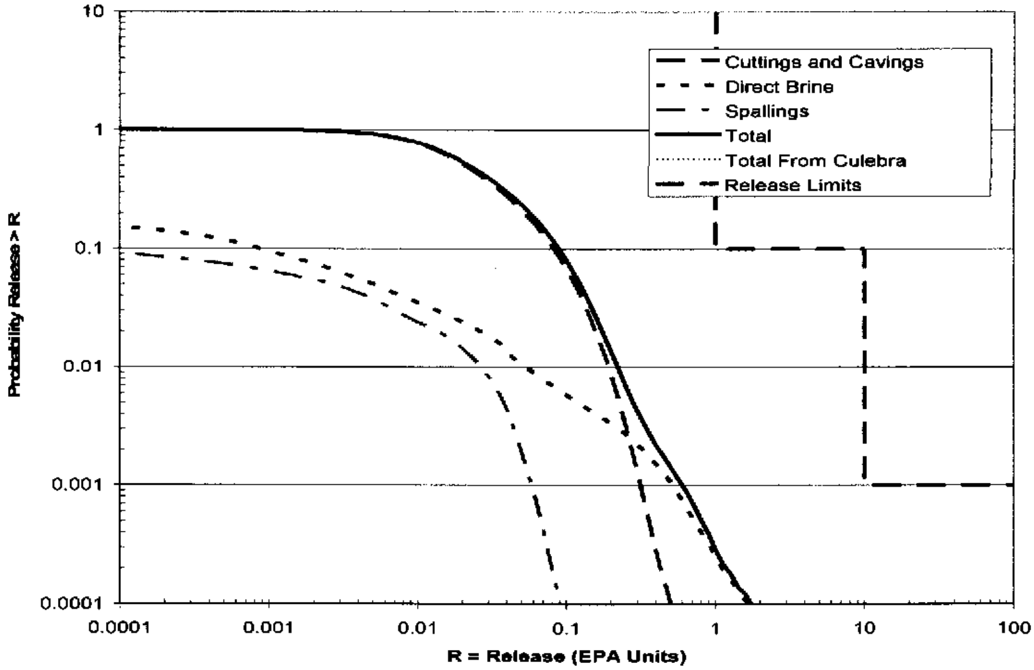

Figure 4. 9. Mean CCDFs for Components of Total Normalized Releases: Replicate 1 of CRA-2004 PABC

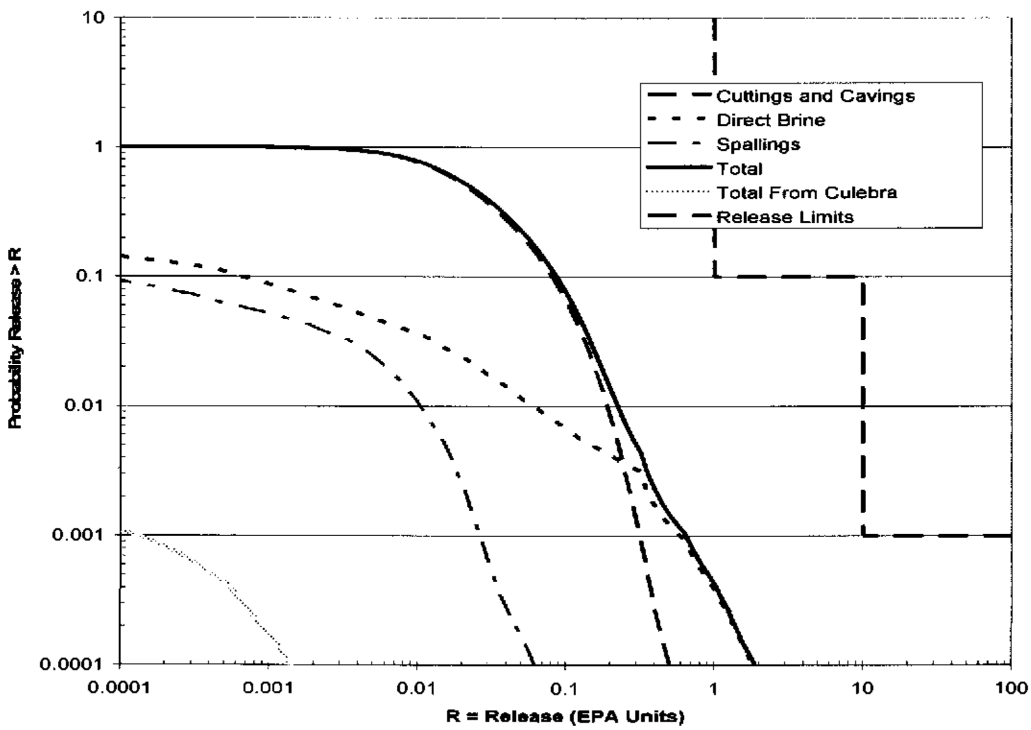

Figure 4. 10. Mean CCDFs for Components of Total Normalized Releases: Replicate 2 of CRA-2004 PABC

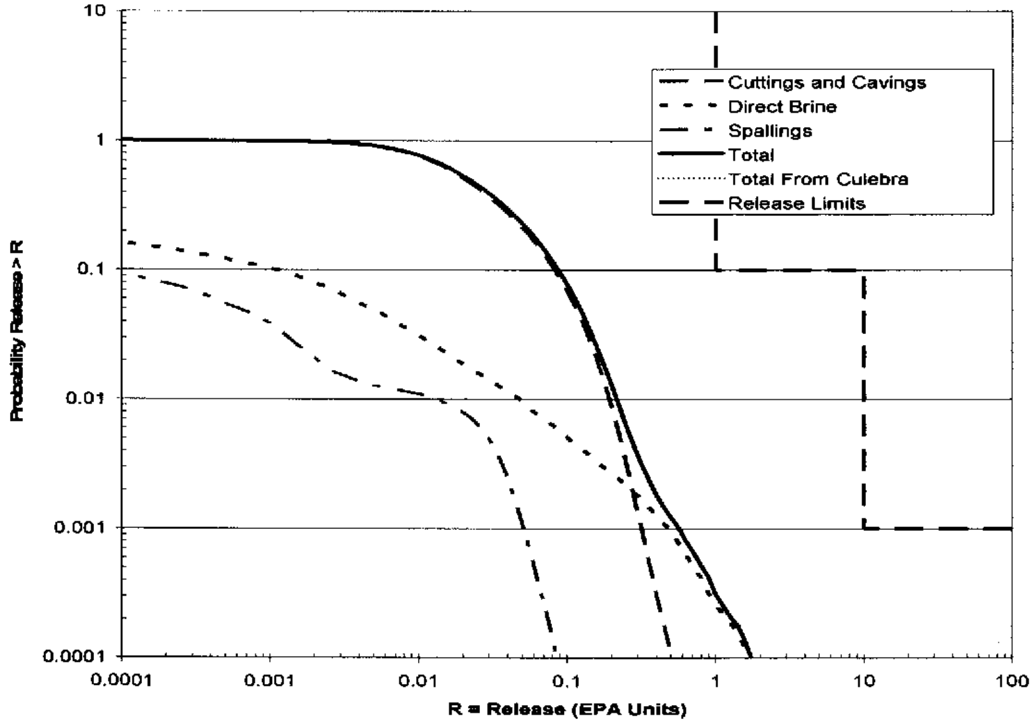

Figure 4. 11. Mean CCDFs for Components of Total Normalized Releases: Replicate 3 of CRA-2004 PABC

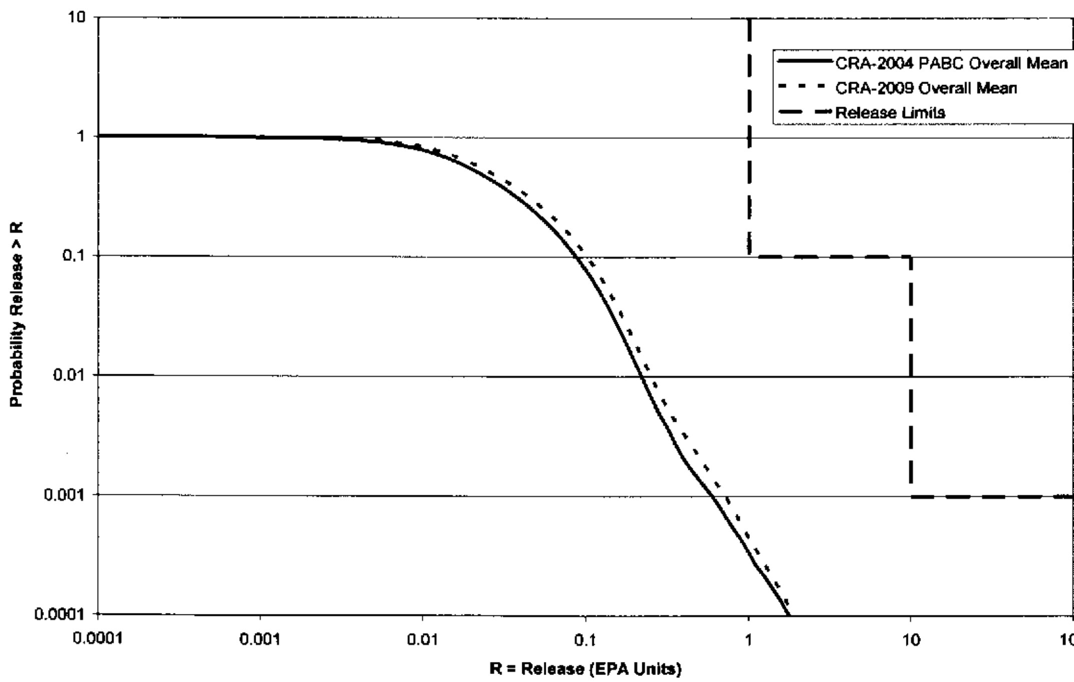

Figure 4. 12. Overall Mean CCDFs for Total Normalized Releases: CRA-2009 PA and CRA-2004 PABC

Table 4. 1 CRA-2004 PABC, and CRA-2009 PA Statistics on the Overall Mean for Total Normalized Releases at Probabilities of 0.1 and 0.001, All Replicates Pooled. CRA-2004 PABC data was initially reported in Vugrin and Dunagan (2005).

Probability	Analysis	Mean Total Release	90^{th} Percentile Total Release	Lower 95% CL	Upper 95% CL
0.1	CRA-2004 PABC	8.770E-2	1.480E-1	8.471E-2	9.072E-2
	CRA-2009 PA	1.015E-1	1.654E-1	9.717e-2	1.060E-1
0.001	CRA-2004 PABC	6.006E-1	8.092E-1	5.175E-1	6.807E-1
	CRA-2009 PA	7.194E-1	9.184E-1	4.773E-1	9.192E-1

4.2 Cuttings and Cavings Normalized Releases

Figure 4.13, Figure 4.14, and Figure 4.15 show the CCDFs for cuttings and cavings releases for replicates 1, 2, and 3 of the CRA-2009 PA, respectively. Figure 4.16 shows the mean CCDFs for cuttings and cavings releases for replicates 1, 2, and 3 of the CRA-2009 PA The releases in each replicate are very similar.

