SANDIA NATIONAL LABORATORIES
WASTE ISOLATION PILOT PLANT

ANALYSIS REPORT FOR NORMALIZED RELEASES IN THE 2026 COMPLIANCE RECERTIFICATION APPLICATION PERFORMANCE ASSESSMENT: INTERIM STATE REPOSITORY

REVISION 0

SETH KING (Affiliate) Digitally signed by SETH KING (Affiliate) Date: 2025.10.13 13:56:06 -06'00'

Authentication

Author:	Seth King	Org.	8881
Author:	Sarah Brunell	Org.	8881
Author:	Todd R. Zeitler	Org.	8912
Technical Reviewer:	Clifford Hansen	Org.	8924
Technical Reviewer:	Kate Weiksnar	Org.	8855
QA Reviewer:	Shelly R. Nielsen	Org.	8883
Management Reviewer:	Steve Wagner	Org.	8881

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Executive Summary

The Waste Isolation Pilot Plant (WIPP) was initially certified as a repository consisting of 10 panels, which were excavated for the long-term storage and placement of transuranic waste (U.S. EPA 1998). However, due to operational constraints, the entire volume of the 10 panels is no longer available for waste disposal. In March 2024, the U.S. Department of Energy (DOE) submitted the Replacement Panels Planned Change Request (RPPCR) to the U.S. Environmental Protection Agency (EPA) for approval of waste emplacement in two new panels. These panels, referred to as replacement panels, are located to the west of the existing operations area. The EPA approved the RPPCR in July 2025.

The addition of the two replacement panels is not expected to provide adequate space for the disposal of the allowable waste volume designated for WIPP under the Land Withdrawal Act (LWA); thus, the 12-panel configuration is regarded as an interim state of the repository. The DOE may pursue approval for waste disposal in seven additional panels to accommodate the full allowable volume of waste. This hypothetical 19-panel configuration is considered the anticipated final state of the repository.

The DOE demonstrates compliance with containment requirements as outlined in the Certification Criteria of Title 40 CFR Part 191.13 through performance assessment (PA). PA calculations estimate the probability and consequences of potential radionuclide releases from the repository to the accessible environment over a regulatory period of 10,000 years following facility closure. WIPP PA models are utilized to support the periodic recertification of WIPP.

The 2026 Compliance Recertification Application (CRA-2026) represents the fifth recertification application submitted to the EPA. A PA has been carried out by Sandia National Laboratories to support the DOE's submission of the CRA-2026. The results presented in the CRA-2026 PA are compared to those from the RPPCR PA, the most recent regulatory submission.

This analysis report documents the construction of complementary cumulative distribution functions (CCDFs) of releases for the CRA-2026 PA with the interim state repository. This report details the effects of the changes introduced and incorporated in the CRA-2026 PA that impact potential releases. In comparison to the RPPCR PA, the primary effects of these changes are slightly higher total releases, driven by increased contributions from spallings and direct brine releases, while releases through the Culebra, already small in the RPPCR, are further reduced to a negligible level. These findings confirm that the interim state repository configuration continues to meet containment requirements under 40 CFR Part 191.

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1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico, has been developed by the U.S. Department of Energy (DOE) for the geologic disposal of transuranic (TRU) waste. The containment of TRU waste at WIPP is regulated by the U.S. Environmental Protection Agency (EPA) under Title 40 of the Code of Federal Regulations (CFR), Part 191.

The DOE demonstrates compliance with the containment requirements of 40 CFR 191.13 by means of performance assessment (PA) as described in the Certification Criteria of Title 40 CFR Part 194. Sandia National Laboratories (SNL) conducts PAs at the request of the DOE. The PA calculations estimate the probability and consequences of potential radionuclide releases from the repository to the accessible environment over a regulatory period of 10,000 years following facility closure. The PA models are continuously maintained and updated with new information, which typically leads to refinements and modifications in both the models and their parameters. Additionally, planned changes to the repository and its components necessitate updates to the WIPP PA models.

All previous WIPP certifications have been based on a repository consisting of 10 panels. In March 2024, the DOE submitted the Replacement Panels Planned Change Request (RPPCR) to seek EPA approval for waste emplacement in two new panels, referred to as replacement panels, located to the west of the existing operations area (Bollinger 2024). The EPA approved the RPPCR in July 2025.

The addition of the two replacement panels is not expected to provide sufficient space for the disposal of the allowable waste volume designated for WIPP under the Land Withdrawal Act (LWA). The 12-panel configuration is thus regarded as an interim state of the repository. The DOE may seek approval for waste disposal in up to seven additional panels to accommodate the full allowable volume of waste. This 19-panel configuration is considered the anticipated final state of the repository.

The CRA-2026 is the fifth recertification application for the WIPP submitted by the DOE for EPA approval. The PA executed by SNL in support of the CRA-2026 PA is described in AP-214 (Hansen et al. 2025). This analysis report documents the construction of complementary cumulative distribution functions (CCDFs) of releases for the CRA-2026 PA with the interim state repository, named the CRA26_IS.

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2.0 CHANGES SINCE THE RPPCR

Several changes are incorporated in the CRA26_IS relative to the RPPCR that may impact the potential releases. These changes include:

- The repository design.
- Parameters related to repository dimensions.
- Updates to the Salado flow and transport computational grid.
- The waste inventory.
- Baseline actinide solubilities.
- Solubility uncertainty distributions.
- Colloid concentration parameters for humic and microbial colloids.
- MgO hydration parameters.
- The Salado flow and transport computational grid.
- A new lower bound on capillary pressure in the anhydrite marker beds.
- Revisions to the porosity-permeability parameter distribution.
- The minimum brine volume needed for a DBR.
- The location of the Culebra release point for the replacement waste panels.
- The drilling rate and probabilities of borehole plugging patterns.

Changes listed above are discussed in more detail in the sections that follow.

2.1 Repository Design

This analysis represents the 12-panel interim state repository consisting of ten original and two replacement panels. Figure 1 depicts the interim state repository. The RPPCR considered the anticipated final repository state, which included a total of 19 waste panels and the entire allowable inventory volume.

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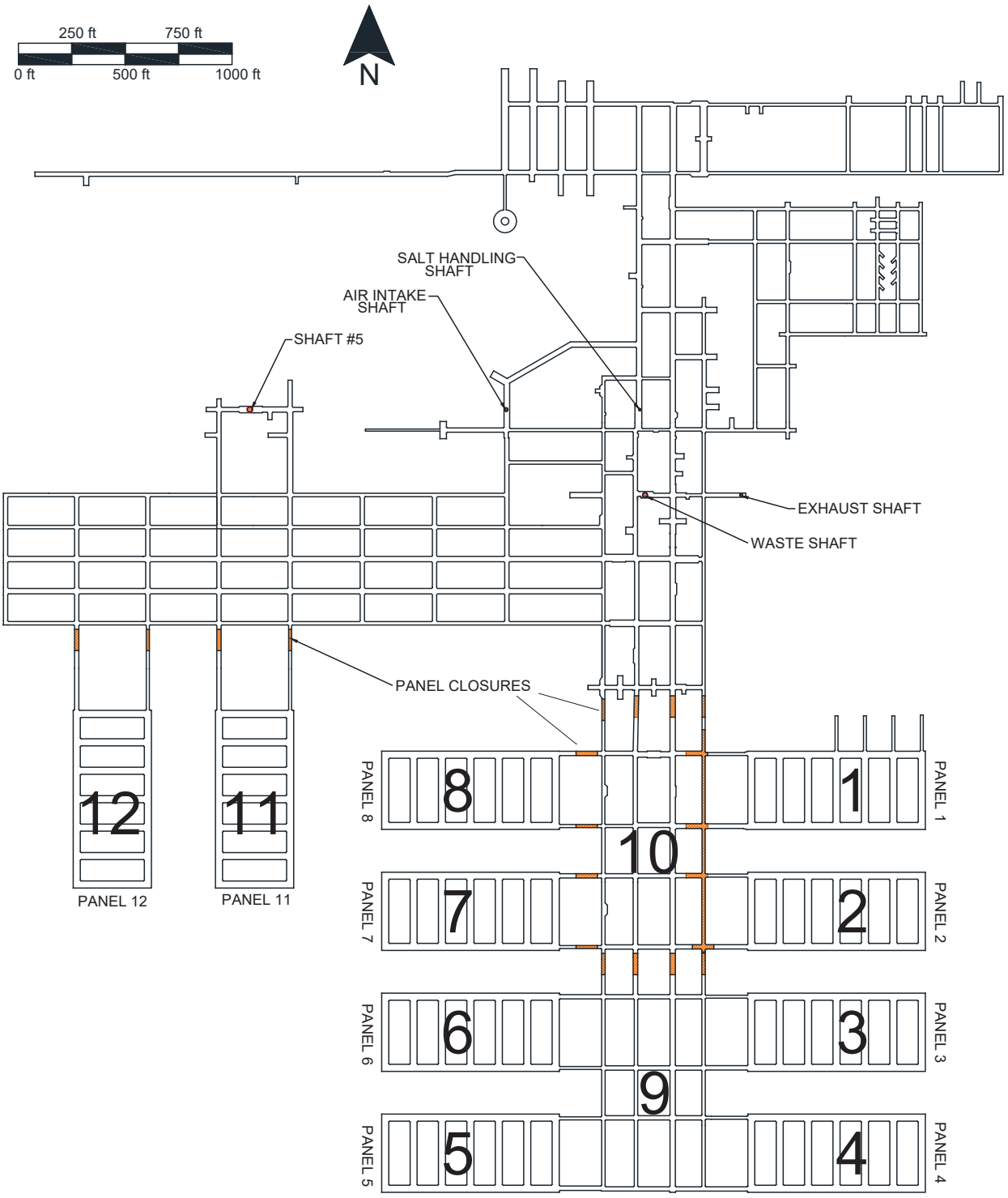


Figure 1. Interim State Repository Layout

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2.2 Parameters Related to Repository Dimensions

The repository design (Section 2.1) requires changes to several parameters describing repository dimensions. Brunell (2025) revises four parameters to align with the dimensions used in the development of the Salado flow and transport grid (Section 0). The parameters include:

- the waste storage volume (REFCON:VREPOS).
- the area of the berm placed over the waste panels (REFCON:ABERM).
- the area allocated for contact-handled (CH) waste disposal (REFCON:AREA_CH).
- the fraction of the repository volume occupied by CH waste (REFCON:FVW).

Although not listed in AP-214 as an anticipated change (Hansen et al. 2025), the area for emplaced remote-handled (RH) waste (REFCON:AREA_RH) is revised by King (2025a) due to the reduced inventory volume used in the CRA26_IS PA calculation (see Section 2.4).

2.3 Updates to the Salado Flow and Transport Computational Grid

Dimensions in the computational grid for the Salado flow (BRAGFLO) and transport (NUTS) calculation are changed to be consistent with the interim state repository dimensions (Section 2.1). Day (2025a) modifies the computational grid based on as-built excavation footprint dimensions within the existing repository, plans for future excavations, and the planned change for alternative panel closure locations for Panels 1 and 2 (Knerr 2020). The Salado flow and transport computational grid is shown in Figure 2.

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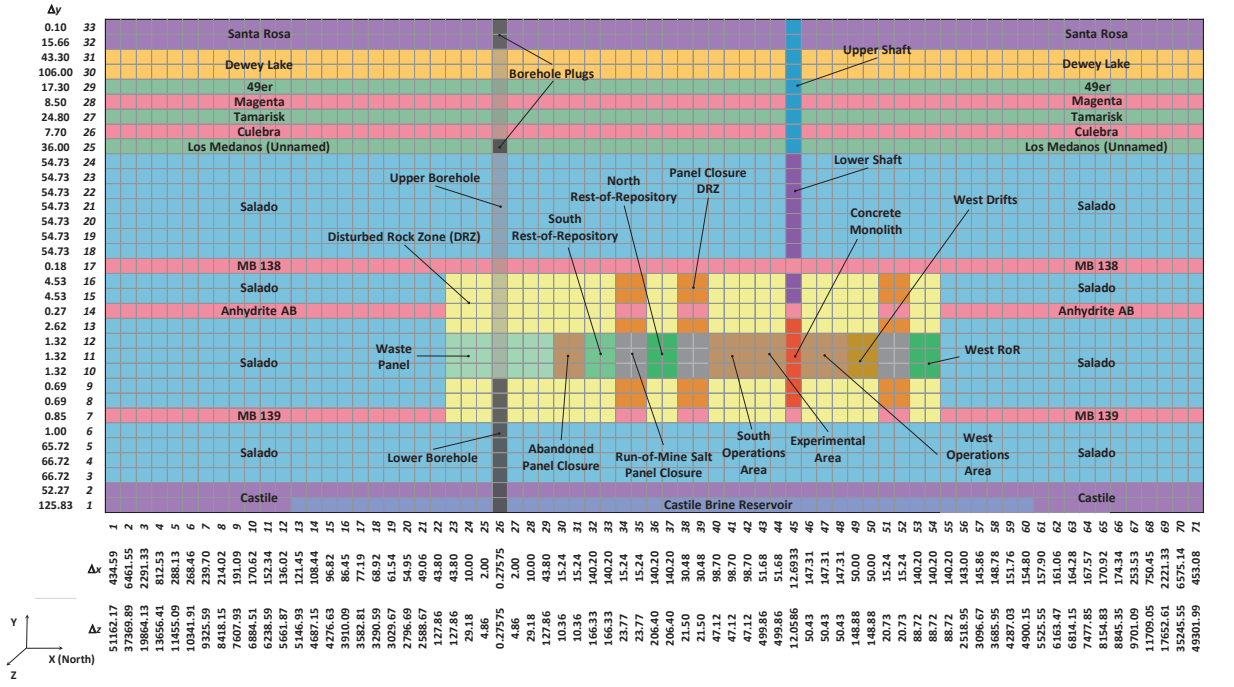


Figure 2. CRA26_IS Salado Flow and Transport Computational Grid

2.4 Waste Inventory

The LWA establishes a statutory limit on the volume of waste that can be disposed of in the WIPP repository, set at 175,564 m^3 (6,200,000 ft^3). Current assessments indicate that the interim state repository will accommodate less waste than the LWA volume. Ward (2025) provided an assessment of the projected waste storage capacity at 157,831.92 m^3, which includes 156,247.12 m^3 of Contact-Handled (CH) waste and 1,584.80 m^3 of Remote-Handled (RH) waste. Based on information collected up to December 31, 2023, the Interim State Performance Assessment Inventory Report – 2024 (ISPAIR-2024; Van Soest 2025) offers an inventory estimate scaled to the waste volume specified by Ward. Kicker (2025) conducted a screening analysis of the inventory estimates for the ISPAIR-2024 to define the inventory-related input parameters for the CRA26_IS PA calculation.

2.5 Baseline Actinide Solubilities

Thermodynamic calculations are used to compute the baseline solubilities for actinides in the +III, +IV, and +V oxidation states in GWB and ERDA-6 brines for five multiples of the minimum brine volume for a DBR event. These baseline solubility calculations account for inventory components and thus are updated to be consistent with inventory estimates. Domski (2025b) reports the baseline solubility values based on the CRA26_IS inventory.

Currently there is no thermodynamic model for WIPP actinides in the +VI oxidation state. The Los Alamos National Laboratory Actinide Chemistry and Repository Science Program (LANL-

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ACRSP) has performed experimental investigations on U(VI) solubility under WIPP-relevant conditions. Based on this experimental work, Kaplan et al. (2025) recommends the solubility of 3×10^{-6} M for actinides in the +VI oxidation state in both Salado and Castile brines used for the CRA26_IS PA calculation.

2.6 Solubility Uncertainty Distributions

Actinide solubility uncertainty distributions, which are independent of the repository inventory, are updated for CRA-2026, as documented in Domski (2025a). A literature review was conducted to identify relevant studies published prior to the CRA-2026 cutoff date. Based on this review, the uncertainty distribution for +III actinide solubilities (SOLMOD3:SOLVAR) is updated. No new literature was found for +IV actinide solubilities; therefore, no update to the +IV solubility uncertainty distribution is made.

2.7 Colloidal Enhancement Parameters

Based on updates to the thermodynamic model and baseline solubility values, Mariner (2025) reevaluated the proportionality constant for humic colloids. Mariner recommends updated values for radionuclides in the +III oxidation state for both Castile and Salado brines (PHUMOX3:PHUMCIM and PHUMOX3:PHUMSIM). Mariner recommends no change to values for radionuclides in the +IV oxidation state.

In previous WIPP PA calculations, microbial colloid enhancement parameters (PROPMIC and CAPMIC) have been specified for each element (parameter materials AM, NP, PU, TH, and U). For the CRA-2026 PA, the microbial enhancement parameters have been specified for each element-oxidation state (materials AM+3, NP+4, NP+5, PU+3, PU+4, TH+4, U+4, and U+6), in order to more closely align to the experimental data used to derive the parameter values. Kaplan et al. (2025) recommended the microbial colloid parameter values used in the CRA26_IS PA.

2.8 MgO Hydration Parameters

The rate of hydration of MgO to form brucite, $Mg(OH)_2$, in the Salado flow model is specified for humid (WAS_AREA:BRUCITEH), Castile brine inundated (WAS_AREA:BRUCITEC), and Salado brine inundated (WAS_AREA:BRUCITES) conditions. Although changes to the MgO hydration rate parameters were not anticipated in AP-214 (Hansen et al. 2025), Nemer (2025) recommends new parameter distributions for the Castile and Salado brine inundated conditions. King (2025b) redefines the recommended distributions to be compatible with the WIPP PA code LHS.

2.9 Lower Bound on Capillary Pressure in the Anhydrite Marker Beds

To improve numerical stability of the Salado flow model when using the modified van Genuchten-Parker capillary pressure function in the anhydrite marker beds, the PA code BRAGFLO was

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updated to Version 8.00 (WIPP PA 2025) to implement a new capillary pressure model which incorporates a lower bound on the capillary pressure. This lower bound is applied when brine saturations exceed one minus the residual gas saturation. Day (2025b) sets the lower bound on capillary pressure to 1 atm (101325 Pa), with the PO_MIN property of the S_MB139, S_ANH_AB, and S_MB138 materials, and applied the new capillary pressure model by setting the CAP_MOD property to 6 for the same materials.

2.10 Porosity-Permeability Parameter Distribution

King (2025b) redefines the distribution for the parameter representing the relationship between porosity and permeability in a run-of-mine salt panel closure system during the secondary time duration (PCS_T2:POR2PERM). Initially defined as a truncated normal distribution, this parameter is revised, along with the MgO hydration parameters (Section 2.8), to a cumulative distribution characterized by discrete data points. This change constitutes a deviation from AP-214 (Hansen et al. 2025).

2.11 Minimum Brine Volume Needed for a DBR

The parameter representing minimum brine volume required for a direct brine release (DBR), GLOBAL:DBRMINBV, is revised (Brunell, 2025) to be consistent with geomechanical modeling that predicts repository porosity and with the repository geometry described in Section 2.1.

2.12 Culebra Release Point Location

For the RPPCR, the Culebra release point CRP 2 was located at the centroid of Panels 11, 12, and 13 in a 19-panel representation of the WIPP repository. For the interim state repository without Panels 13-19, CRP 2 is located at the centroid of Panels 11 and 12 (Wilgus and Brunell 2025).

2.13 Drilling Rate and Borehole Plugging Pattern Probabilities

The DOE surveys drilling activity in the Delaware Basin to meet the requirements established in 40 CFR Part 194.33. Local well operators are surveyed annually to provide the WIPP project with information on drilling practices, encounters with Castile brine, and related data. Survey results through August 2024 are documented in the 2024 Waste Isolation Pilot Plant Delaware Basin Monitoring Annual Report (DBMAR) (U.S. DOE 2025).

Survey results are used to define the frequency of hypothetical drilling intrusions into the WIPP repository (parameter GLOBAL:LAMBDAD) and to determine the probabilities associated with different plugging configurations used to seal a wellbore. The possible configurations are grouped into three plugging patterns for PA purposes; probabilities associated with each pattern are represented by the parameters GLOBAL:ONEPLG, GLOBAL:TWOPLG, and GLOBAL:THREEPLG. The methodology for updating these parameter values is provided in King (2025c).

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2.14 Parameters Not Updated as Anticipated in Analysis Plan AP-214

AP-214 (Hansen et al. 2025) indicates that several parameters were expected to be updated for CRA-2026. Specifically, the parameter specifying the likelihood of low or high oxidation state for an actinide (property OXCUTOFF for materials NP, PU, and U) and the parameters related to mineral and intrinsic colloids (properties CONCMIN and CONCINT for materials AM, NP, PU, TH, and U) were anticipated to undergo revisions. Kaplan et al. (2025) re-examines the basis for these parameter values and recommends the continued use of the RPPCR values. As a result, no changes were made to these parameters for CRA-2026.

3.0 CONCEPTUAL APPROACH FOR THE CRA-2026

The conceptual structure of the CRA-2026 remains the same as for the RPPCR PA. A formal definition of this conceptual structure is found in Appendix PA of U.S. DOE (2019). The CRA-2026 analysis incorporates both aleatory and epistemic uncertainty to evaluate repository performance over a regulatory period of 10,000 years.

Aleatory uncertainty pertains to unknowable future events, such as intrusion times and locations, and is accounted for by simulating random sequences of future events. Epistemic uncertainty concerns parameters that are assumed to have constant values but are uncertain due to a lack of knowledge about the system. Examples include permeability and porosity. Epistemic uncertainty is addressed through Latin Hypercube Sampling (LHS) to generate a sample of parameter values from assigned distributions (King and Zeitler 2025).

For each member of the sample, termed a vector, many futures are randomly generated. Each future comprises a sequence of simulated drilling intrusions and mining events over a 10,000-year period. The total of the various releases at the end of the 10,000-year period yields one data point for total releases; the collection of total release data points over all futures forms one complementary cumulative distribution function (CCDF) of releases. The simulation of many possible realizations, or futures, characterizes aleatory uncertainty in releases, conditional on epistemic uncertainty. The collection of CCDFs represents epistemic uncertainty in releases.

The CRA-2026 Interim State PA (CRA26_IS) calculates results for 300 vectors, divided among three independent replicates of 100 vectors each, to satisfy regulatory requirements for convergence and uncertainty characterization (Helton et al. 1998). The results are presented as CCDFs, which summarize the probability of exceeding specific release levels.

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4.0 RELEASE CONSTRUCTION METHODOLOGY

The release construction methodology builds upon the conceptual framework described in Section 3.0 by detailing the technical process for generating CCDFs. The CCDFGF code assembles results from deterministic models described in Brunell and Kicker (2025), Day and King (2025), Docherty and Kim (2025), Kim and Kicker (2025), Wilgus and Bethune (2025), and Zeitler (2025). Futures constructed by the CCDFGF code are generated through random and repeated sampling of key variables, including:

1. The time between drilling events (derived from the drilling rate);
2. The location of each drilling intrusion (among the waste panels);
3. The waste streams intersected by each drilling intrusion for calculating cuttings and cavings releases;
4. The plug configuration of each borehole;
5. The penetration of a Castile brine reservoir; and
6. The occurrence of mining in the Upper Salado formation.

The CCDFGF code computes CCDFs for total releases and for releases attributable to each of four pathways:

- Cuttings and Cavings Releases: Determined by the quantity of solid waste brought to the surface during a drilling intrusion (Brunell and Kicker 2025; Kim and Kicker 2025).
- Spallings Releases: Calculated based on waste disaggregation during a drilling intrusion (Brunell and Kicker 2025; Kim and Kicker 2025).
- Direct Brine Releases: Occur when brine migrates up through an intruding borehole under conditions of sufficient brine pressure and saturation (Zeitler 2025; Day and King 2025).
- Transport Releases: Result from brine flow through a borehole to the Culebra and out to the land withdrawal boundary (Docherty and Kim 2025; Wilgus and Bethune 2025).

The CCDFs summarize the likelihood of releases across all futures conditional on one vector of parameter values. A mean CCDF is calculated for each replicate as the arithmetic mean of the exceedance probability at each release level. The overall mean CCDF is computed as the arithmetic mean of the three mean CCDFs, with confidence limits calculated using the Student's t-distribution.

4.1 Random Seeds for Realizing Aleatory Uncertainty

The CCDFGF control file contains a seed that initializes the random number generator in the code that determines the sequence of pseudo random numbers used by CCDFGF. This sequence of numbers affects several stochastic parameters, such as the drilling location, penetration of a brine reservoir, and type of plugging pattern, utilized when CCDFGF simulates the drilling of boreholes at the surface of the WIPP repository.

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For the CRA26_IS, the same random seeds for CCDFGF were used as in the RPPCR. This approach allows a vector-by-vector comparison of the results of the RPPCR to those obtained in the CRA26_IS. As the random seeds used to initialize the sampling of the epistemic parameters are also the same for the RPPCR and the CRA26_IS, any differences between the analyses can be attributed solely to the changes in the parameters, modeled processes, and repository reconfiguration, rather than the random seed choices. Random seeds used in the CRA26_IS calculations are specified in the CCDFGF input files ccgf_RPPCR_control_r*n*.inp, where *n* = 1,2,3. Random seeds for the epistemic uncertainty sampling can be found in the PRELHS input files lhs1_CRA26_IS_r*n*_con.inp where n= 1,2,3 (Long 2025).

4.2 Code Execution and Run Control

A full description of the run control for the RPPCR analysis, including names and locations of input and output files, can be found in Long (2025). Calculations are automated by the WIPP PA Run Control System and executed on the WIPP PA HPC/Linux Cluster.

4.3 Sensitivity Analysis

The STEPWISE code is used to conduct a sensitivity analysis to determine the relative influence of the uncertain parameters on the distributions of CCDFs of results. Statistics for the CCDFs of direct releases (cuttings and cavings, spallings, and direct brine), direct brine release volumes, releases to and from the Culebra, and total releases are input into STEPWISE along with the relevant sampled input parameter values. The STEPWISE code relates the input parameter values to the output metrics by performing a stepwise regression analysis on rank-transformed variables and reporting the results in tables. The results from the RPPCR sensitivity analysis (Brunell and Zeitler 2023) are compared to the CRA26_IS results for each release pathway and for total releases. To aid in interpretation and discussion of the results, parameters with ΔR^2 values (the difference in R^2 between the current step and the previous step) greater than 0.05 are highlighted in the tabulated results.

A discussion of stepwise linear multiple regression, determination of significance, regression coefficients, predicted error sum of squares, limitation of the analysis, spurious correlations, and statistical significance can be found in Appendix A (Section 8.0).

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5.0 RESULTS

This section presents the results of the CRA26_IS analysis, including releases from both undisturbed and disturbed performance scenarios. The undisturbed performance scenario, which includes potential radionuclide transport through marker beds and up the shaft, is discussed in Section 5.1. The disturbed performance scenario results are presented for each of the four release pathways—cuttings and cavings, spallings, direct brine releases, and releases through the Culebra—and are followed by total releases in Section 5.6.

The results are presented as CCDFs of releases, which summarize the probability of exceeding specific release levels. These CCDFs are constructed using outputs from deterministic models and reflect both aleatory uncertainty (random future events) and epistemic uncertainty (parameter variability). Sensitivity analyses were conducted to identify the key parameters driving variability in releases, using rank-based regression methods implemented in the STEPWISE code.

5.1 Undisturbed Repository Releases

The undisturbed performance scenario includes two potential release pathways: transport through the marker beds and transport up the shaft. Screening runs using a non-sorbing, highly soluble tracer determine which vectors have the potential to transport radionuclides to the accessible environment. Full Salado transport simulations are then performed for all screened-in vectors that have the potential to transport radionuclides to the accessible environment.

As in the RPPCR, no vectors in the CRA26_IS exceeded the screening criterion for the undisturbed repository (Docherty and Kim 2025). Consequently, no vectors show radionuclide transport through the Salado to the land withdrawal boundary (LWB) in the CRA26_IS. Similarly, no vectors show radionuclide transport through the shafts to the Culebra. These results confirm that radionuclide transport under undisturbed conditions is effectively zero, and no releases from the undisturbed repository are calculated for the CRA26_IS.

5.2 Cuttings and Cavings

5.2.1 Cuttings and Cavings Releases

For each intrusion, cuttings and cavings releases are calculated from the cuttings volume, cavings volume, and the radionuclide concentration of the intersected waste streams. Figure 3 shows the mean cuttings and cavings volume for Replicate 1.

The cuttings and cavings volumes for individual boreholes reported by Brunell and Kicker (2025) in the CRA26_IS are unchanged from the RPPCR. However, changes in repository footprint and the increased drilling rate impact the number of boreholes per future in the CRA26_IS compared to the RPPCR. With the smaller repository footprint in the CRA26_IS compared to the RPPCR, a smaller number of boreholes are realized and the cutting and cavings volumes for a future are smaller (Figure 3). The volumes represented in Figure 3 are the excavated volumes rather than the

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waste volumes. The waste volume in cuttings and cavings releases is computed by multiplying the excavated volume by either the fraction of the repository volume that contains contact-handled waste, REFCON:FVW (FVW), or the fraction of the repository volume that contains remote-handled waste, REFCON:FVRW (FVRW). A change in either FVW or FVRW will therefore cause a proportional change in waste release volumes from each intrusion. Figure 4 shows the estimated mean cuttings and cavings release waste volumes for RPPCR and CRA26_IS, i.e., release volumes scaled by their respective values of FVW (0.197 for RPPCR and 0.279 for CRA26_IS; see Section 2.2). The similarity in waste release volumes between the RPPCR and CRA26_IS, despite the larger footprint and greater number of boreholes in the RPPCR, is primarily due to the higher fraction of the repository volume occupied by contact-handled waste (FVW) in the CRA26_IS, which scales the waste release volumes upward and offsets the impact of fewer boreholes. Note that the CCDFGF code outputs a combined volume for releases of CH and RH waste. The combined volume of CH and RH waste has been scaled by the value of FVW in Figure 4 for comparison purposes only.