Figure 4.17 compares the mean, 90^{th}, 50^{th}, and 10^{th} percentiles for each replicate's distribution of CCDFs for cuttings and cavings releases. Figure 4.17 shows that each replicate's distribution is quite similar. Figure 4.18 shows the 95 percent confidence intervals about the overall cuttings and cavings mean. The confidence interval is extremely tight.

Figure 4.19 shows the mean CCDFs for cuttings and cavings releases for all replicates of the CRA-2004 PABC. For further comparison, the overall mean CCDFs for cuttings and cavings releases from both analyses are shown in Figure 4.20. These resulting overall mean CCDFs are very similar, with only a slight increase in the CRA-2009 PA mean due to the increase in the drilling rate. The overall mean volume CCDFs are very similar as well (Figure 4.21), with the only difference due to the increase in the drilling rate.

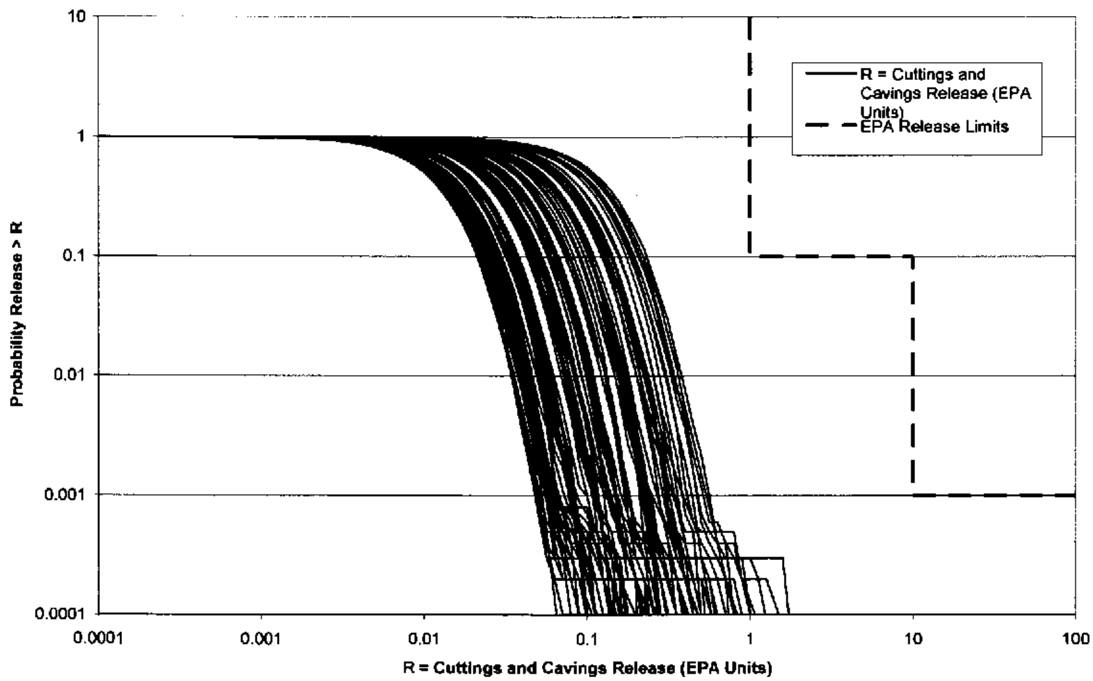

Figure 4.13. Cuttings and Cavings Normalized Releases: Replicate 1 of the CRA-2009 PA

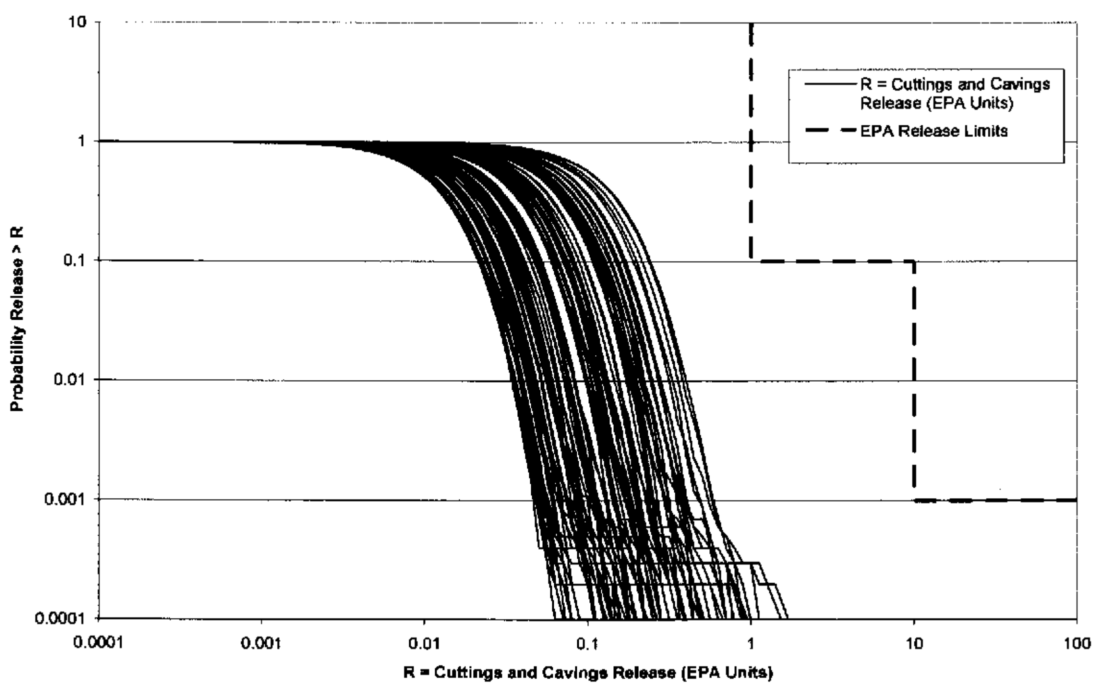

Figure 4.14. Cuttings and Cavings Normalized Releases: Replicate 2 of the CRA-2009 PA

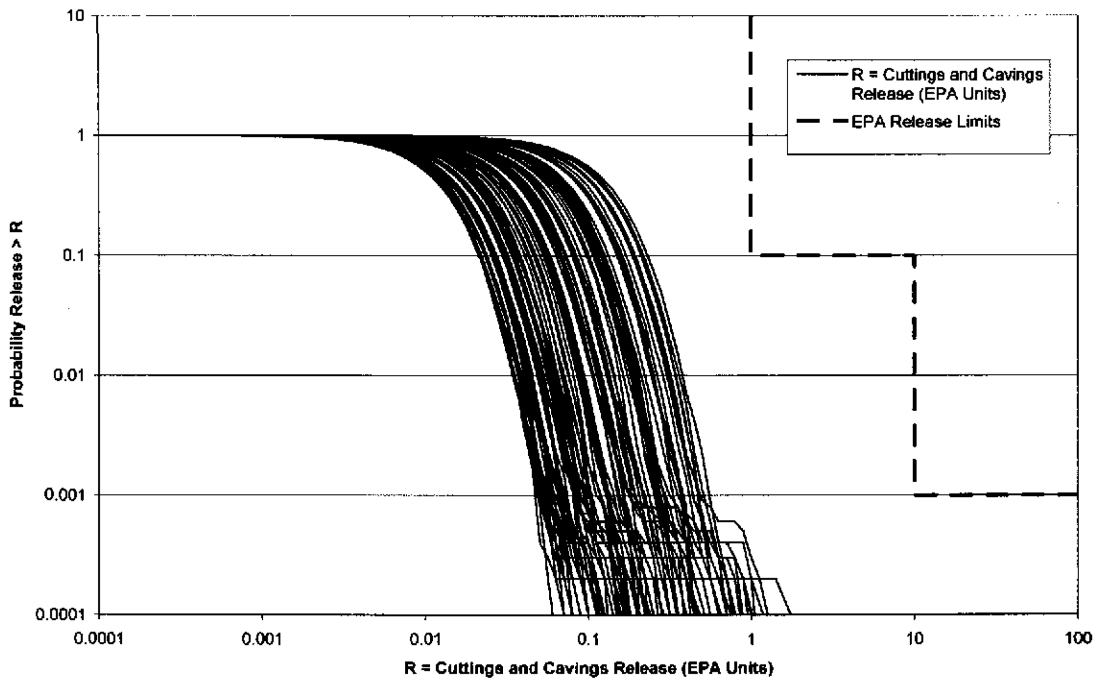

Figure 4.15. Cuttings and Cavings Normalized Releases: Replicate 3 of the CRA-2009 PA

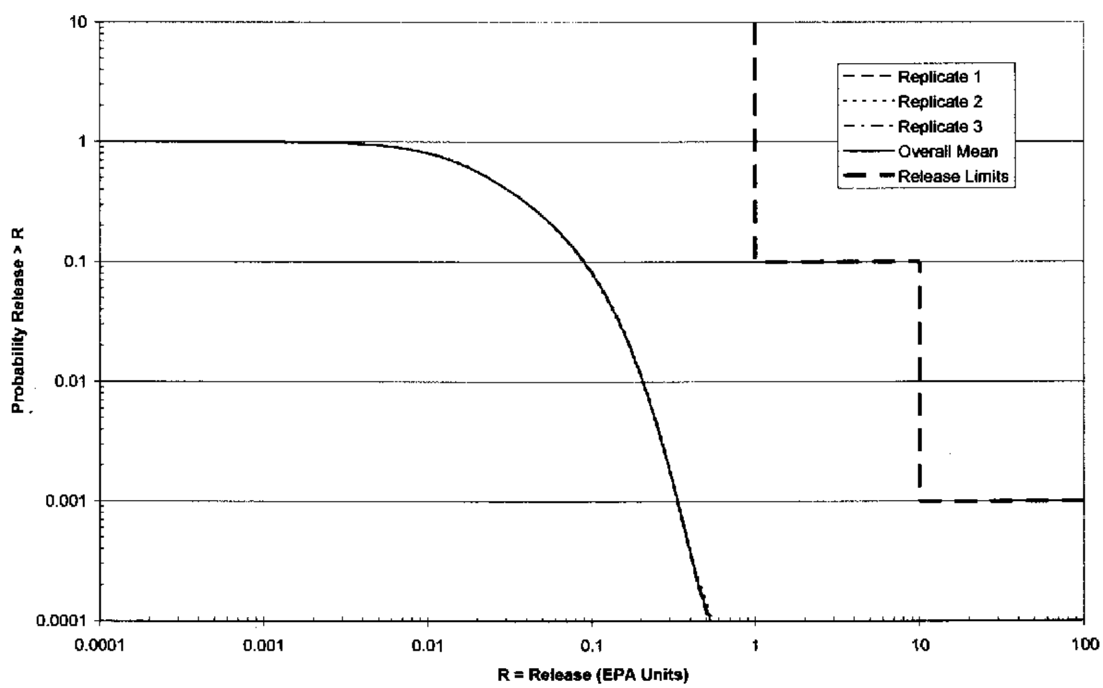

Figure 4.16. Mean CCDFs for Cuttings and Cavings Releases: All Replicates of the CRA-2009 PA