Figure 5, Figure 6, and Figure 7 show the CCDFs for cuttings and cavings releases, with the mean CCDF, for Replicate 1, Replicate 2, and Replicate 3 of the CRA26_IS. Figure 8 shows the overall mean, with the 95% confidence interval, for the RPPCR and CRA26_IS. Table 5-1 provides statistics on the overall mean cuttings and cavings release at the compliance limit probabilities.

Despite the cuttings and cavings waste release volumes being nearly equal between the RPPCR and CRA26_IS, cuttings and cavings releases in the CRA26_IS have increased for probabilities below roughly 60%. Kim and Kicker (2025) show that due to the shift toward longer half-lived radionuclides in the waste inventory, CRA26_IS has higher waste activity concentrations at most times than the RPPCR. The higher releases observed below the 60% probability level are attributed to the likelihood that a future includes a cuttings and cavings intrusion into the high activity concentration surplus plutonium waste streams (SR-KAC-PuOx-2, SR-KAC-PuOx) (Kim and Kicker 2025). These waste streams contribute significantly to the elevated radionuclide activity concentrations in the CRA26_IS inventory, amplifying releases at lower probabilities.

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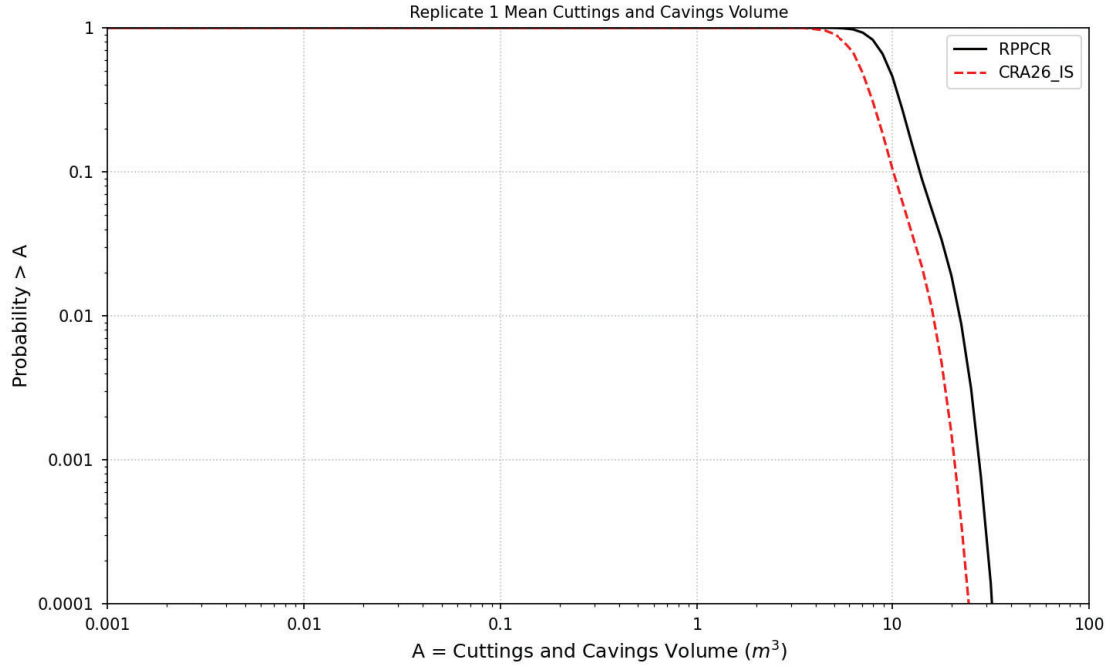


Figure 3. Mean Cuttings and Cavings Volume for Replicate 1

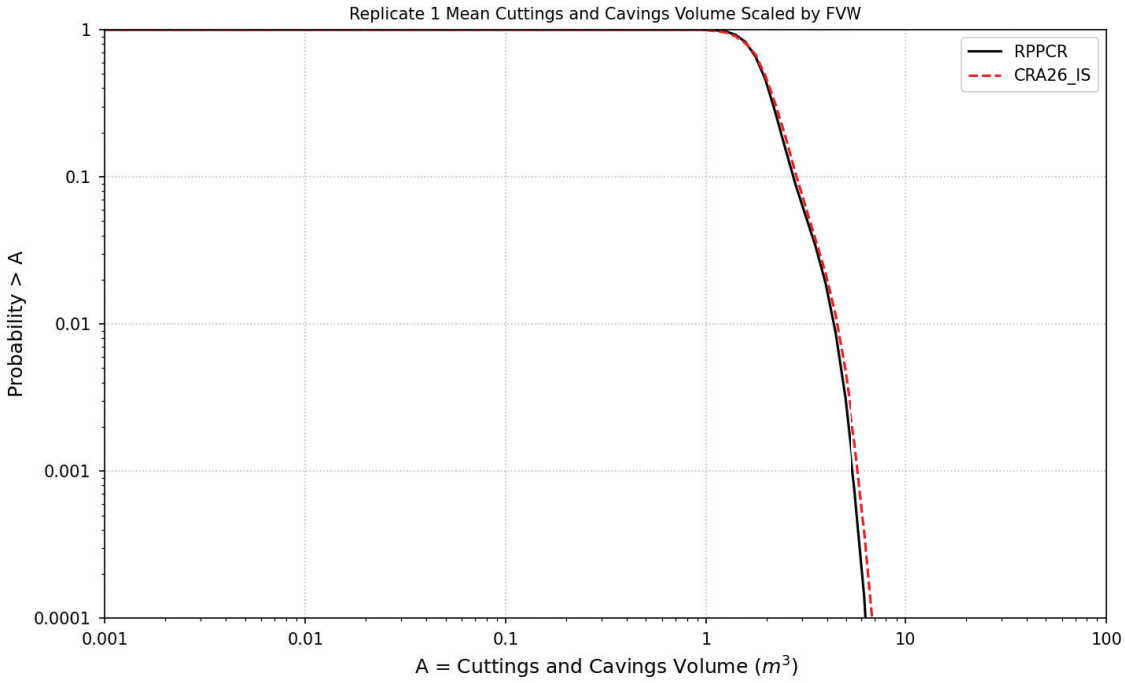


Figure 4. Mean Cuttings and Cavings Volume Scaled by the FVW Factor for Replicate 1

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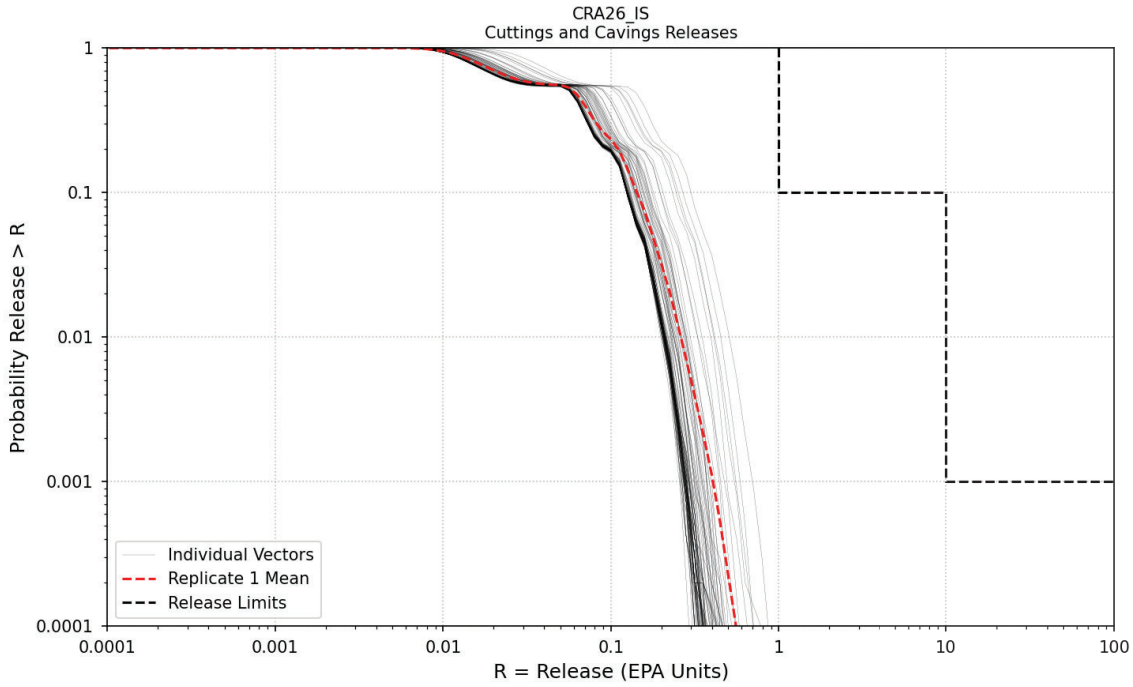


Figure 5. Cuttings and Cavings Releases for Replicate 1 of the CRA26_IS

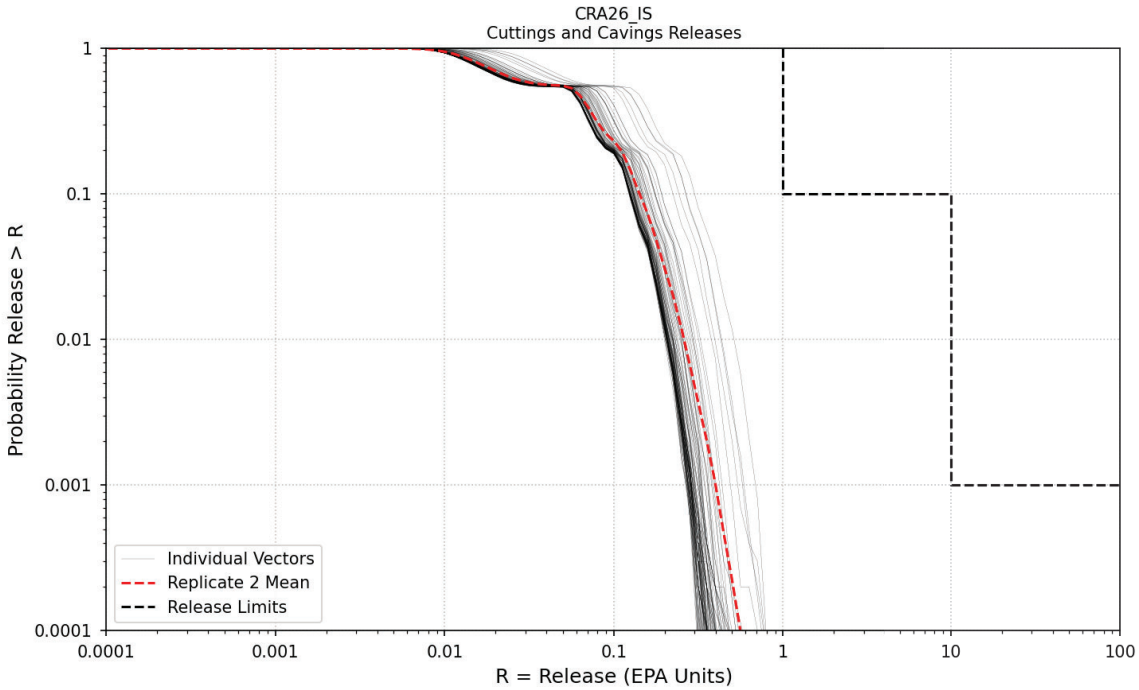


Figure 6. Cuttings and Cavings Releases for Replicate 2 of the CRA26_IS

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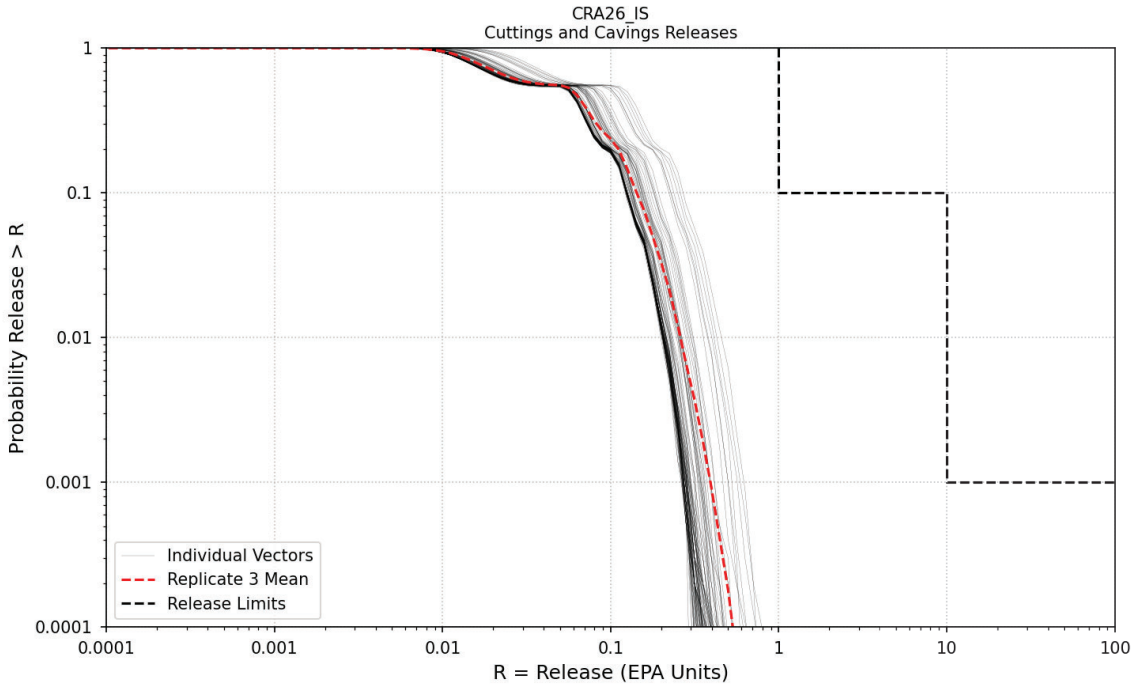