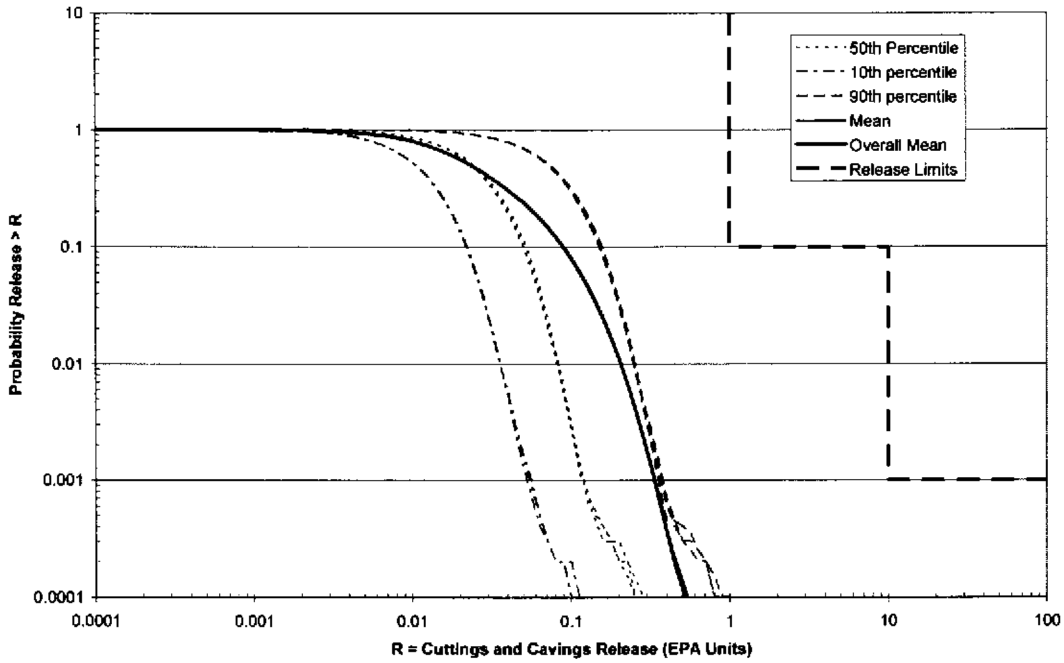

Figure 4.17. Mean and Percentile CCDFs for Cuttings and Cavings Normalized Releases: All Replicates of the CRA-2009 PA

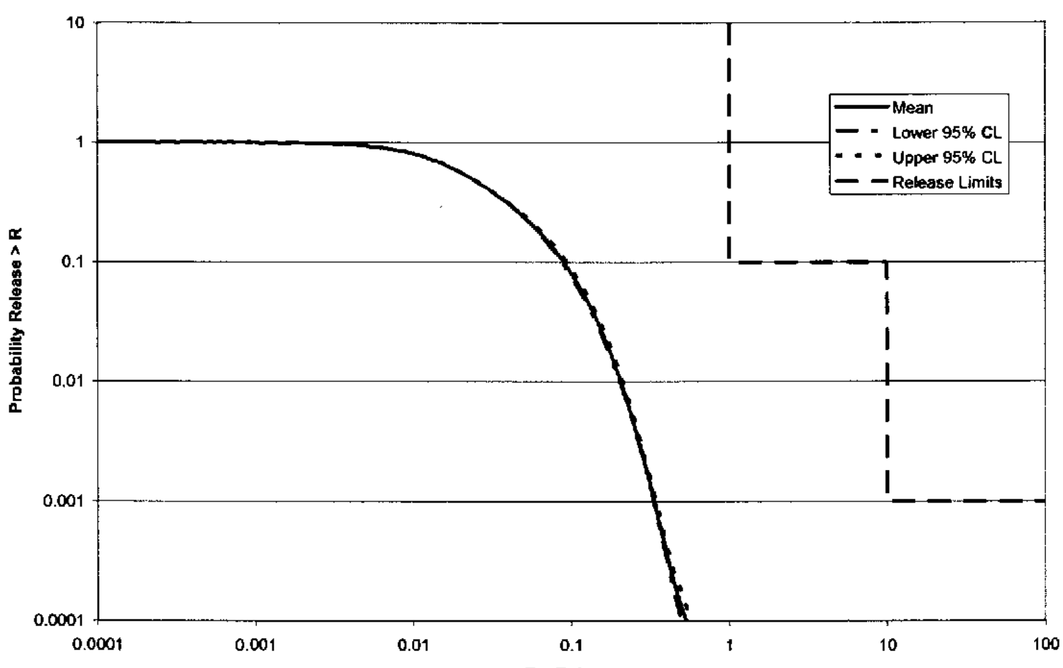

Figure 4.18. Confidence Interval on Overall Mean CCDF for Cuttings and Cavings Normalized Releases: CRA-2009 PA

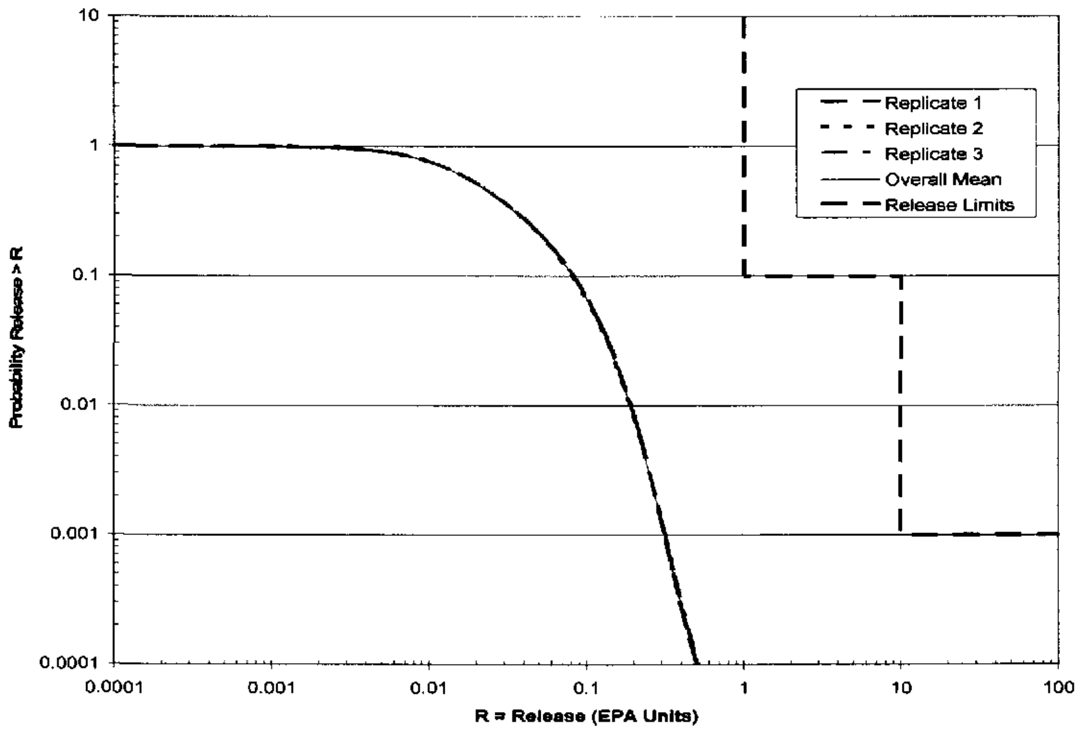

Figure 4.19. Mean CCDFs for Cuttings and Cavings Releases: All Replicates of the CRA-2004 PABC

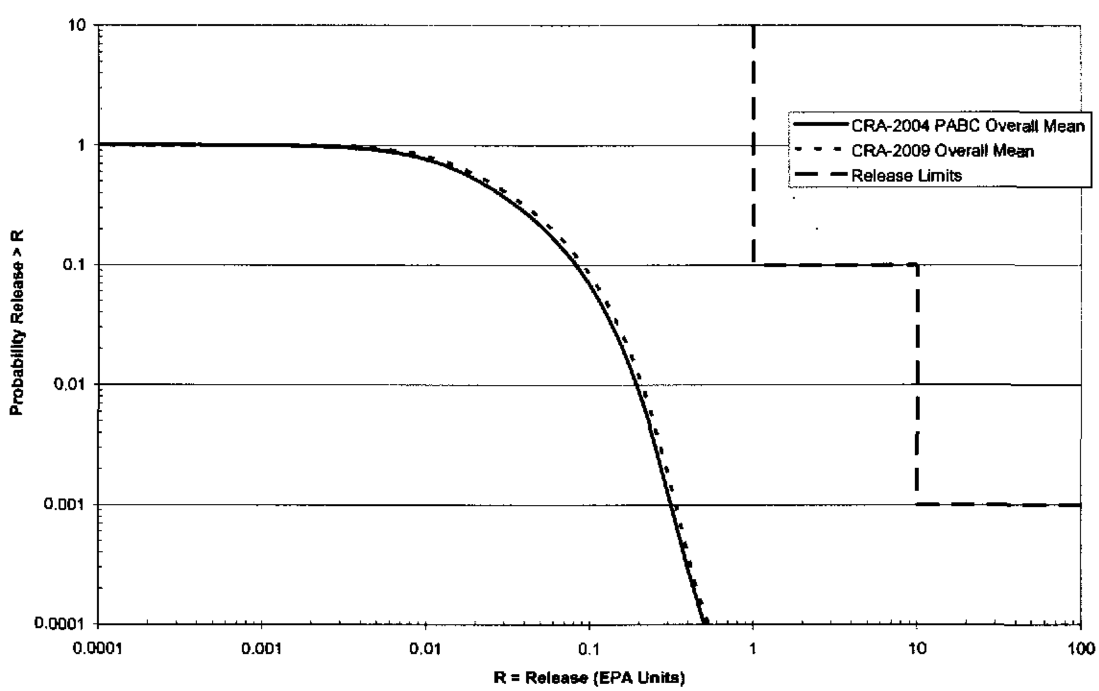

Figure 4.20. Overall Mean CCDFs for Cuttings and Cavings Releases: CRA-2009 PA and CRA-2004 PABC

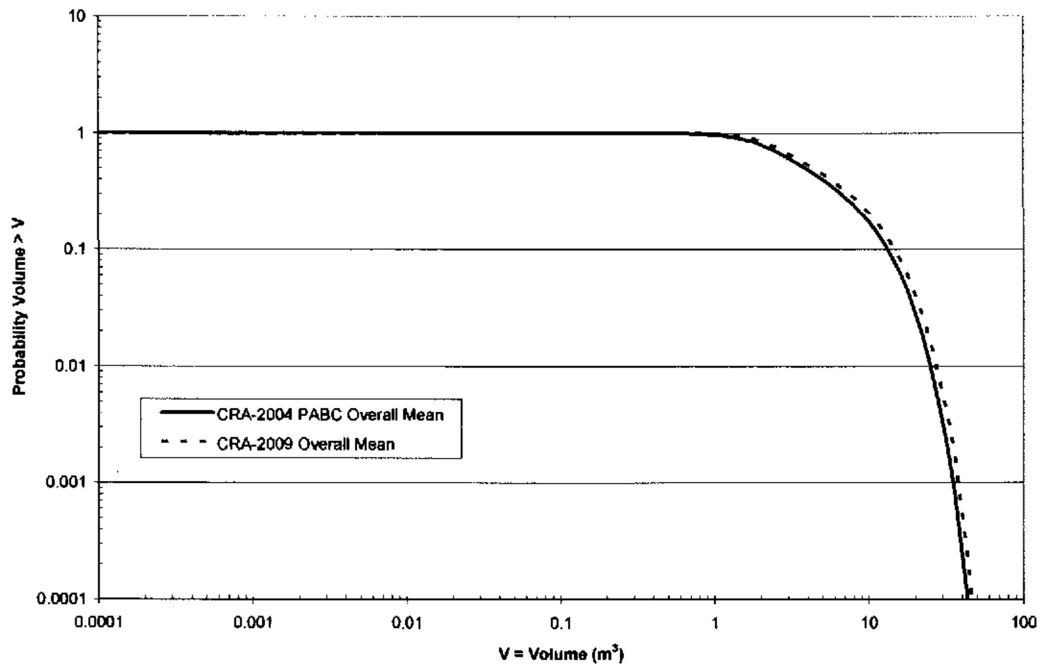

Figure 4.21. Overall Mean CCDFs for Cuttings and Cavings Volumes: CRA-2009 PA and CRA-2004 PABC

4.3 Spallings Normalized Releases

Figure 4.22, Figure 4.23, and Figure 4.24 show the CCDFs for spallings releases for replicates 1, 2, and 3 of the CRA-2009 PA. These figures display the vectors when a spallings event occurred. Only 34 vectors in replicate 1, 41 vectors in replicate 2, and 36 vectors in replicate 3 had non-zero spallings releases as compared to 34, 37, and 31 vectors having non-zero spallings releases in each of the three replicates for the CRA-2004 PABC (Ismail 2008).

Figure 4.25 compares the mean and 90th percentiles for each replicate's distribution of CCDFs for spallings releases. It is possible for the mean CCDF to be higher than the 90th percentile since there are many vectors that have zero releases. The vectors with zero releases cause the distribution to be strongly right-skewed resulting in a mean that exceeds the 90th percentile. Figure 4.26 shows the 95 percent confidence intervals about the overall spallings mean.

Figure 4.27 shows the mean spallings release CCDFs for all replicates of the CRA-2009 PA. For comparison, the mean spallings release CCDFs from the CRA-2004 PABC are shown in Figure 4.28, and Figure 4.29 shows the overall mean spallings release CCDFs for both analyses.

This increase in overall mean spallings release values can be directly attributed to an increase in overall mean spallings volumes (Figure 4.30). Spallings releases are calculated by multiplying spallings volume by the average repository activity at the time of the release. For any given probability shown in Figure 4.29 and Figure 4.30, the overall mean spallings release increased by approximately the same order of magnitude as the overall mean spallings volume.

The frequency of non-zero spallings intrusions calculated by CUTTINGS_S increased. CUTTINGS_S interpolates the DRSPALL volumes using repository pressures calculated by BRAGFLO to calculate the spallings volume released from a single intrusion for the WIPP PA intrusion scenarios. Ismail (2008) concludes that these increases are largely attributable to the increase in pressure in the repository as a result of the larger amounts of brine available. The increase of the brine in the repository is due to higher disturbed rock zone (DRZ) porosities (Nemer and Clayton 2008).