Figure 7. Cuttings and Cavings Releases for Replicate 3 of the CRA26_IS

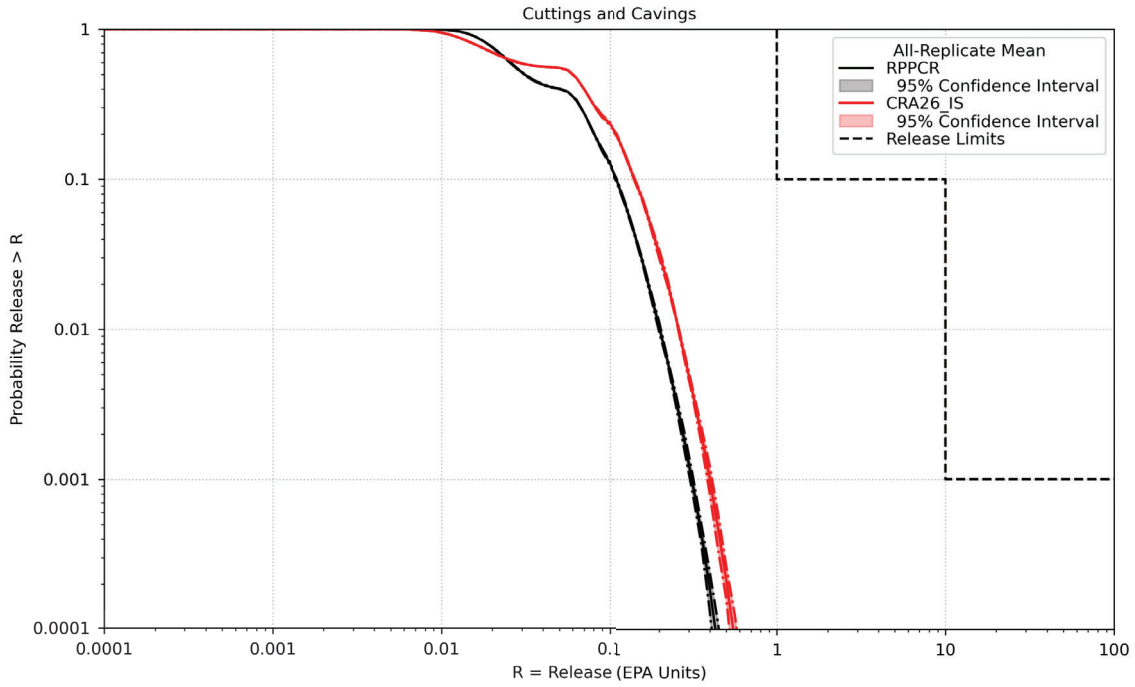


Figure 8. Overall Mean Cuttings and Cavings Release

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Table 5-1. Statistics on the Overall Mean Cuttings and Cavings Release

Analysis	P(R)>0.1 Lower CI (EPA Units)	P(R)>0.1 Mean (EPA Units)	P(R)>0.1 Upper CI (EPA Units)	P(R)>0.1 Release Limit (EPA Units)	P(R)>0.001 Lower CI (EPA Units)	P(R)>0.001 Mean (EPA Units)	P(R)>0.001 Upper CI (EPA Units)	P(R)>0.001 Release Limit (EPA Units)
RPPCR	0.1100	0.1111	0.1122	1	0.3074	0.3135	0.3204	10
CRA26_IS	0.1417	0.1429	0.1442	1	0.3898	0.4007	0.4164	10

5.2.2 Sensitivity Analysis for Cuttings and Cavings Releases

The sensitivity analysis for cuttings and cavings releases was conducted using the STEPWISE code to identify the relative influence of uncertain parameters on the means of the CCDFs of releases. Table 5-2, Table 5-3, and Table 5-4 summarize the stepwise ranked regression analysis results for Replicates 1, 2, and 3 of the RPPCR and CRA26_IS.

Across all replicates, BOREHOLE:TAUFAIL (effective shear strength for erosion) is the dominant parameter controlling variability in cuttings and cavings releases. BOREHOLE:TAUFAIL explains between 57% and 68% of the variability in the RPPCR and between 60% and 65% in the CRA26_IS. Figure 9 illustrates the negative correlation between BOREHOLE:TAUFAIL and mean cuttings and cavings releases. Lower values of BOREHOLE:TAUFAIL correspond to higher release volumes.

BOREHOLE:DOMEGA (drill string angular velocity) is the second most influential parameter across all replicates. BOREHOLE:DOMEGA accounts for 4% to 10% of the variability in the RPPCR and 6% to 13% in the CRA26_IS.

Other parameters appearing in the RPPCR sensitivity analysis, such as PCS_T1:PRMX_LOG (log of intrinsic permeability for the panel closure system during the initial time period), PCS_T2:POR2PERM (distribution used to calculate permeability from sampled porosity values for the panel closure system during the second time period), and SPALLMOD:PARTDIAM (particle diameter for disaggregated waste), are spurious correlations. These parameters are not part of the cuttings and cavings calculation and were excluded from the CRA26_IS sensitivity analysis. Their presence in the RPPCR results reflects statistical artifacts rather than functional relationships.

Overall, the sensitivity analysis results for CRA26_IS confirm that BOREHOLE:TAUFAIL and BOREHOLE:DOMEGA are the primary drivers of variability in cuttings and cavings releases.

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Table 5-2. Stepwise Ranked Regression Analysis for Mean Cuttings and Cavings Releases for Replicate 1 of the RPPCR and CRA26_IS

	RPPCR Replicate 1			CRA26_IS Replicate 1		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	BOREHOLE:TAUFAIL	0.57	-0.76	BOREHOLE:TAUFAIL	0.60	-0.77
2	BOREHOLE:DOMEGA	0.67	0.31	BOREHOLE:DOMEGA	0.73	0.36
3	PCS_T1:PRMX_LOG	0.70	-0.15			
4	CASTILER:COMP_RCK	0.71	-0.12			
5	PCS_T3:POROSITY	0.72	0.12			
6	SHFTL_T2:PRMX_LOG	0.73	0.11			

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

Table 5-3. Stepwise Ranked Regression Analysis for Mean Cuttings and Cavings Releases for Replicate 2 of the RPPCR and CRA26_IS

	RPPCR Replicate 2			CRA26_IS Replicate 2		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	BOREHOLE:TAUFAIL	0.68	-0.83	BOREHOLE:TAUFAIL	0.65	-0.81
2	BOREHOLE:DOMEGA	0.77	0.30	BOREHOLE:DOMEGA	0.74	0.30
3	PCS_T2:POR2PERM	0.78	0.10			

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

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Table 5-4. Stepwise Ranked Regression Analysis for Mean Cuttings and Cavings Releases for Replicate 3 of the RPPCR and CRA26_IS

	RPPCR Replicate 3			CRA26_IS Replicate 3		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	BOREHOLE:TAUFAIL	0.64	-0.79	BOREHOLE:TAUFAIL	0.61	-0.77
2	BOREHOLE:DOMEGA	0.68	0.19	BOREHOLE:DOMEGA	0.67	0.23
3	SPALLMOD:PARTDIAM	0.70	-0.14			
4	STEEL:HUMCORR	0.71	0.13			

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

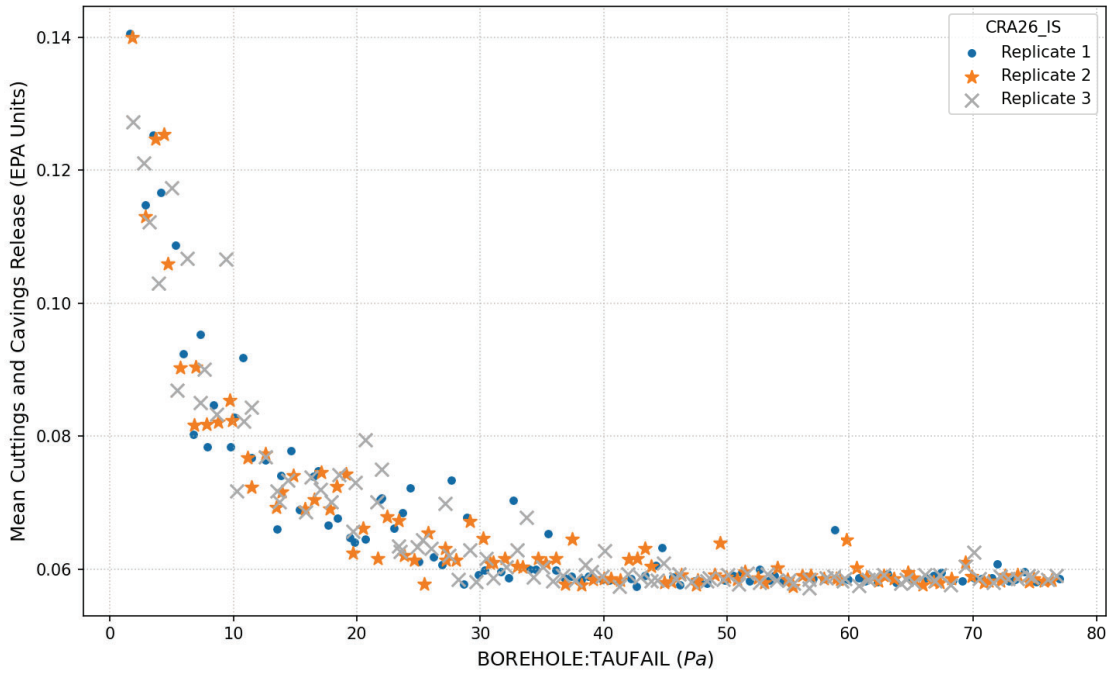


Figure 9. BOREHOLE:TAUFAIL versus Mean Cuttings and Cavings Releases for CRA26_IS

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5.3 Spallings

5.3.1 Spallings Releases

Spallings releases are calculated based on spallings volumes and the average waste activity concentration in CH waste. Figure 10 shows the mean spallings volume for Replicate 1 of the CRA26_IS and RPPCR, while Figure 11 presents the mean spallings volume scaled by the REFCON:FVW factor for Replicate 1.

The spallings results for individual boreholes reported by Brunell and Kicker (2025) for the CRA26_IS show minimal differences from those in the RPPCR. Changes in repository footprint and drilling rate affect the number of boreholes per future in the CRA26_IS compared to the RPPCR. With the smaller repository footprint in the CRA26_IS, fewer boreholes are realized, resulting in smaller spallings volumes overall (Figure 10). When scaled by the REFCON:FVW factor (0.279 for CRA26_IS and 0.197 for RPPCR), the waste release volumes for spallings in the CRA26_IS are brought closer to those observed in the RPPCR (Figure 11). Changes in repository pressure conditions are not seen as a major driver in changes to spallings releases, as the waste volumes spalled are nearly equal between the CRA26_IS and RPPCR.

Figure 12, Figure 13, and Figure 14 show the CCDFs for spallings releases for Replicates 1, 2, and 3 of the CRA26_IS, respectively. Figure 15 presents the overall mean spallings releases, along with the 95% confidence interval, for the CRA26_IS and RPPCR. Table 5-5 provides statistics on the overall mean spallings release at the compliance limit probabilities. The values in Table 5-5 indicate an increase in spallings releases for the CRA26_IS at both compliance limit probabilities. This increase is mainly attributed to the increase in waste activity concentration, as described in Brunell and Kicker (2025).

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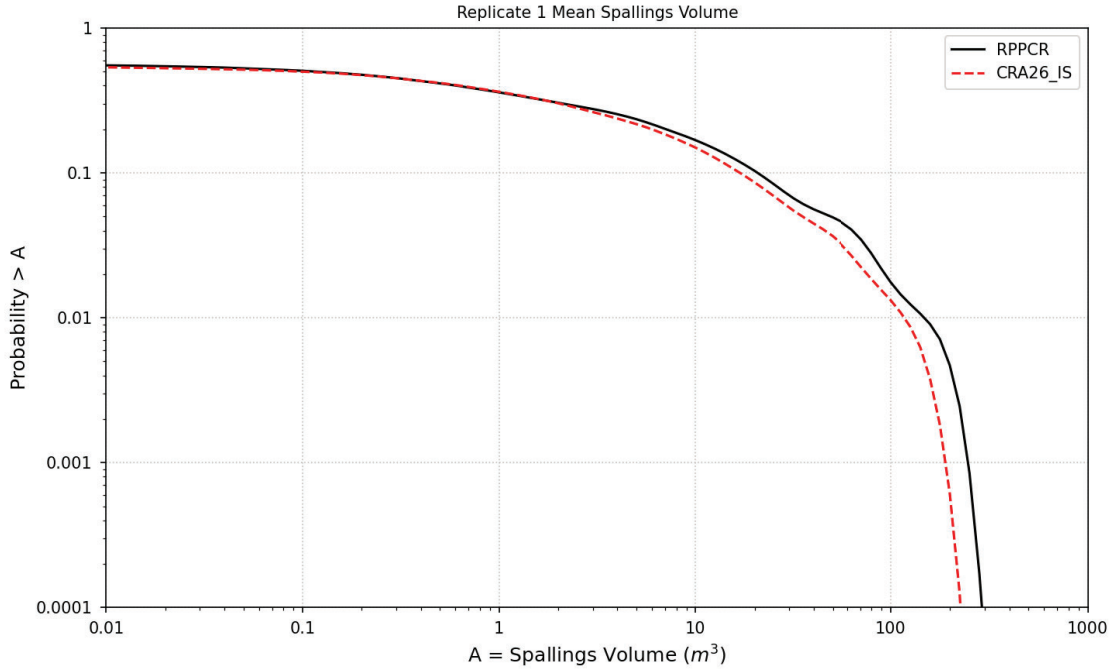