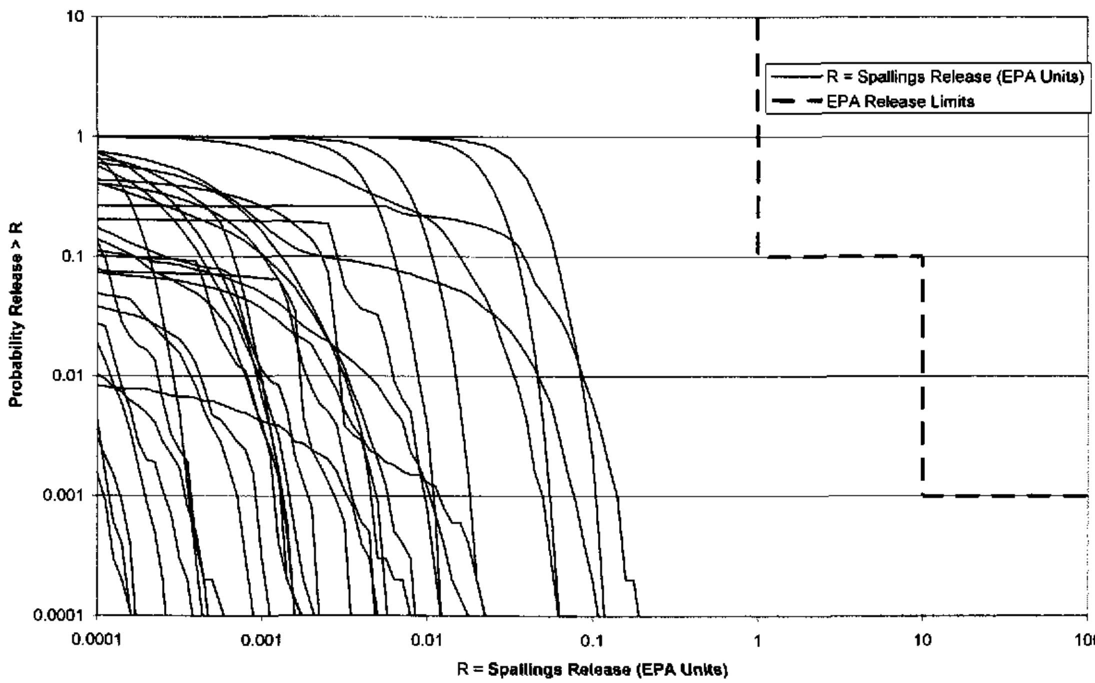

Figure 4.22. Spallings Normalized Releases: Replicate 1 of the CRA-2009 PA

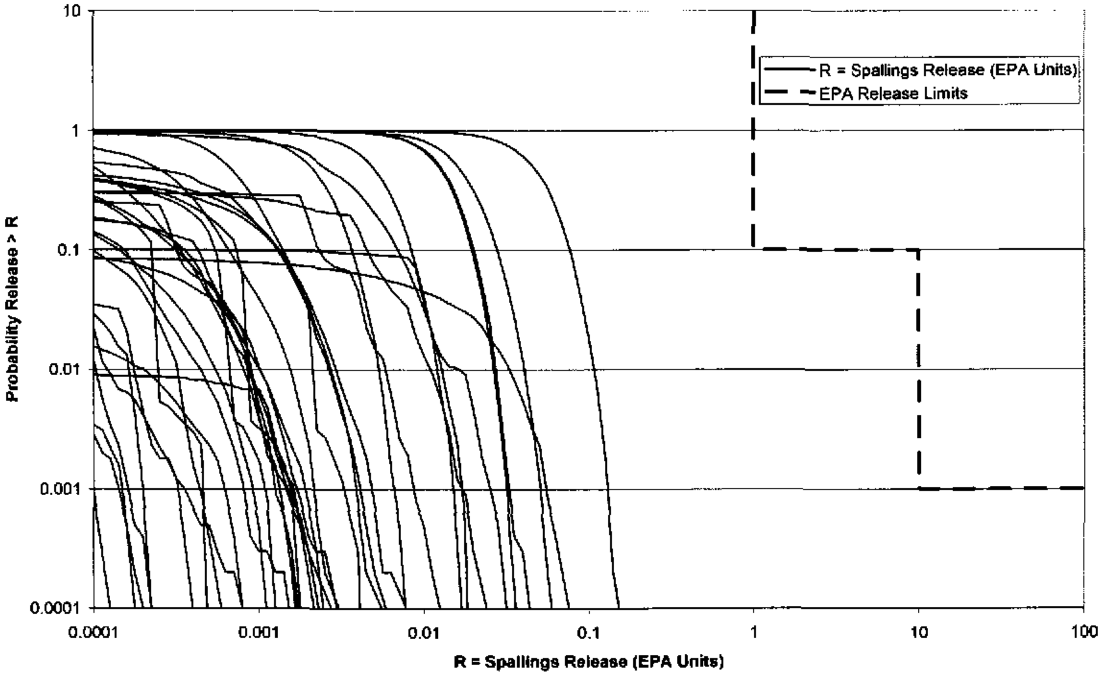

Figure 4.23. Spallings Normalized Releases: Replicate 2 of the CRA-2009 PA

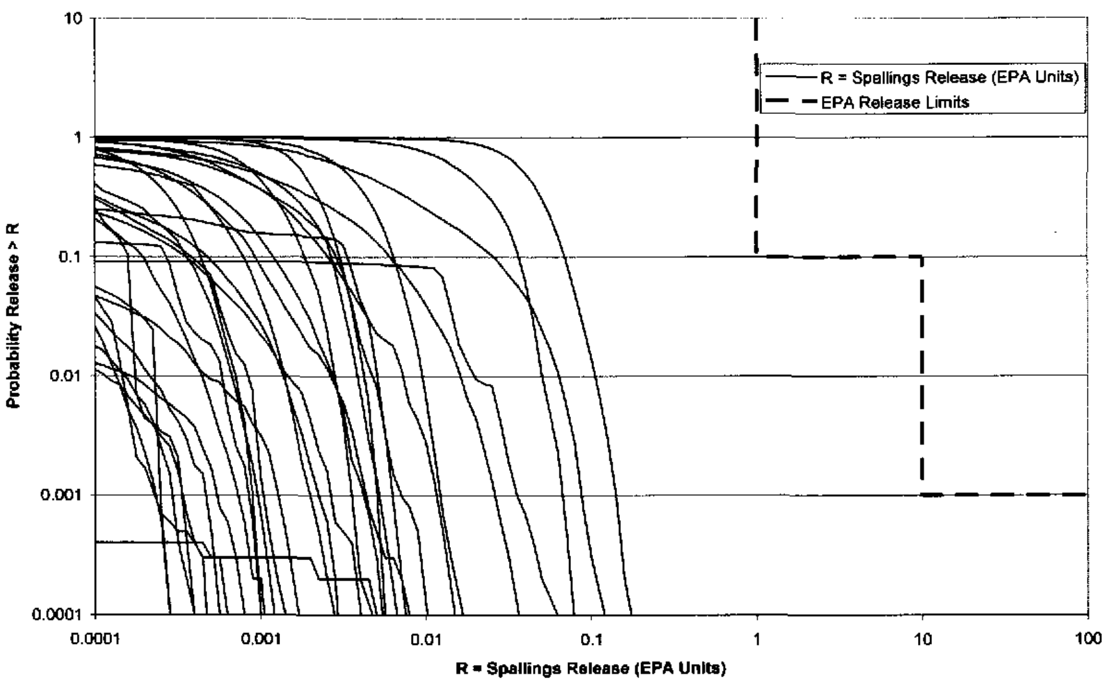

Figure 4.24. Spallings Normalized Releases: Replicate 3 of the CRA-2009 PA

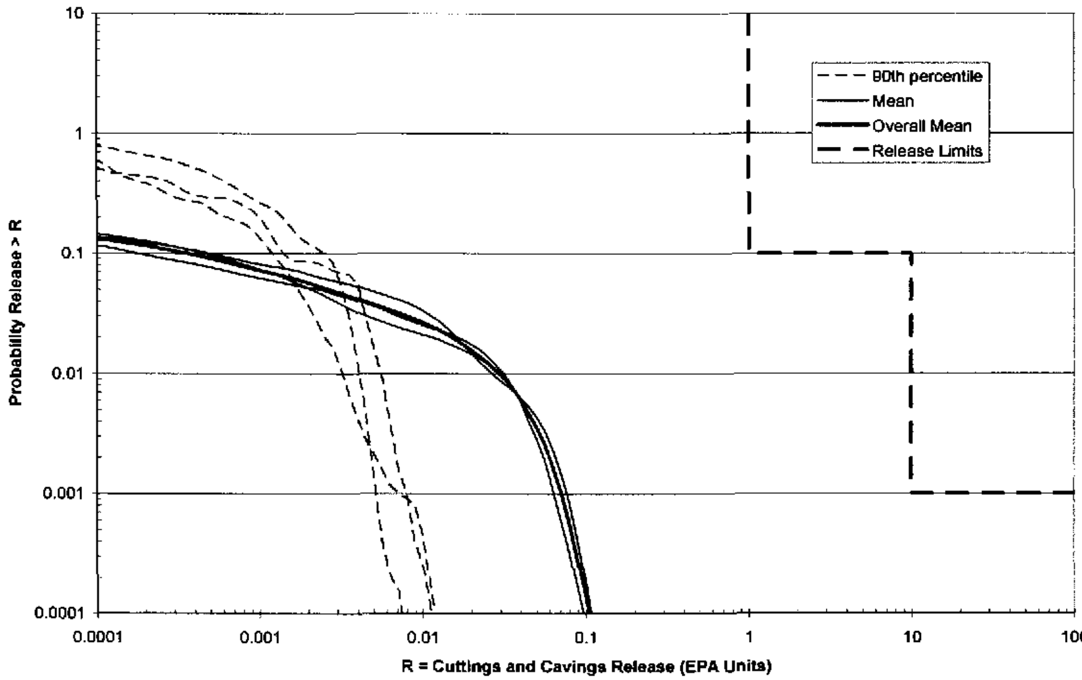

Figure 4.25. Mean and Percentile CCDFs for Spallings Normalized Releases: All Replicates of the CRA-2009 PA

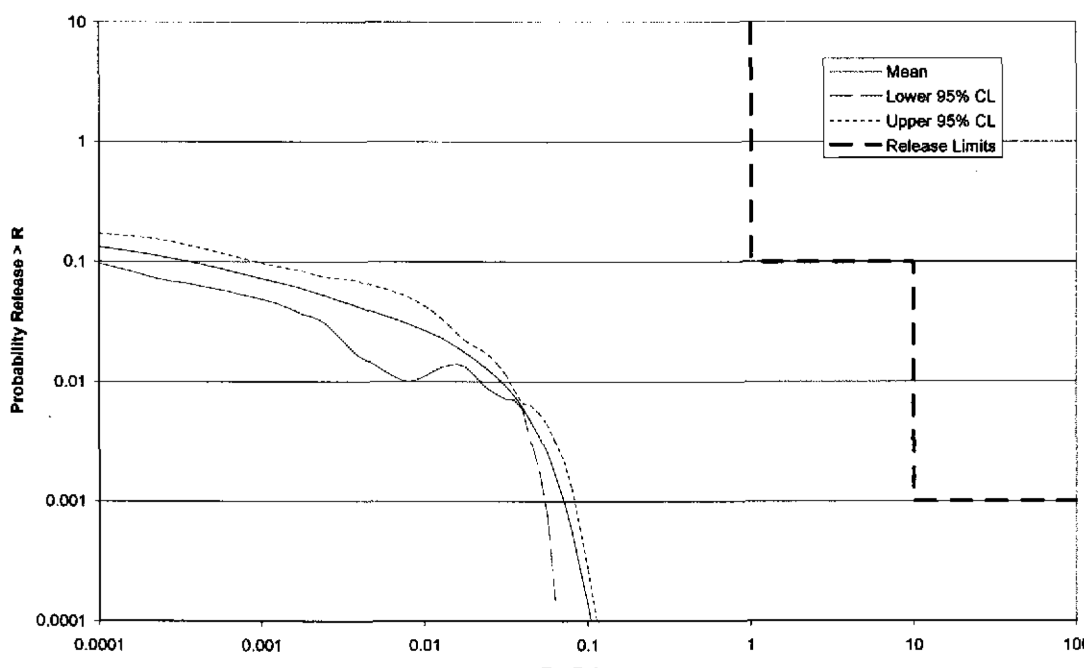

Figure 4.26. Confidence Interval on Overall Mean CCDF for Spallings Normalized Releases: CRA-2009 PA

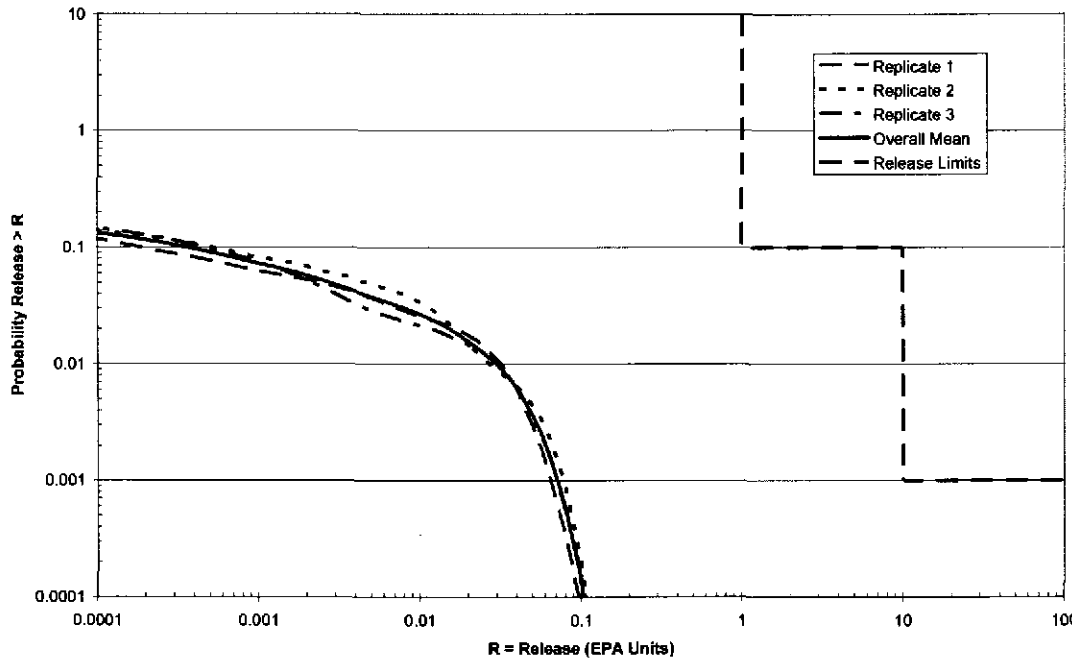

Figure 4.27. Mean CCDFs for Spallings Releases: All Replicates of the CRA-2009 PA

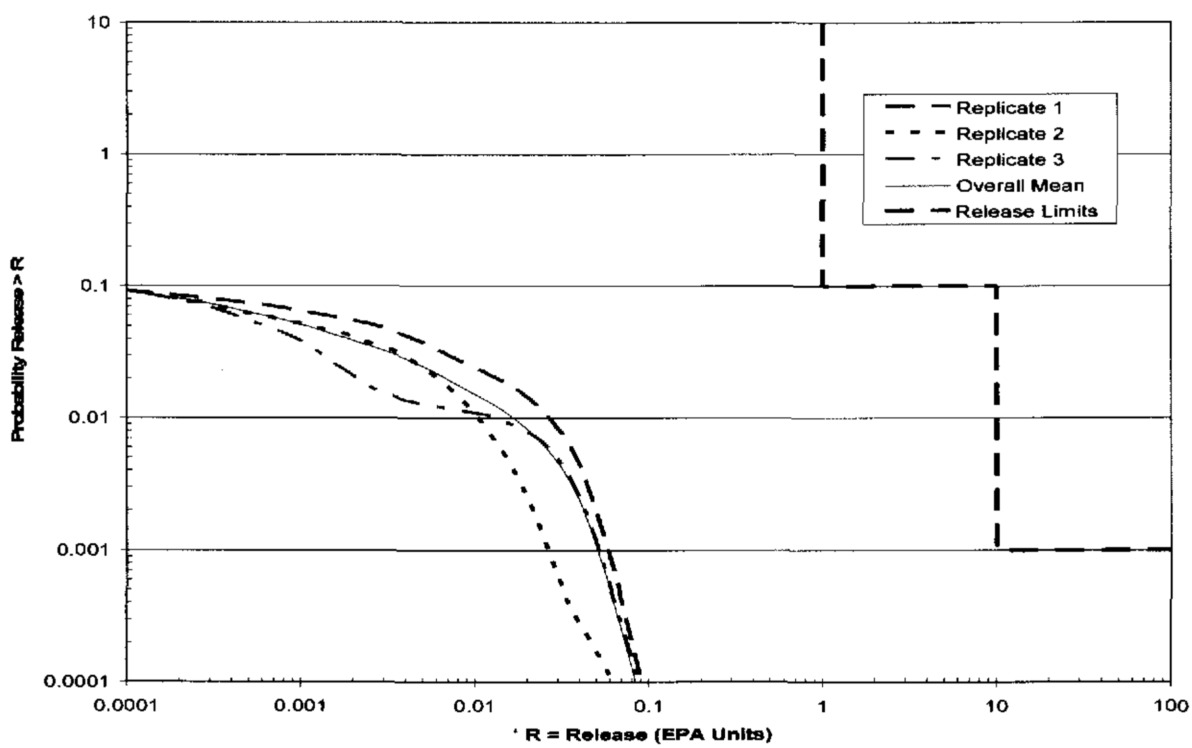

Figure 4.28. Mean CCDFs for Spallings Releases: All Replicates of the CRA-2004 PABC

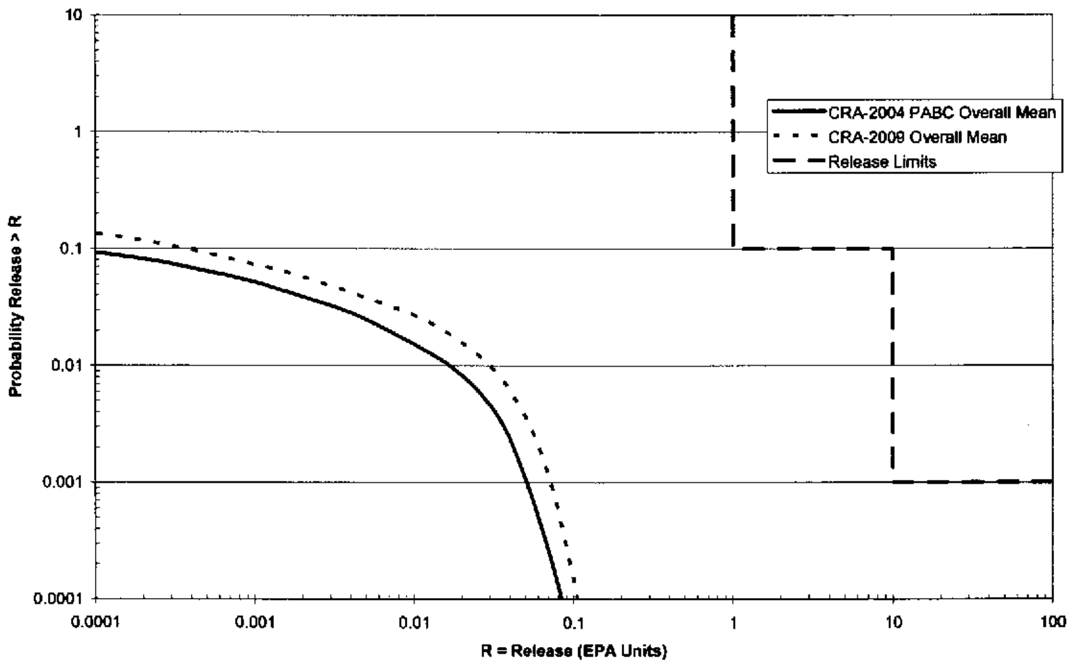

Figure 4.29. Overall Mean CCDFs for Spallings Releases: CRA-2009 PA and CRA-2004 PABC

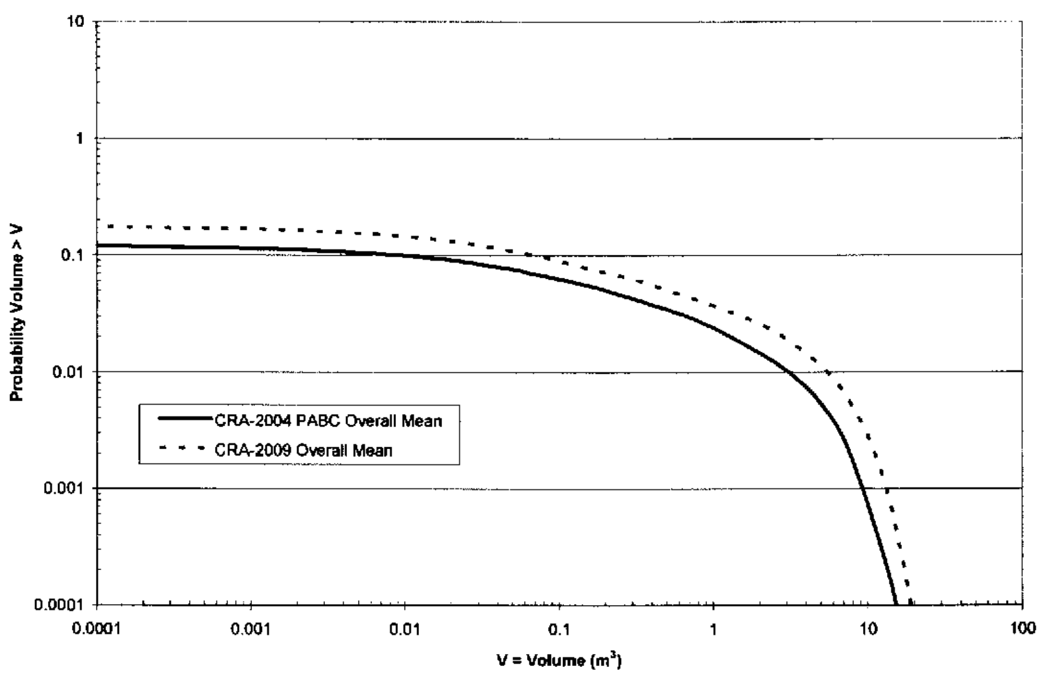

Figure 4.30. Overall Mean CCDFs for Spallings Volumes: CRA-2009 PA and CRA-2004 PABC

4.4 Normalized Direct Brine Releases

Figure 4.31, Figure 4.32, and Figure 4.33 show the CCDFs for DBR releases for replicates 1, 2, and 3 of the CRA-2009 PA. Figure 4.34 compares the mean, 90th, 50th, and 10th percentiles for each replicate's distribution of CCDFs for DBR releases. The mean DBR CCDF is higher than the 90th percentile CCDF at low probability showing that the distribution is strongly right-skewed. Figure 4.35 shows the 95 percent confidence intervals about the overall DBR mean.

Figure 4.36 shows the mean DBR CCDFs for all replicates of the CRA-2009 PA. For comparison, the mean DBR CCDFs for the CRA-2004 PABC are shown in Figure 4.37, and Figure 4.38 shows the overall mean DBR CCDFs from both analyses. CRA-2009 PA mean DBRs increased from the CRA-2004 PABC values, particularly at higher probabilities.

Two of the changes that were made to WIPP PA that affected calculation of DBRs were the modification to the DBR duration and the change to the DRZ porosity variable (Clayton 2008a). Changes and their affects on DBRs are discussed in Clayton (2008b). Clayton (2008b) shows that the DBR volumes were higher on average in the CRA-2009 PA than in the CRA-2004 PABC but that the maximum values in the CRA-2009 PA are lower than in the CRA-2004 PABC. This can be seen in overall mean DBR volumes, Figure 4.39, where there is an increase at most probabilities and a slight decrease at very low probabilities in the CRA-2009 PA compared to the CRA-2004 PABC.