Figure 10. Mean Spallings Volume for Replicate 1

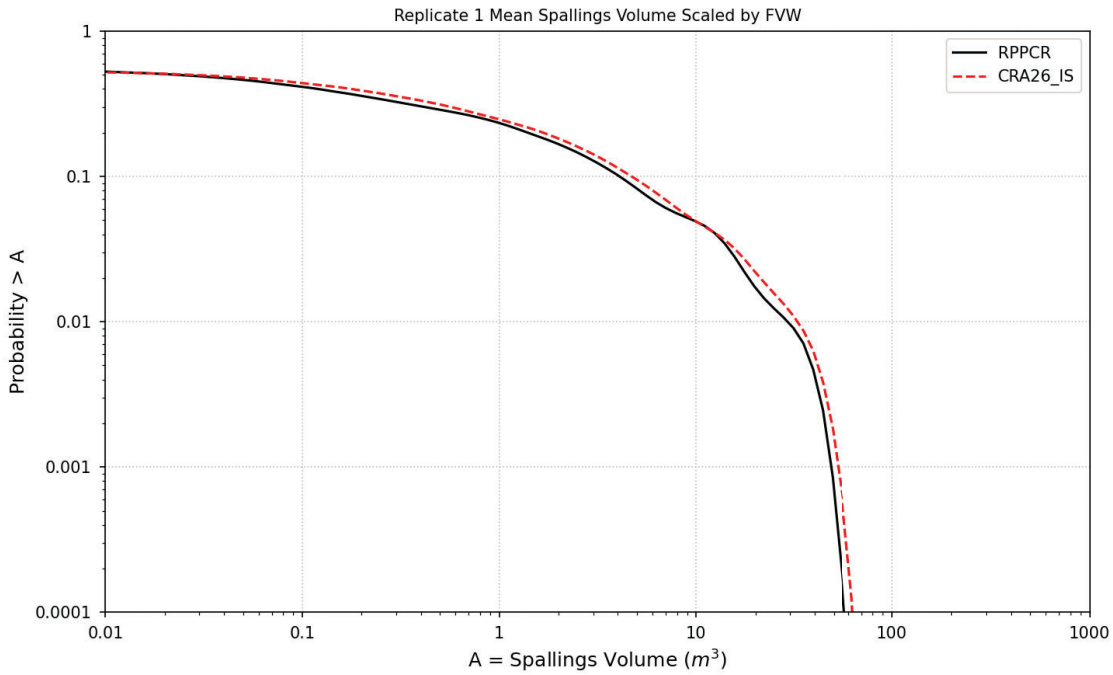


Figure 11. Mean Spallings Volume Scaled by the FVW Factor for Replicate 1

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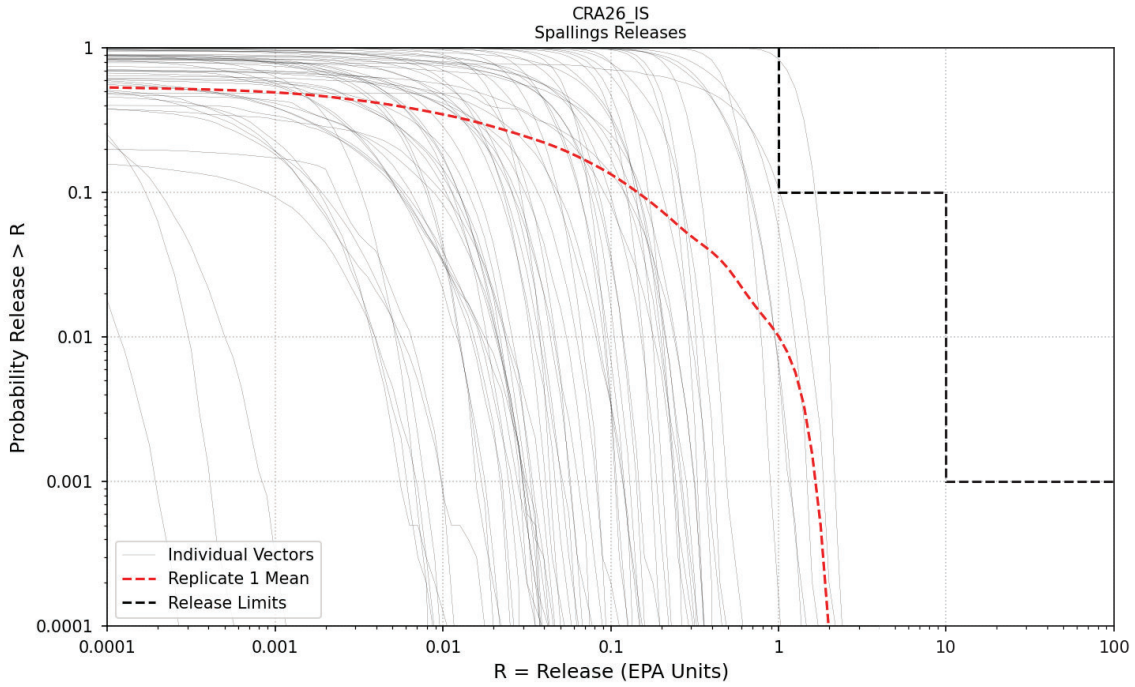


Figure 12. Spallings Releases for Replicate 1 of the CRA26_IS

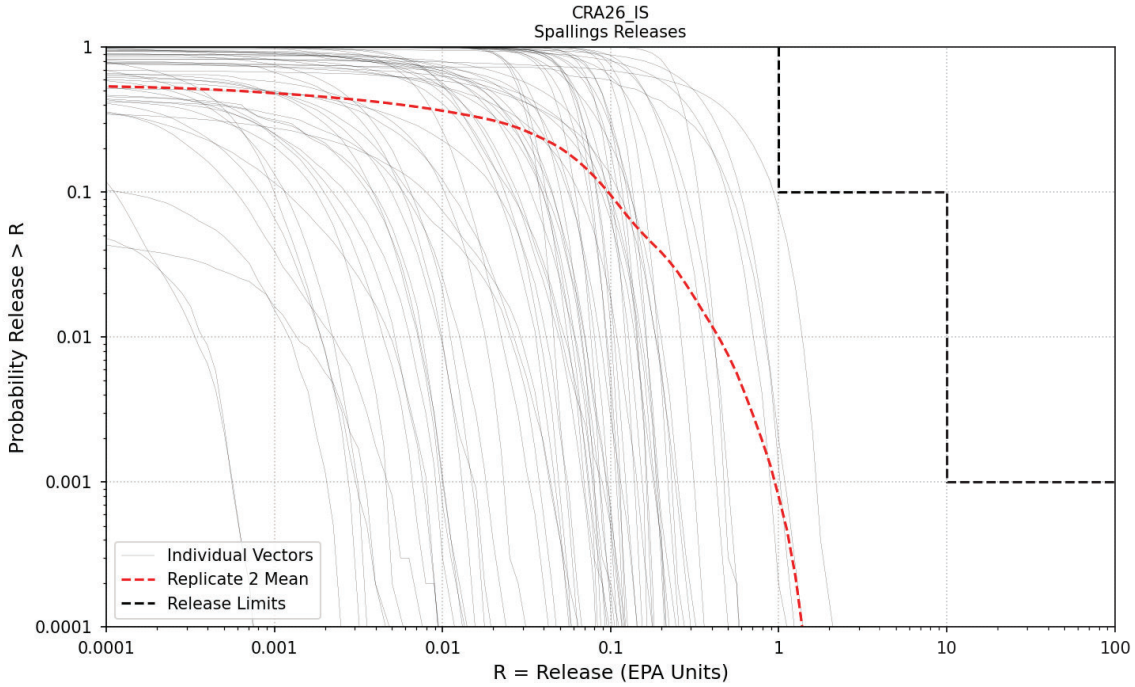


Figure 13. Spallings Releases for Replicate 2 of the CRA26_IS

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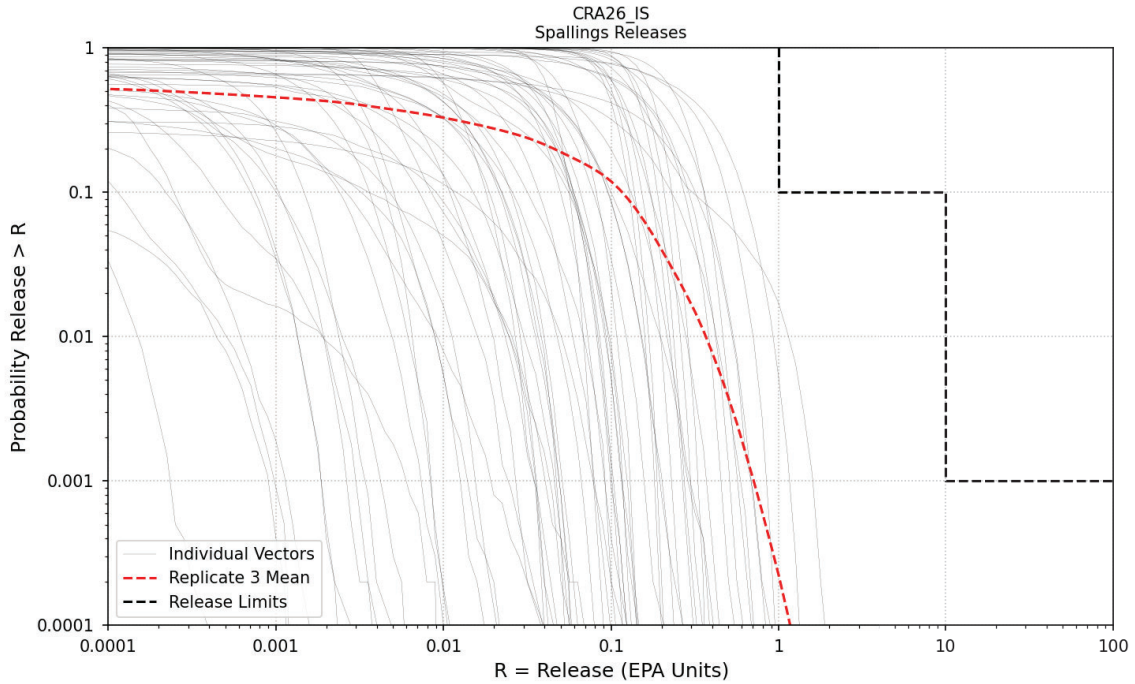


Figure 14. Spallings Releases for Replicate 3 of the CRA26_IS

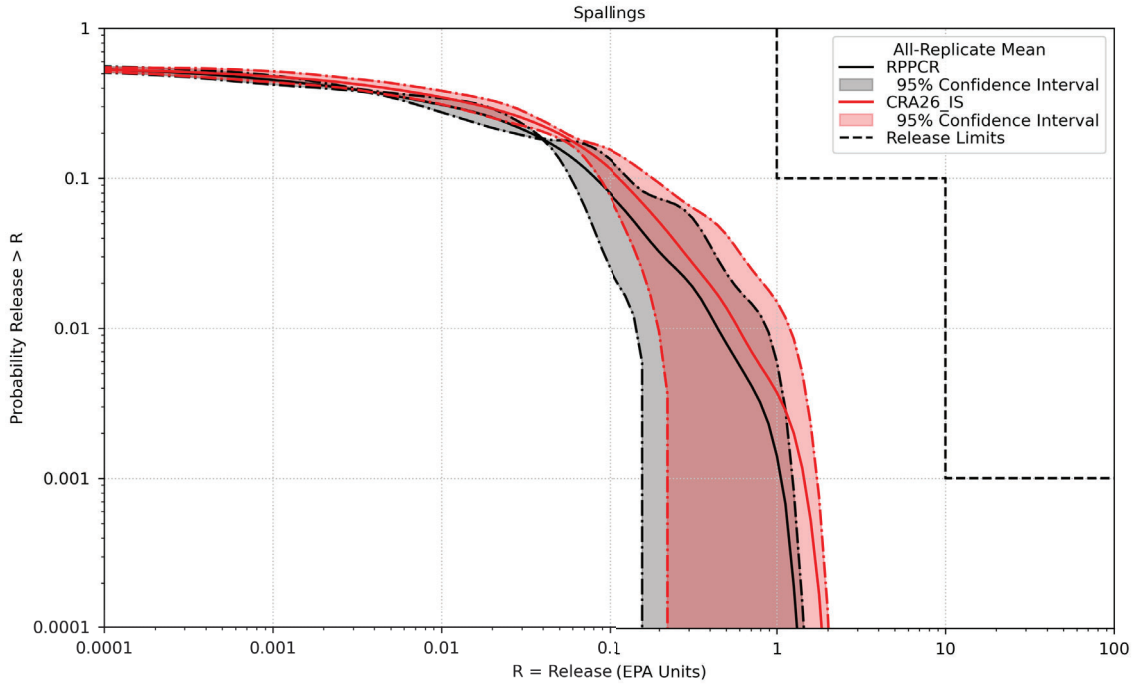


Figure 15. Overall Mean Spallings Releases

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Table 5-5. Statistics on the Overall Mean Spallings Release

Analysis	P(R)>0.1 Lower CI (EPA Units)	P(R)>0.1 Mean (EPA Units)	P(R)>0.1 Upper CI (EPA Units)	P(R)>0.1 Release Limit (EPA Units)	P(R)>0.001 Lower CI (EPA Units)	P(R)>0.001 Mean (EPA Units)	P(R)>0.001 Upper CI (EPA Units)	P(R)>0.001 Release Limit (EPA Units)
RPPCR	0.0587	0.0822	0.1312	1	0.1712	1.0674	1.2469	10
CRA26_IS	0.0871	0.1153	0.1833	1	0.2389	1.4579	1.7470	10

5.3.2 Sensitivity Analysis for Spallings Releases

The sensitivity analysis for spallings releases was conducted using the STEPWISE code to identify the relative influence of uncertain parameters on the means of the CCDFs of releases. Table 5-6, Table 5-7, and Table 5-8 summarize the stepwise ranked regression analysis results for Replicates 1, 2, and 3 of the RPPCR and CRA26_IS.

Across all replicates, SPALLMOD:PARTDIAM (particle diameter for disaggregated waste) and SPALLMOD:REPIPERM (waste permeability) are consistently the dominant parameters controlling variability in spallings releases. SPALLMOD:PARTDIAM explains between 11% and 23% of the variability in the RPPCR and between 13% and 29% in the CRA26_IS. SPALLMOD:REPIPERM accounts for 13% to 22% of the variability in the RPPCR and 11% to 29% in the CRA26_IS. These results highlight the importance of waste permeability and particle size in determining spallings releases. Figure 16 and Figure 17 illustrate the negative correlation between mean spallings releases and SPALLMOD:REPIPERM and SPALLMOD:PARTDIAM, respectively. Sampling small values of SPALLMOD:REPIPERM and SPALLMOD:PARTDIAM are necessary conditions for large mean spallings releases.

S_HALITE:POROSITY (intact halite porosity) also plays a significant role, explaining 14% to 20% of the variability in the RPPCR and 9% to 16% in the CRA26_IS. The influence of halite porosity reflects its impact on repository pressures, which is a key factor in spallings releases.

Other parameters, such as DRZ_PCS:PRMX_LOG (log of intrinsic permeability for the disturbed rock zone above the panel closure system) and CASTILER:PRESSURE (initial brine pore pressure in the Castile), contribute less to the variability in spallings releases but appear consistently across replicates. Their influence is generally smaller in the CRA26_IS compared to the RPPCR, reflecting changes in repository configuration and waste inventory.

Overall, the sensitivity analysis results demonstrate that SPALLMOD:PARTDIAM, SPALLMOD:REPIPERM, and S_HALITE:POROSITY are the primary drivers of variability in spallings releases for both the RPPCR and CRA26_IS.

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Table 5-6. Stepwise Ranked Regression Analysis for Mean Spallings Releases for Replicate 1 of the RPPCR and CRA26_IS

	RPPCR Replicate 1			CRA26_IS Replicate 1		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	SPALLMOD:REPIPERM	0.22	0.46	SPALLMOD:REPIPERM	0.21	0.45
2	S_HALITE:POROSITY	0.36	0.37	SPALLMOD:PARTDIAM	0.37	-0.39
3	SPALLMOD:PARTDIAM	0.49	-0.36	S_HALITE:POROSITY	0.46	0.30
4	DRZ_PCS:PRMX_LOG	0.53	-0.21	DRZ_PCS:PRMX_LOG	0.49	-0.16
5	GLOBAL:GDEPFAC	0.57	0.18	CASTILER:PRESSURE	0.52	0.17
6	CASTILER:PRESSURE	0.59	0.14	GLOBAL:GDEPFAC	0.55	0.17
7				SPALLMOD:REPIPOR	0.57	-0.15
8				WAS_AREA:BIOGENFC	0.59	0.14

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

Table 5-7. Stepwise Ranked Regression Analysis for Mean Spallings Releases for Replicate 2 of the RPPCR and CRA26_IS

	RPPCR Replicate 2			CRA26_IS Replicate 2		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	S_HALITE:POROSITY	0.20	0.44	S_HALITE:POROSITY	0.16	0.40
2	SPALLMOD:REPIPERM	0.35	0.40	SPALLMOD:PARTDIAM	0.31	-0.39
3	SPALLMOD:PARTDIAM	0.46	-0.33	SPALLMOD:REPIPERM	0.44	0.37
4	BH_SAND:PRMX_LOG	0.50	-0.19	WAS_AREA:SAT_WICK	0.49	0.20
5	WAS_AREA:GRATMICI	0.53	0.17	WAS_AREA:BIOGENFC	0.52	0.19
6	WAS_AREA:BIOGENFC	0.56	0.18	WAS_AREA:GRATMICI	0.55	0.17
7	CASTILER:PRESSURE	0.59	0.17	BH_SAND:PRMX_LOG	0.58	-0.16
8	WAS_AREA:SAT_WICK	0.62	0.16	CASTILER:PRESSURE	0.59	0.14
9	GLOBAL:PBRINE	0.63	0.13	GLOBAL:PBRINE	0.61	0.14

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

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Table 5-8. Stepwise Ranked Regression Analysis for Mean Spallings Releases for Replicate 3 of the RPPCR and CRA26_IS

	RPPCR Replicate 3			CRA26_IS Replicate 3		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	SPALLMOD:PARTDIAM	0.23	-0.43	SPALLMOD:PARTDIAM	0.29	-0.49
2	S_HALITE:POROSITY	0.38	0.37	SPALLMOD:REPIPERM	0.40	0.31
3	SPALLMOD:REPIPERM	0.51	0.37	S_HALITE:POROSITY	0.49	0.29
4	SPALLMOD:REPIPOR	0.56	-0.22	SPALLMOD:REPIPOR	0.54	-0.23
5	DRZ_PCS:PRMX_LOG	0.59	-0.17	WAS_AREA:GRATMICI	0.58	0.18
6	SPALLMOD:TENSLSTR	0.62	-0.16	DRZ_PCS:PRMX_LOG	0.61	-0.15
7	WAS_AREA:GRATMICI	0.64	0.17	SHFTL_T2:PRMX_LOG	0.63	0.15
8	CASTILER:PRESSURE	0.66	0.15	S_HALITE:PRESSURE	0.65	-0.12
9	WAS_AREA:PROBDEG	0.68	0.14	PCS_T2:POR2PERM	0.66	-0.14
10	PCS_T1:POROSITY	0.70	-0.13	CASTILER:PRESSURE	0.68	0.13
11	PCS_T2:POR2PERM	0.71	-0.12	SPALLMOD:TENSLSTR	0.70	-0.13
12				WAS_AREA:SAT_WICK	0.71	0.13
13				PCS_T1:POROSITY	0.73	-0.13
				WAS_AREA:SAT_RGAS	0.74	-0.12

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

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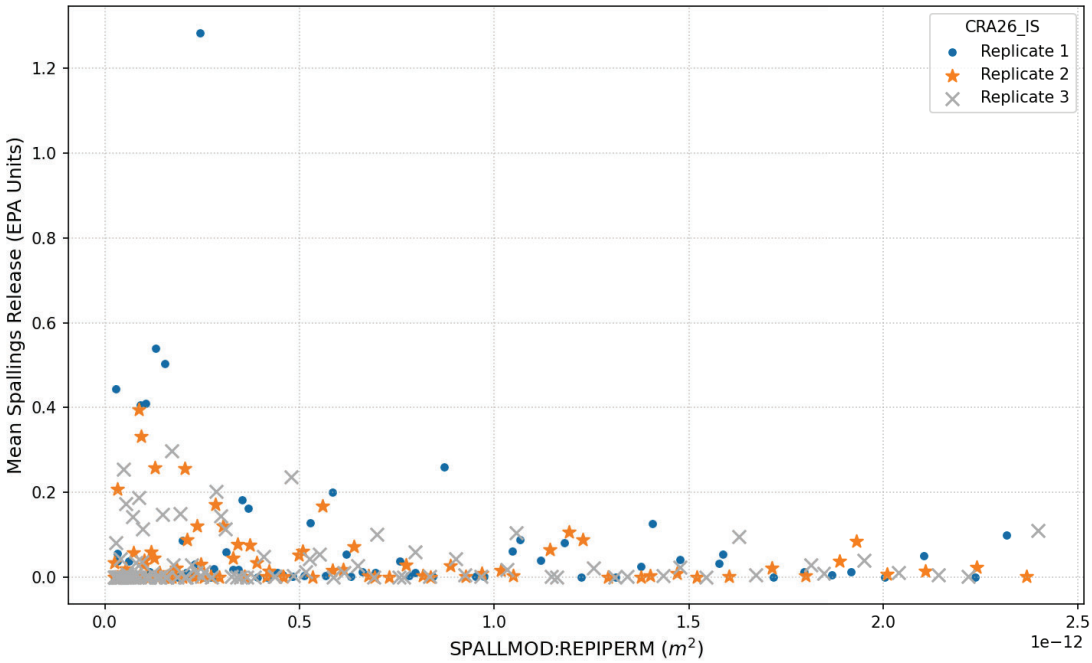


Figure 16. SPALLMOD:REPIPERM versus Mean Spallings Releases for CRA26_IS

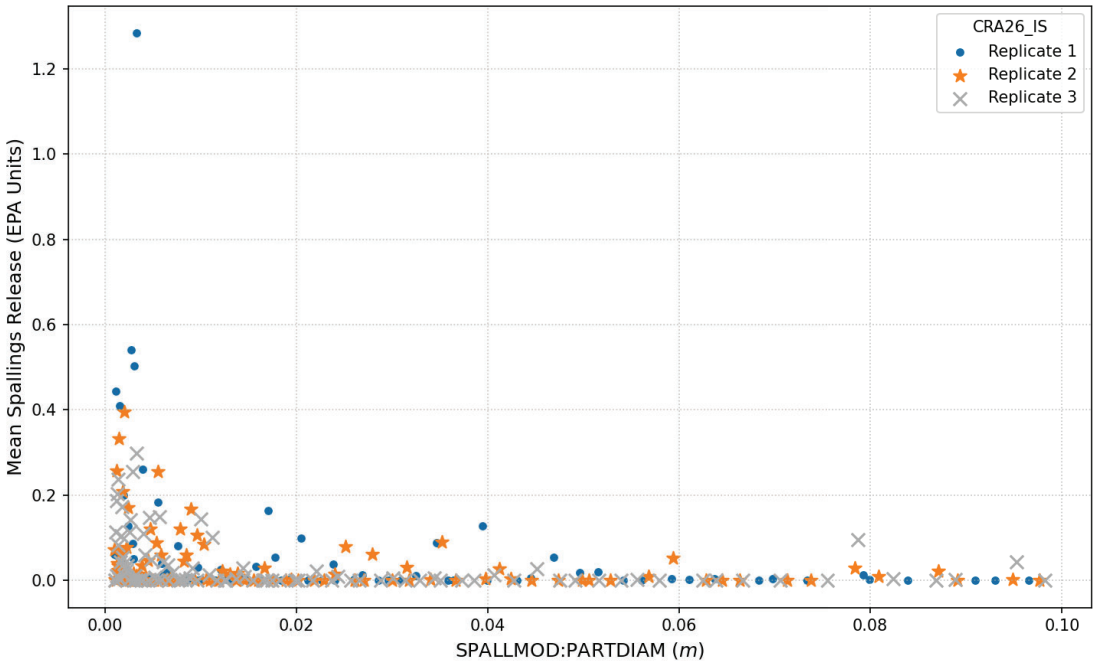


Figure 17. SPALLMOD:PARTDIAM versus Mean Spallings Releases for CRA26_IS

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5.4 Direct Brine

5.4.1 Direct Brine Releases

Direct brine releases (DBRs) occur when the WIPP repository is penetrated by a borehole under conditions of sufficient brine pressure and saturation, causing brine to migrate up through the borehole to the surface. DBRs are calculated as the product of the volume of brine released and the concentration of radionuclides mobilized in the brine. Figure 18 shows the mean direct brine volume for Replicate 1 of the CRA26_IS and the RPPCR, while Figure 19, Figure 20, and Figure 21 present the CCDFs for direct brine releases for Replicates 1, 2, and 3, respectively. Figure 22 shows the overall mean direct brine releases, along with the 95% confidence interval, for the CRA26_IS and RPPCR.

Table 5-9 provides statistics on the overall mean direct brine release at the compliance limit probabilities. The values in Table 5-9 indicate that while direct brine releases are lower at higher probabilities (P(R)>0.1) in the CRA26_IS, they are slightly higher at lower probabilities (P(R)>0.001).

The changes in direct brine release CCDFs between the CRA26_IS and RPPCR are driven by several factors related to repository pressures, brine saturation, and waste inventory characteristics. As described by Day and King (2025), the CRA26_IS Salado flow results show a decrease in mean brine pressures for scenarios without an E1 intrusion and an increase in mean brine pressures for scenarios with an E1 intrusion (except for the westernmost waste areas). Additionally, there is a substantial decrease in brine saturation across all waste areas and scenarios. These effects lead to mixed impacts on direct brine releases: reduced brine saturation decreases the frequency of non-zero DBR volumes, while increased maximum pressures for individual vectors contribute to larger magnitude releases in certain scenarios (Zeitler 2025). For scenarios with an E1 intrusion (e.g., S2-DBR and S3-DBR), the CRA26_IS shows a 20–25% reduction in mean non-zero DBR volumes compared to the RPPCR, primarily due to reduced brine saturation despite elevated brine pressures (Day and King 2025; Zeitler 2025). Conversely, scenarios without an E1 intrusion (e.g., S4-DBR and S5-DBR) exhibit increased mean DBR volumes in the CRA26_IS, attributed to higher maximum pressures observed in these scenarios (Zeitler 2025).

Additional changes introduced in the CRA26_IS analysis further impact direct brine releases. The repository size is reduced from 19 panels to 12 panels, radionuclide inventory and WUF values are increased, and actinide solubility in the waste area is elevated due to updates to baseline solubility, solubility uncertainty, and colloid enhancement parameters (Docherty and Kim 2025). These changes result in higher radionuclide concentrations in the waste area for equivalent brine volume multipliers compared to the RPPCR. However, the minimum brine volume required for a DBR event is significantly reduced in the CRA26_IS, meaning that DBR concentrations may be determined using different brine volume multipliers in the two analyses. The increase in low-probability releases in the CRA26_IS is attributed to the higher radionuclide concentrations, as there is a decrease in the brine volume released.

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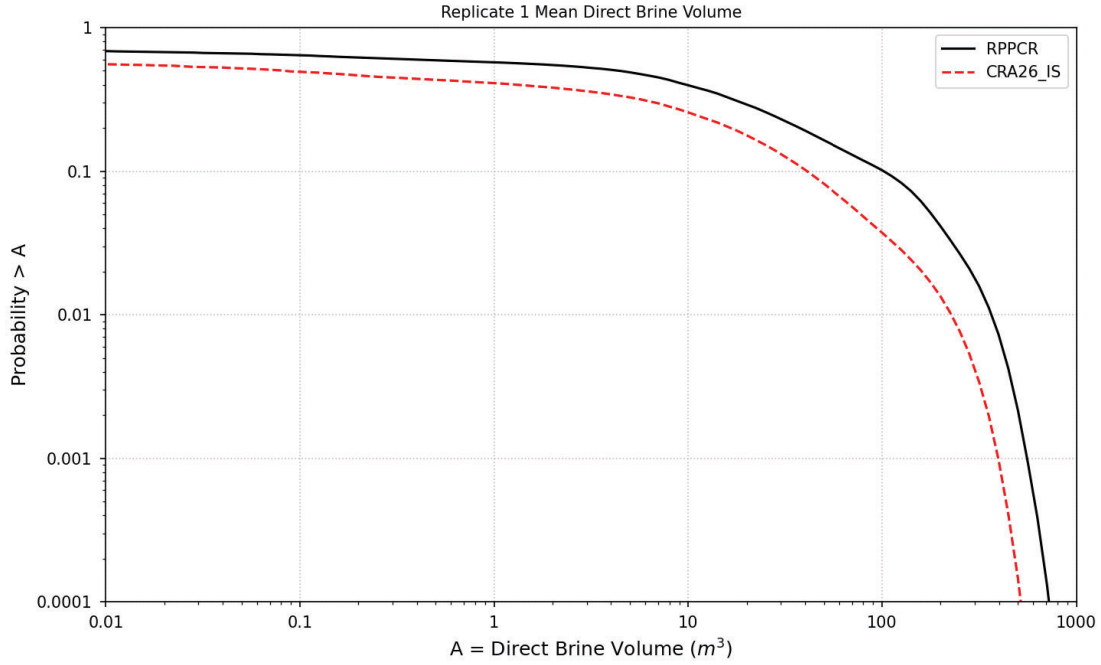