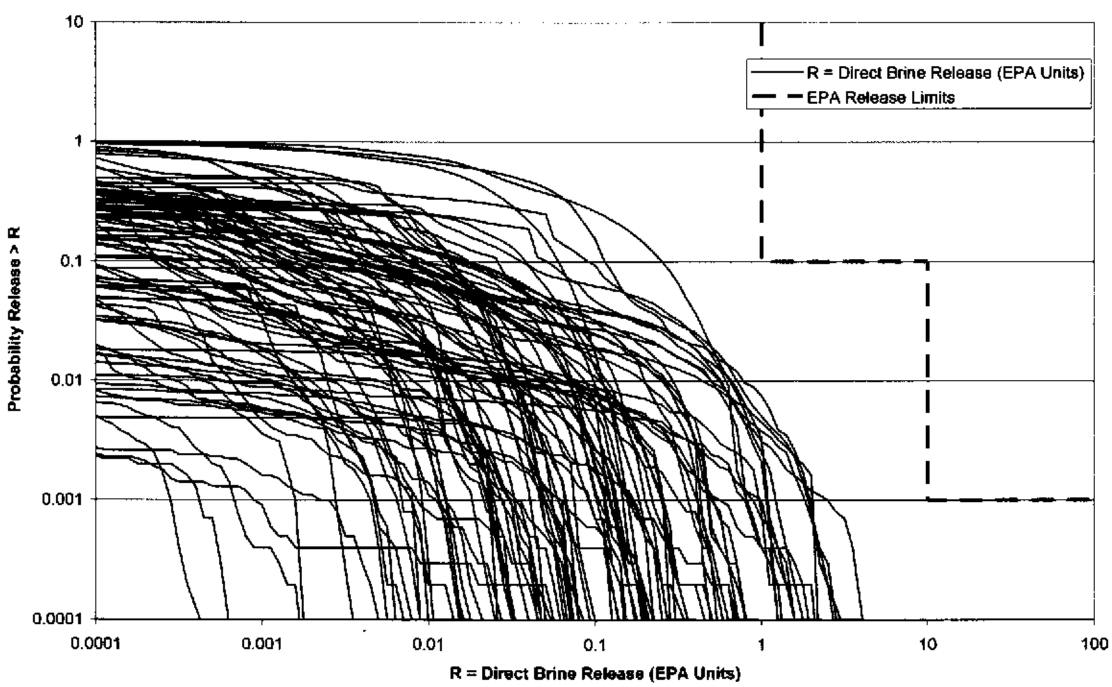

Figure 4.31. DBR Normalized Releases: Replicate 1 of the CRA-2009 PA

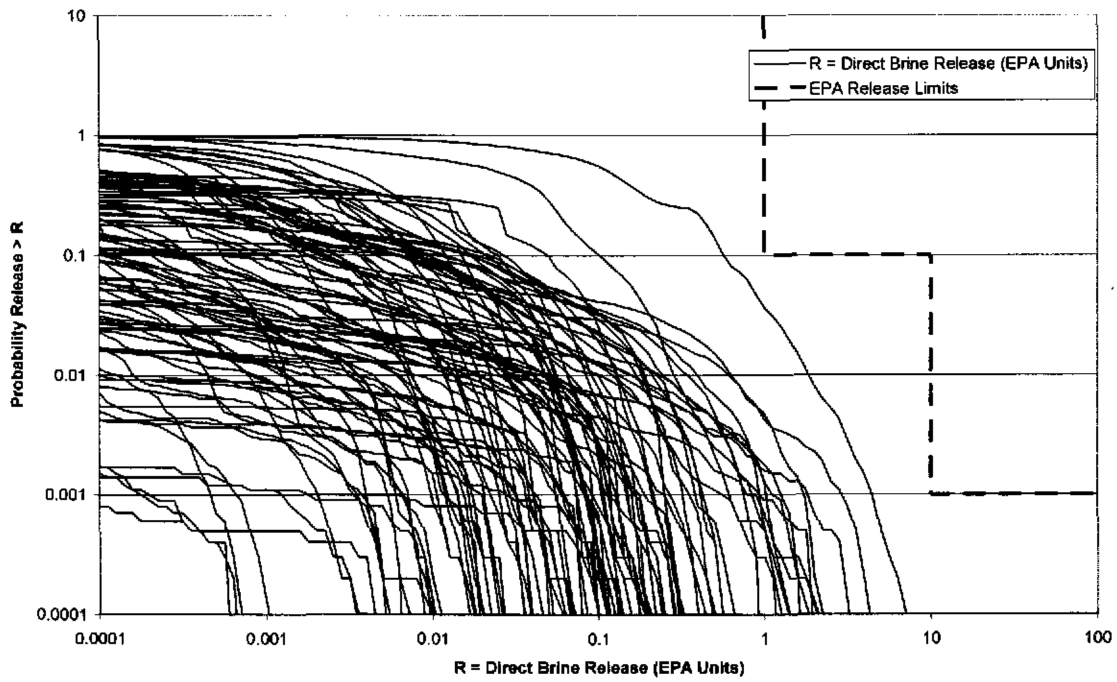

Figure 4.32. DBR Normalized Releases: Replicate 2 of the CRA-2009 PA

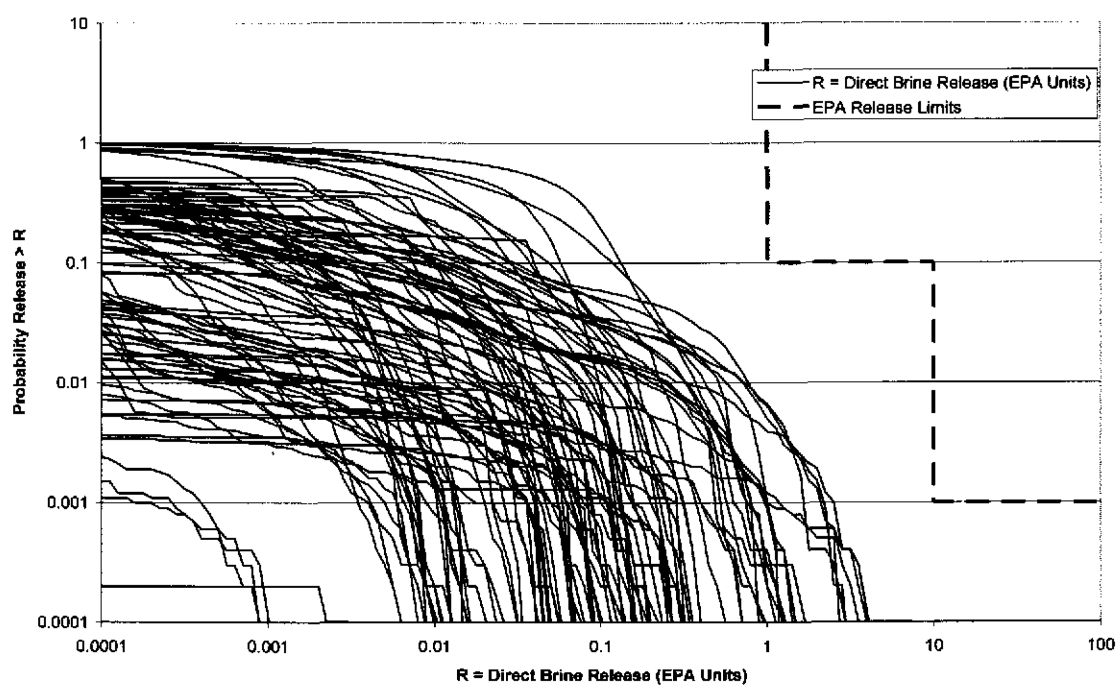

Figure 4.33. DBR Normalized Releases: Replicate 3 of the CRA-2009 PA

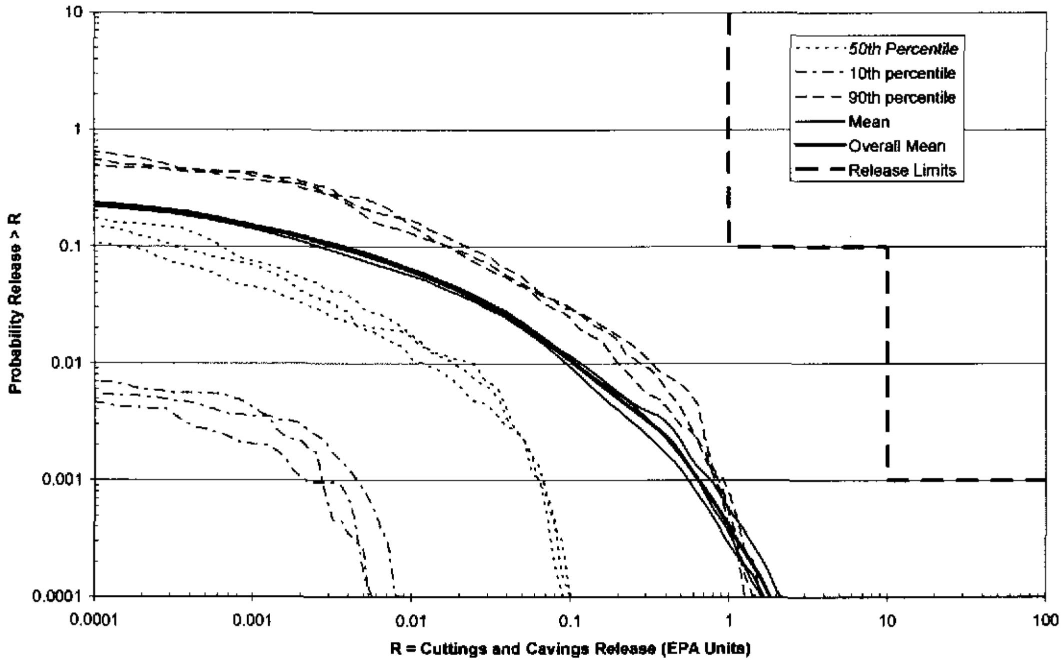

Figure 4.34. Mean and Percentile CCDFs for DBR Normalized Releases: All Replicates of the CRA-2009 PA

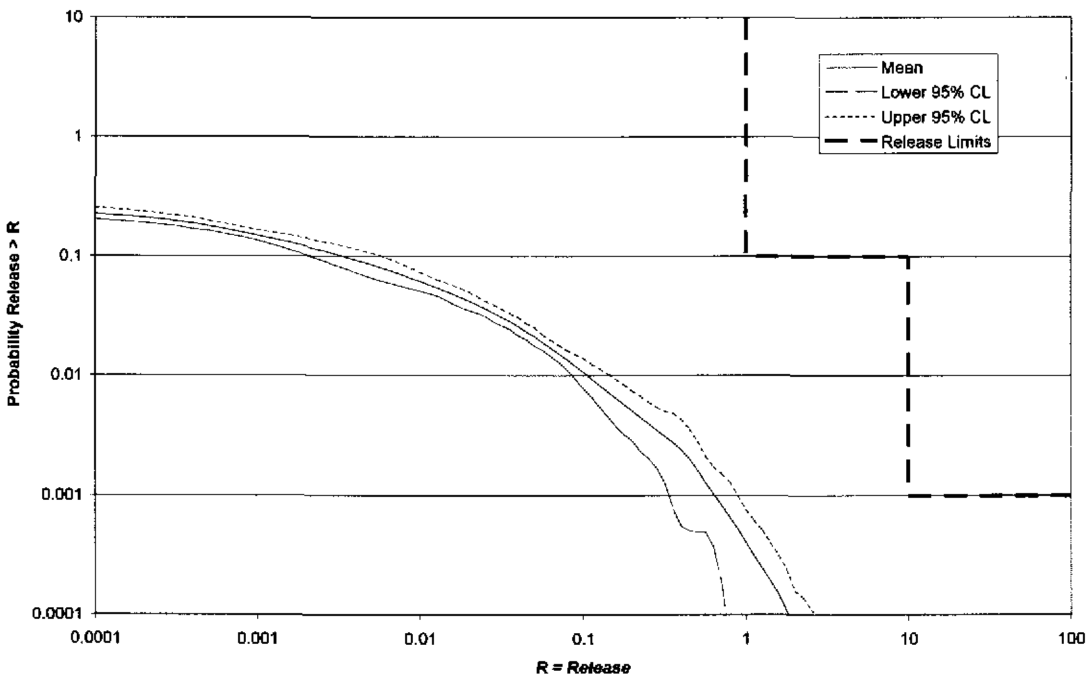

Figure 4.35. Confidence Interval on Overall Mean CCDF for DBR Normalized Releases: CRA-2009 PA