Figure 18. Mean Direct Brine Volume for Replicate 1

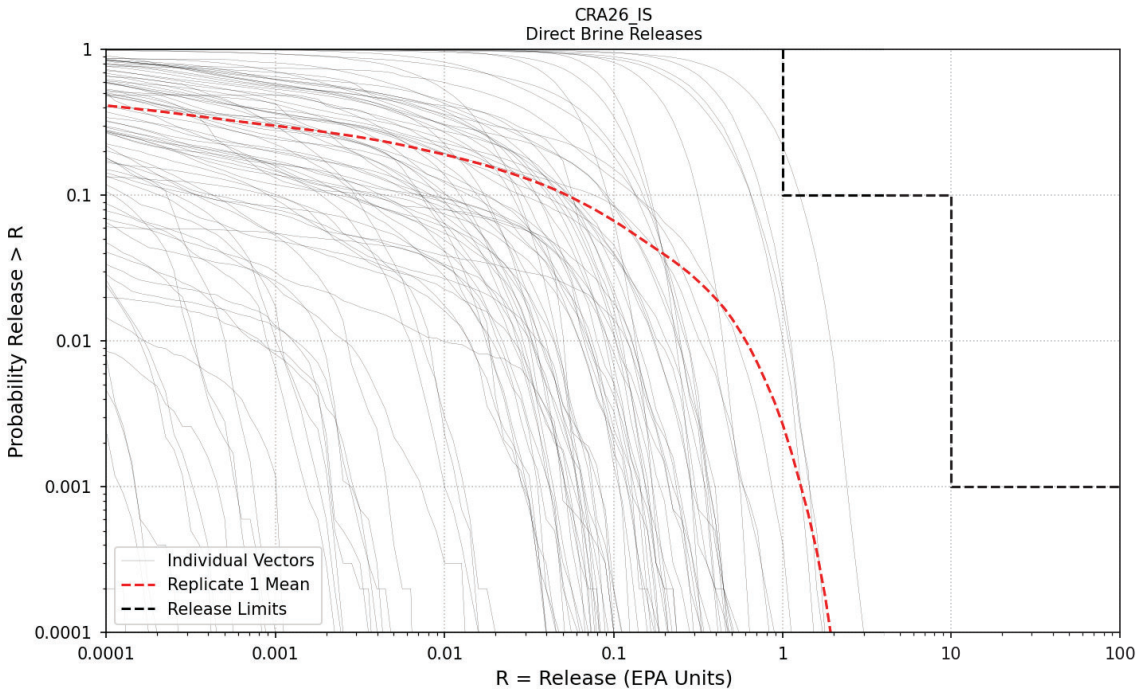


Figure 19. Direct Brine Releases for Replicate 1 of the CRA26_IS

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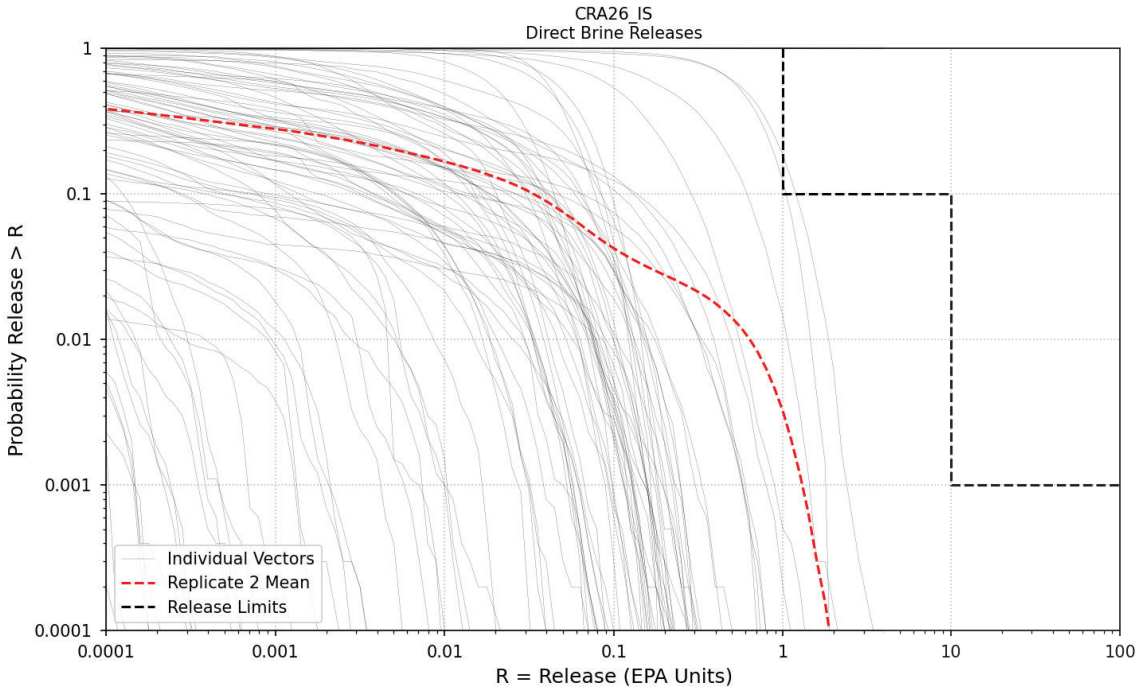


Figure 20. Direct Brine Releases for Replicate 2 of the CRA26_IS

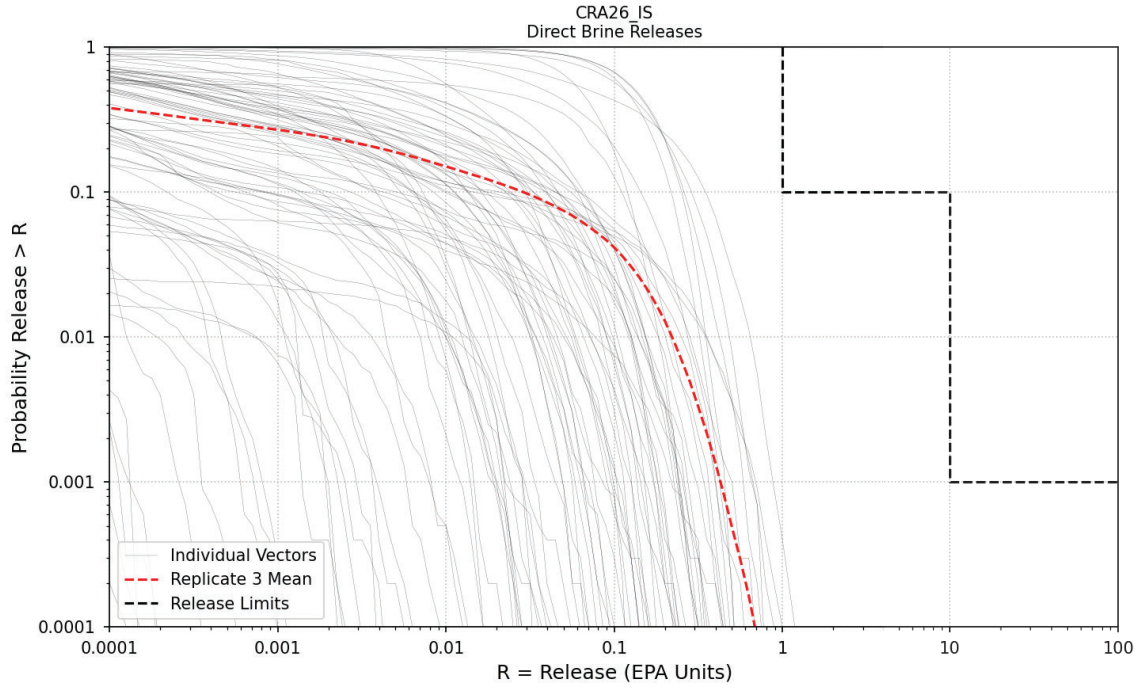


Figure 21. Direct Brine Releases for Replicate 3 of the CRA26_IS

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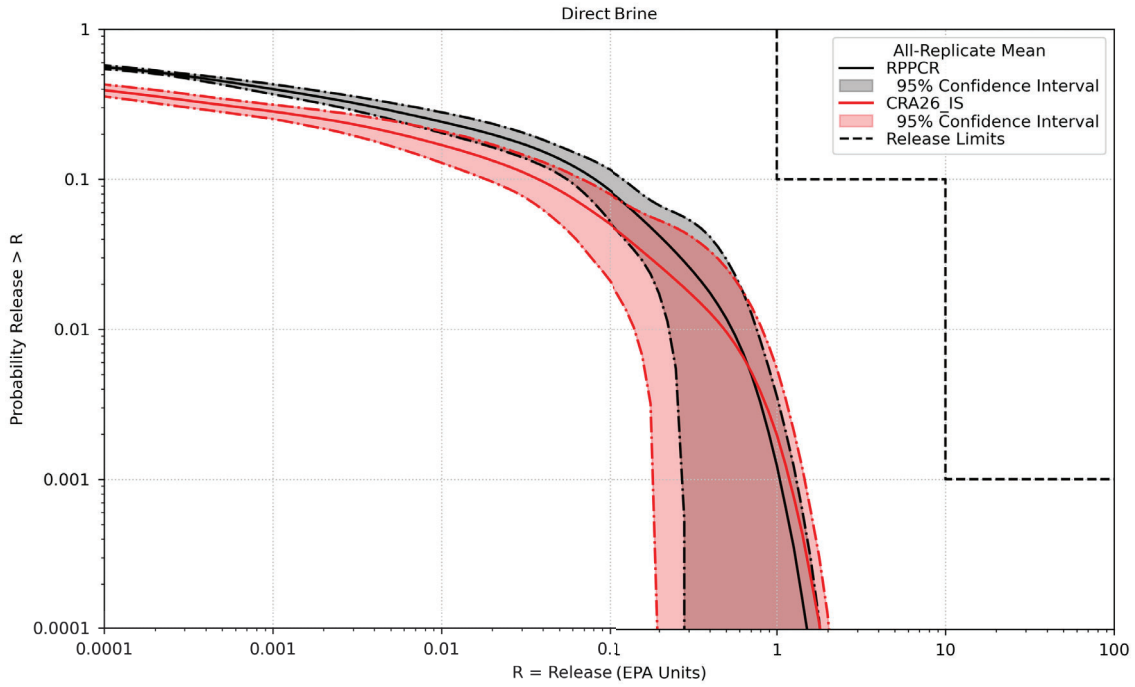


Figure 22. Overall Mean Direct Brine Releases

Table 5-9. Statistics on the Overall Mean Direct Brine Release

Analysis	P(R)>0.1 Lower CI (EPA Units)	P(R)>0.1 Mean (EPA Units)	P(R)>0.1 Upper CI (EPA Units)	P(R)>0.1 Release Limit (EPA Units)	P(R)>0.001 Lower CI (EPA Units)	P(R)>0.001 Mean (EPA Units)	P(R)>0.001 Upper CI (EPA Units)	P(R)>0.001 Release Limit (EPA Units)
RPPCR	0.0555	0.0813	0.1217	1	0.2790	1.0485	1.3139	10
CRA26_IS	0.0184	0.0376	0.0685	1	0.1929	1.1927	1.4710	10

5.4.2 Sensitivity Analysis for Direct Brine Volume

The sensitivity analysis for direct brine volumes was conducted using the STEPWISE code to identify the relative influence of uncertain parameters on the means of the CCDFs of brine volumes. Table 5-10, Table 5-11, and Table 5-12 summarize the stepwise ranked regression analysis results for Replicates 1, 2, and 3 of the RPPCR and CRA26_IS.

Across all replicates, STEEL:CORRMCO2 (inundated iron corrosion rate) is consistently the dominant parameter controlling variability in direct brine volumes. STEEL:CORRMCO2 explains between 12% and 23% of the variability in the RPPCR and between 18% and 32% in the CRA26_IS. The increased influence of STEEL:CORRMCO2 in the CRA26_IS reflects changes in repository pressures and brine saturation levels, which amplify the impact of corrosion rates on brine mobilization.

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S_HALITE:POROSITY (intact halite porosity) is the second most influential parameter across most replicates. It explains between 12% and 18% of the variability in the RPPCR and between 6% and 9% in the CRA26_IS. The influence of halite porosity reflects its role in controlling brine availability and repository pressure, which are critical factors in determining brine volumes.

Other parameters, such as CASTILER:PRESSURE (initial brine pore pressure in the Castile), DRZ_1:PRMX_LOG (log of intrinsic permeability for the disturbed rock zone), and WAS_AREA:SAT_RBRN (residual brine saturation in the waste area), also contribute to variability in direct brine volumes. CASTILER:PRESSURE explains between 3% and 11% of the variability in the CRA26_IS, while DRZ_1:PRMX_LOG accounts for 4% to 18%.

Overall, the sensitivity analysis demonstrates that STEEL:CORRMCO2, S_HALITE:POROSITY, CASTILER:PRESSURE, DRZ_1:PRMX_LOG and WAS_AREA:SAT_RBRN are the primary drivers of variability in direct brine volumes for both the RPPCR and CRA26_IS.

Table 5-10. Stepwise Ranked Regression Analysis for Mean Direct Brine Volumes for Replicate 1 of the RPPCR and CRA26_IS

	RPPCR Replicate 1			CRA26_IS Replicate 1		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	S_HALITE:POROSITY	0.18	0.41	STEEL:CORRMCO2	0.18	-0.43
2	STEEL:CORRMCO2	0.30	-0.37	DRZ_1:PRMX_LOG	0.36	0.42
3	DRZ_1:PRMX_LOG	0.39	0.28	WAS_AREA:SAT_RBRN	0.45	-0.30
4	WAS_AREA:SAT_RBRN	0.47	-0.29	S_HALITE:POROSITY	0.54	0.29
5	CASTILER:PRESSURE	0.55	0.27	CASTILER:PRESSURE	0.57	0.17
6	BH_SAND:PRMX_LOG	0.58	0.18	GLOBAL:GDEPFAC	0.60	-0.14
7	GLOBAL:PBRINE	0.61	0.17	SHFTL_T2:PRMX_LOG	0.61	0.12
8	WAS_AREA:BIOGENFC	0.64	0.15	DRZ_PCS:PRMX_LOG	0.63	0.14
9	WAS_AREA:SAT_RGAS	0.66	-0.14	WAS_AREA:SAT_RGAS	0.65	-0.14
10				S_MB139:RELP_MOD	0.66	-0.13

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

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Table 5-11. Stepwise Ranked Regression Analysis for Mean Direct Brine Volumes for Replicate 2 of the RPPCR and CRA26_IS

	RPPCR Replicate 2			CRA26_IS Replicate 2		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	STEEL:CORRMCO2	0.23	-0.48	STEEL:CORRMCO2	0.32	-0.55
2	S_HALITE:POROSITY	0.35	0.35	WAS_AREA:SAT_RBRN	0.42	-0.32
3	CASTILER:PRESSURE	0.46	0.31	DRZ_1:PRMX_LOG	0.49	0.26
4	DRZ_1:PRMX_LOG	0.54	0.27	DRZ_PCS:PRMX_LOG	0.56	0.28
5	WAS_AREA:SAT_RBRN	0.59	-0.23	S_HALITE:POROSITY	0.62	0.25
6	GLOBAL:PBRINE	0.63	0.21	WAS_AREA:SAT_WICK	0.65	-0.20
7	DRZ_PCS:PRMX_LOG	0.67	0.21	CASTILER:PRESSURE	0.68	0.17
8	WAS_AREA:GRATMICH	0.69	-0.15	SHFTL_T1:PRMX_LOG	0.71	0.15
9	WAS_AREA:SAT_WICK	0.71	-0.15	WAS_AREA:SAT_RGAS	0.72	-0.13
10	SHFTL_T1:PRMX_LOG	0.73	0.13	PCS_T1:PORE_DIS	0.74	0.12

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

Table 5-12. Stepwise Ranked Regression Analysis for Mean Direct Brine Volumes for Replicate 3 of the RPPCR and CRA26_IS

	RPPCR Replicate 3			CRA26_IS Replicate 3		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	STEEL:CORRMCO2	0.18	-0.44	STEEL:CORRMCO2	0.26	-0.53
2	S_HALITE:POROSITY	0.32	0.38	CASTILER:PRESSURE	0.37	0.30
3	CASTILER:PRESSURE	0.45	0.33	S_HALITE:POROSITY	0.46	0.29
4	WAS_AREA:SAT_RBRN	0.50	-0.26	WAS_AREA:SAT_RBRN	0.53	-0.31
5	S_HALITE:PRESSURE	0.54	-0.19	GLOBAL:GDEPFAC	0.58	-0.21
6	DRZ_1:PRMX_LOG	0.57	0.18	DRZ_1:PRMX_LOG	0.62	0.21
7	GLOBAL:GDEPFAC	0.59	-0.15	S_HALITE:PRESSURE	0.64	-0.14
8				GLOBAL:PBRINE	0.66	0.14

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

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5.4.3 Sensitivity Analysis for Direct Brine Releases

The sensitivity analysis for direct brine releases was conducted using the STEPWISE code to identify the relative influence of uncertain parameters on the means of the CCDFs of releases. Table 5-13, Table 5-14, and Table 5-15 summarize the stepwise ranked regression analysis results for Replicates 1, 2, and 3 of the RPPCR and CRA26_IS.