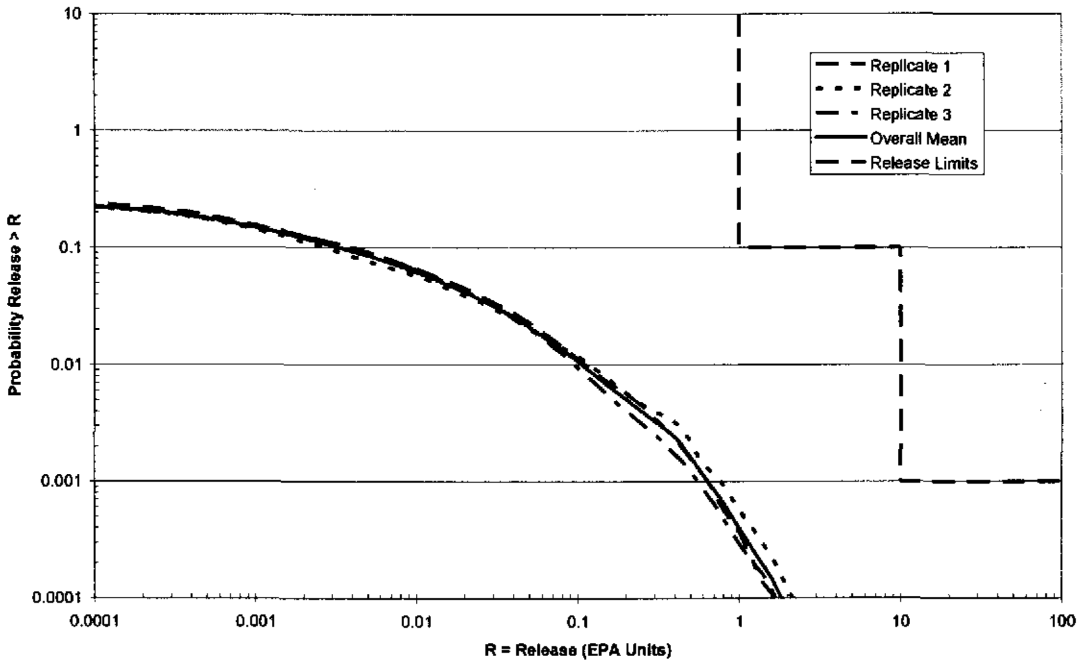

Figure 4.36. Mean CCDFs for DBRs: All Replicates of the CRA-2009 PA

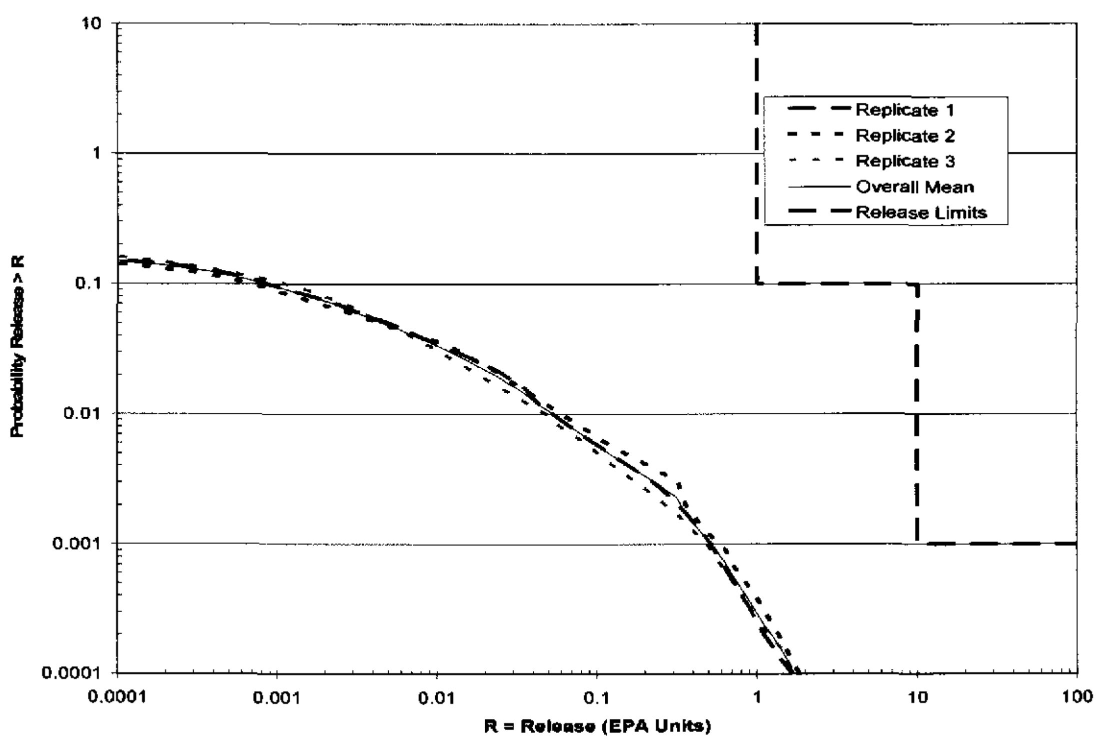

Figure 4.37. Mean CCDFs for DBRs: All Replicates of the CRA-2004 PABC

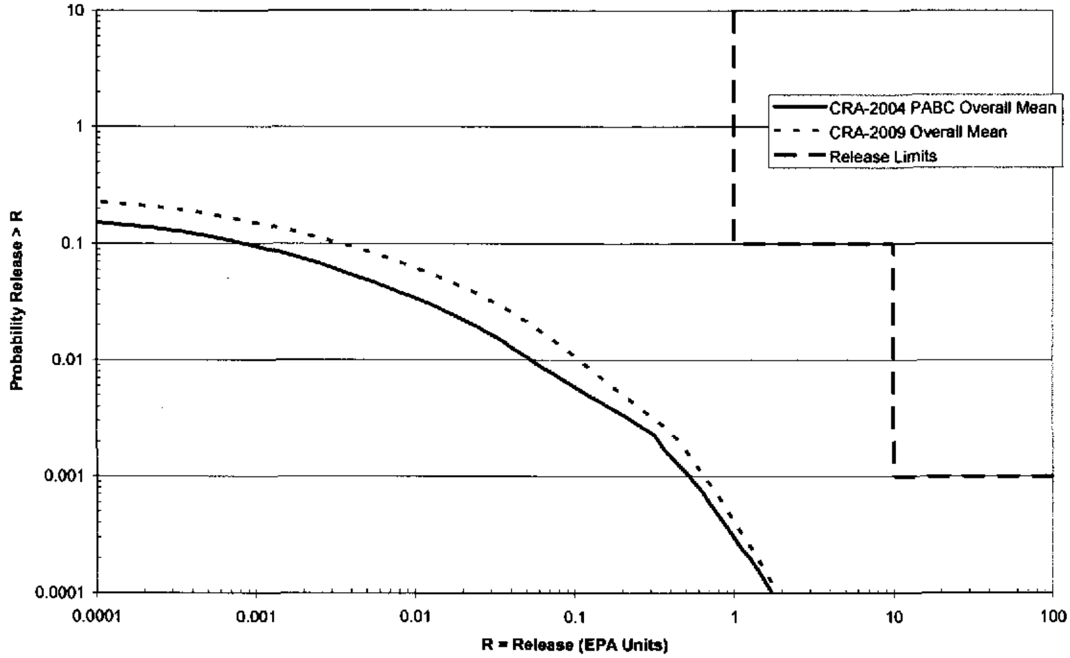

Figure 4.38. Overall Mean CCDFs for DBRs: CRA-2009 PA and CRA-2004 PABC

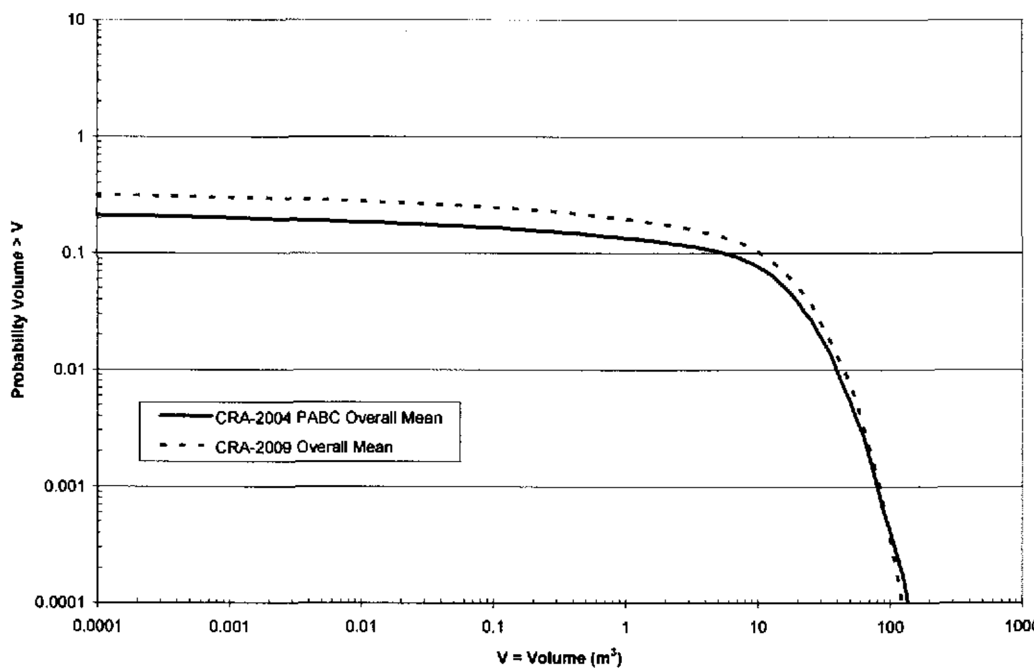

Figure 4.39. Overall Mean CCDFs for DBR Volumes: CRA-2009 PA and CRA-2004 PABC

4.5 Normalized Culebra Transport Releases

Figure 4.40 shows the mean CCDF for normalized releases due to transport through the Culebra for replicate 2 of the CRA-2009 PA and CRA-2004 PABC (No culebra transport releases larger than 10^{-6} EPA units occurred in replicates 1 and 3).

Normalized culebra transport releases for the CRA-2009 PA are qualitatively similar to the CRA-2004 PABC results in that only one replicate exhibits releases that are significantly larger than the numerical error inherent in the transport calculations. Overall, the mean releases for replicate 2 of the two analyses are quite similar and the numbers of vectors that had releases are identical.

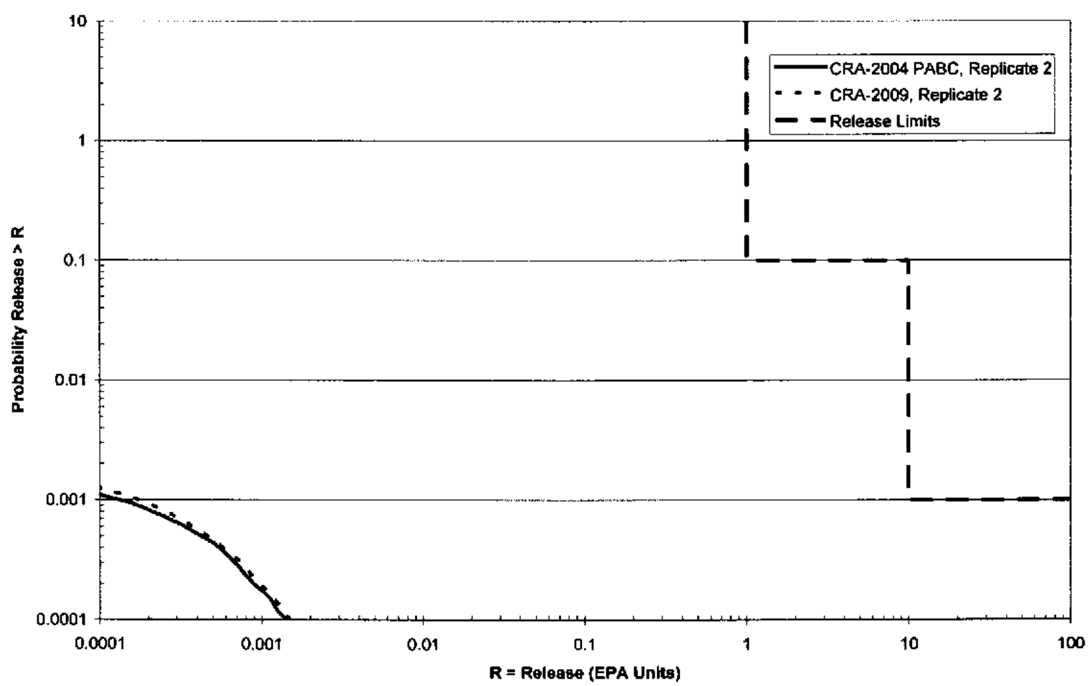

Figure 4.40. Mean CCDF for Releases from the Culebra for Replicate 2 of the CRA-2009 PA and CRA-2004 PABC

5.0 Summary

In summary, despite the changes and corrections made between the CRA-2004 PABC and the CRA-2009 PA, there were no major changes in the overall pattern of releases. Cuttings and cavings and DBR remain the most significant pathways for release of radioactive material to the accessible environment. Release by subsurface transport in the Salado or Culebra continue to make essentially no contribution to total releases. Finally, the resulting CCDFs of both analyses are within regulatory limits.

6.0 References

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