Across all replicates, S_HALITE:POROSITY (intact halite porosity), DRZ_1:PRMX_LOG (log of intrinsic permeability for the disturbed rock zone), and STEEL:CORRMCO2 (inundated iron corrosion rate) are consistently the dominant parameters controlling variability in direct brine releases. Figure 23, Figure 24, and Figure 25 show the relationship between mean DBRs and S_HALITE:POROSITY, DRZ_1:PRMX_LOG, and STEEL:CORRMCO2, respectively. The figures illustrate that sampling large values for S_HALITE:POROSITY and DRZ_1:PRMX_LOG, and a small value for STEEL:CORRMCO2 are necessary for the largest DBRs to occur.

S_HALITE:POROSITY accounts for 14% to 17% of the variability in the RPPCR and 7% to 12% in the CRA26_IS. The influence of halite porosity reflects its role in controlling brine availability and repository pressure, which are critical factors in determining brine releases.

DRZ_1:PRMX_LOG contributes between 11% and 21% of the variability in the CRA26_IS, compared to 6% to 12% in the RPPCR. This parameter's influence also highlights the importance in controlling brine availability and repository pressure.

STEEL:CORRMCO2 explains between 11% and 17% of the variability in the RPPCR and between 12% and 26% in the CRA26_IS. The increased influence of STEEL:CORRMCO2 in the CRA26_IS reflects changes in repository pressures and brine saturation levels, which amplify the impact of corrosion rates on brine mobilization.

Other parameters, such as CASTILER:PRESSURE (initial brine pore pressure in the Castile brine reservoir), SOLMOD3:SOLVAR (solubility multiplier for actinides in the +III oxidation state), and WAS_AREA:SAT_RBRN (residual brine saturation in the waste area), also contribute to variability in direct brine releases.

Overall, the sensitivity analysis results demonstrate that S_HALITE:POROSITY, DRZ_1:PRMX_LOG, and STEEL:CORRMCO2 are the primary drivers of variability in direct brine releases for both the RPPCR and CRA26_IS.

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Table 5-13. Stepwise Ranked Regression Analysis for Mean Direct Brine Releases for Replicate 1 of the RPPCR and CRA26_IS

	RPPCR Replicate 1			CRA26_IS Replicate 1		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	S_HALITE:POROSITY	0.17	0.41	DRZ_1:PRMX_LOG	0.21	0.44
2	DRZ_1:PRMX_LOG	0.29	0.32	S_HALITE:POROSITY	0.33	0.36
3	STEEL:CORRMCO2	0.38	-0.33	STEEL:CORRMCO2	0.45	-0.35
4	SOLMOD3:SOLVAR	0.46	0.28	WAS_AREA:SAT_RBRN	0.52	-0.26
5	CASTILER:PRESSURE	0.53	0.25	SOLMOD3:SOLVAR	0.58	0.22
6	WAS_AREA:SAT_RBRN	0.57	-0.20	CASTILER:PRESSURE	0.61	0.18
7	GLOBAL:PBRINE	0.60	0.17	GLOBAL:GDEPFAC	0.64	-0.15
8	BH_SAND:PRMX_LOG	0.63	0.17	GLOBAL:PBRINE	0.66	0.15
9	WAS_AREA:BIOGENFC	0.65	0.16	DRZ_PCS:PRMX_LOG	0.67	0.12
10	WAS_AREA:SAT_RGAS	0.68	-0.15	S_MB139:RELP_MOD	0.69	-0.12
11	GLOBAL:GDEPFAC	0.70	-0.14			

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

Table 5-14. Stepwise Ranked Regression Analysis for Mean Direct Brine Releases for Replicate 2 of the RPPCR and CRA26_IS

	RPPCR Replicate 2			CRA26_IS Replicate 2		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	STEEL:CORRMCO2	0.17	-0.40	STEEL:CORRMCO2	0.26	-0.49
2	S_HALITE:POROSITY	0.32	0.39	DRZ_1:PRMX_LOG	0.37	0.31
3	DRZ_1:PRMX_LOG	0.43	0.31	WAS_AREA:SAT_RBRN	0.47	-0.31
4	CASTILER:PRESSURE	0.52	0.29	S_HALITE:POROSITY	0.54	0.27
5	WAS_AREA:SAT_RBRN	0.57	-0.23	DRZ_PCS:PRMX_LOG	0.60	0.25
6	GLOBAL:PBRINE	0.61	0.19	CASTILER:PRESSURE	0.63	0.17
7	DRZ_PCS:PRMX_LOG	0.63	0.18	SOLMOD3:SOLVAR	0.66	0.16
8	SOLMOD3:SOLVAR	0.65	0.14	WAS_AREA:SAT_WICK	0.68	-0.18
9	WAS_AREA:GRATMICH	0.67	-0.13	SHFTL_T1:PRMX_LOG	0.70	0.16
10	S_MB139:PRMX_LOG	0.68	0.12	(Composite):OXSTAT	0.72	-0.13
11	WAS_AREA:SAT_WICK	0.70	-0.12			

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

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Table 5-15. Stepwise Ranked Regression Analysis for Mean Direct Brine Releases for Replicate 3 of the RPPCR and CRA26_IS

	RPPCR Replicate 3			CRA26_IS Replicate 3		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	CASTILER:PRESSURE	0.16	0.36	STEEL:CORRMCO2	0.22	-0.49
2	STEEL:CORRMCO2	0.29	-0.39	CASTILER:PRESSURE	0.34	0.31
3	S_HALITE:POROSITY	0.43	0.36	S_HALITE:POROSITY	0.45	0.33
4	DRZ_1:PRMX_LOG	0.49	0.24	WAS_AREA:SAT_RBRN	0.53	-0.31
5	SOLMOD3:SOLVAR	0.54	0.23	DRZ_1:PRMX_LOG	0.58	0.22
6	WAS_AREA:SAT_RBRN	0.58	-0.20	S_HALITE:PRESSURE	0.62	-0.18
7	S_HALITE:PRESSURE	0.60	-0.17	GLOBAL:GDEPFAC	0.65	-0.17
8				SOLMOD3:SOLVAR	0.67	0.15

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

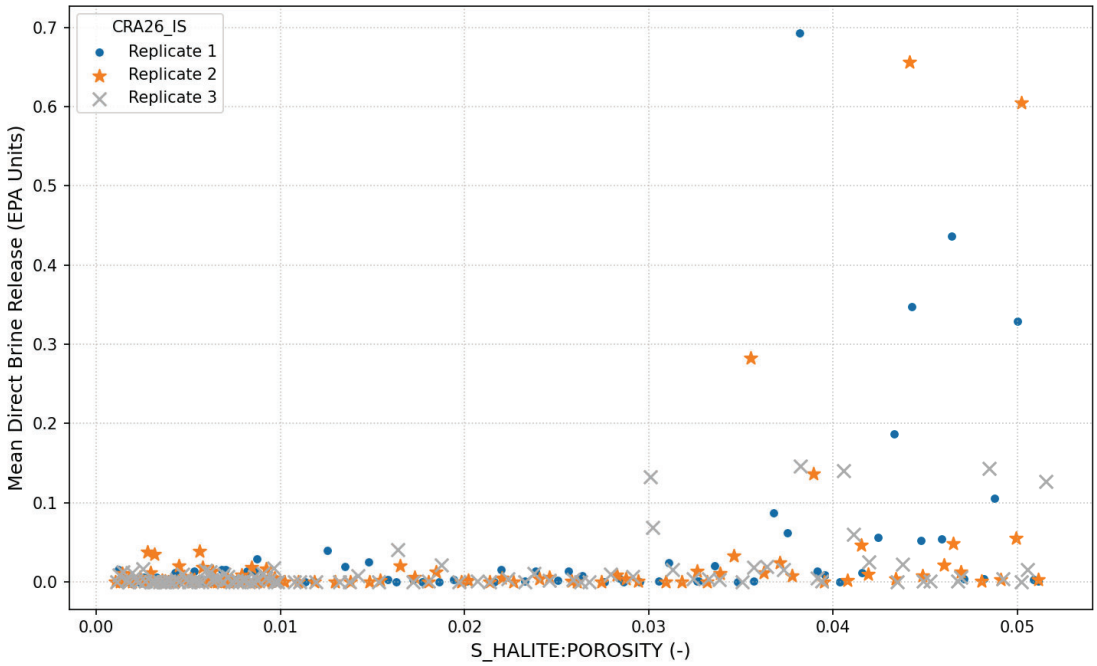


Figure 23. S_HALITE:POROSITY versus Mean Direct Brine Releases for CRA26_IS

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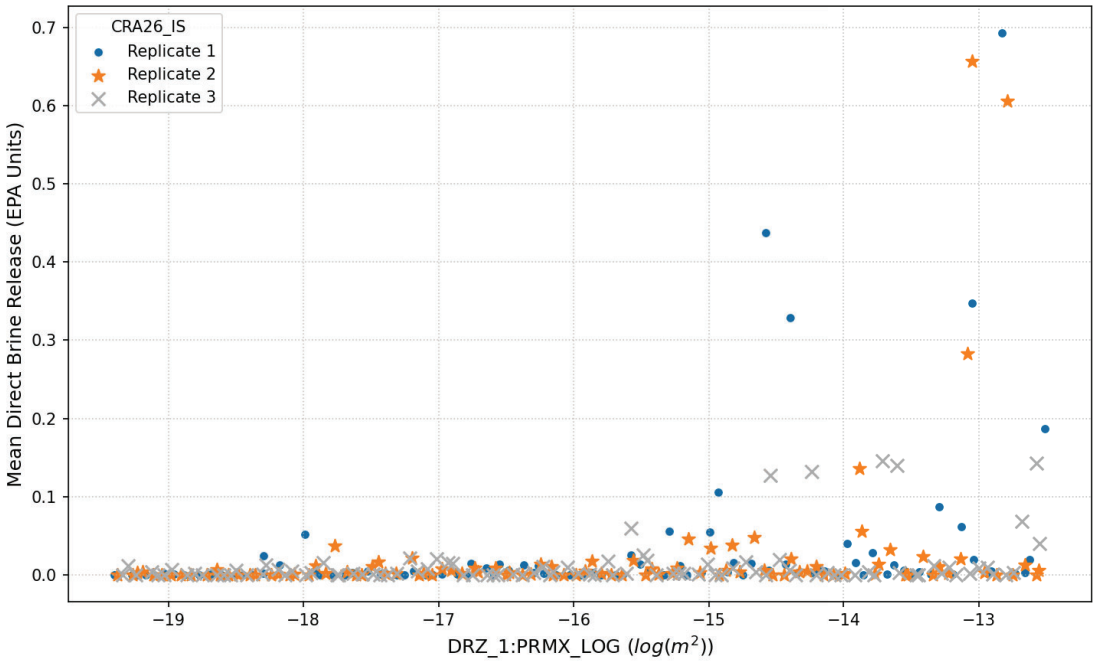


Figure 24. DRZ_1:PRMX_LOG versus Mean Direct Brine Releases for CRA26_IS

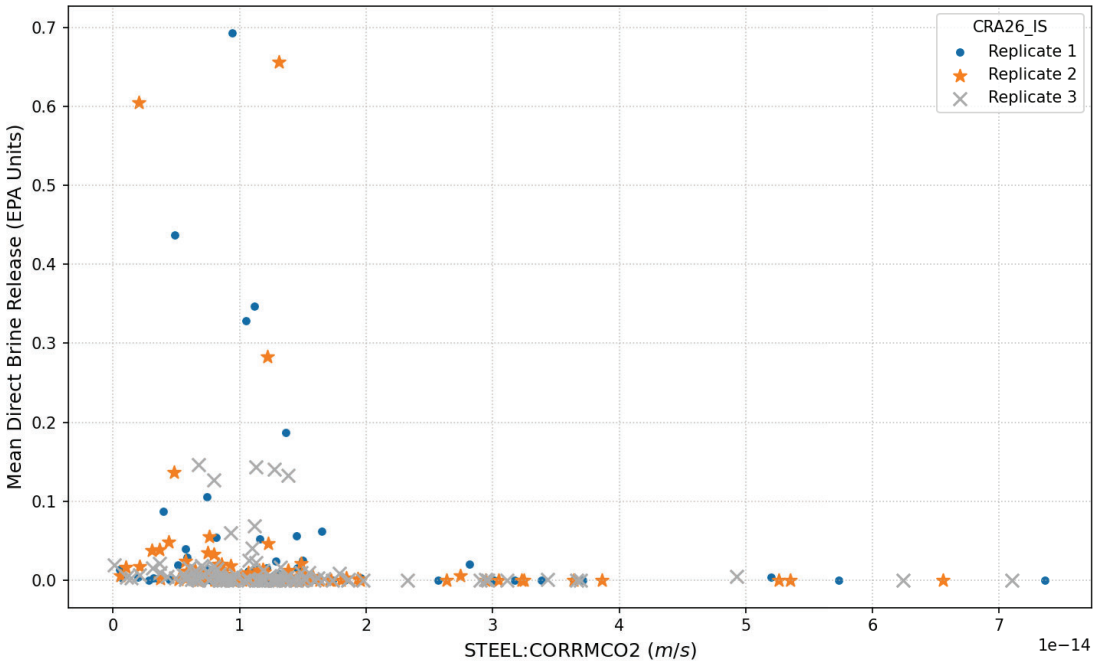


Figure 25. STEEL:CORRMCO2 versus Mean Direct Brine Releases for CRA26_IS

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5.5 Long-Term Radionuclide Transport

5.5.1 Activity Entering the Culebra

Activity entering the Culebra represents the radionuclide source term for transport through the Culebra Dolomite Member of the Rustler Formation. This activity is calculated based on brine flow through boreholes intersecting waste panels and is influenced by repository configuration, brine pressure, and radionuclide mobilization mechanisms. It is important to note that activity entering the Culebra is not considered a release in the regulatory sense but serves as an intermediate step in radionuclide transport modeling.

Figure 26, Figure 27, and Figure 28 show the activity entering the Culebra for Replicates 1, 2, and 3 of the CRA26_IS, respectively. Figure 29 shows the mean activity entering the Culebra by radionuclide for Replicate 1 of CRA26_IS. Activity entering the Culebra is dominated by ^{241}Am followed by ^{239}Pu, with activity from ^{230}Th and ^{234}U being orders of magnitude smaller. Figure 30 presents the overall mean activity entering the Culebra, along with the 95% confidence interval, for the CRA26_IS and RPPCR.

Table 5-16 provides statistics on the overall mean activity entering the Culebra at the compliance limit probabilities. The values in Table 5-16 indicate a reduction in activity entering the Culebra for the CRA26_IS at both compliance limit probabilities.

The reduction in activity entering the Culebra is primarily attributed to the smaller repository footprint in the CRA26_IS, which reduces the likelihood of radionuclide transport to the Culebra. Additionally, changes in radionuclide inventory and brine transport dynamics contribute to the observed differences between the CRA26_IS and RPPCR Salado transport results. In the process models, activity entering the Culebra decreases for intrusion scenarios 1–5 and increases for scenario 6 compared to the RPPCR (Docherty and Kim 2025).

Overall, the CRA26_IS results demonstrate that activity entering the Culebra is influenced by repository configuration, radionuclide inventory, and brine transport dynamics. These factors play a critical role in determining the magnitude and probability of radionuclide transport to the Culebra.

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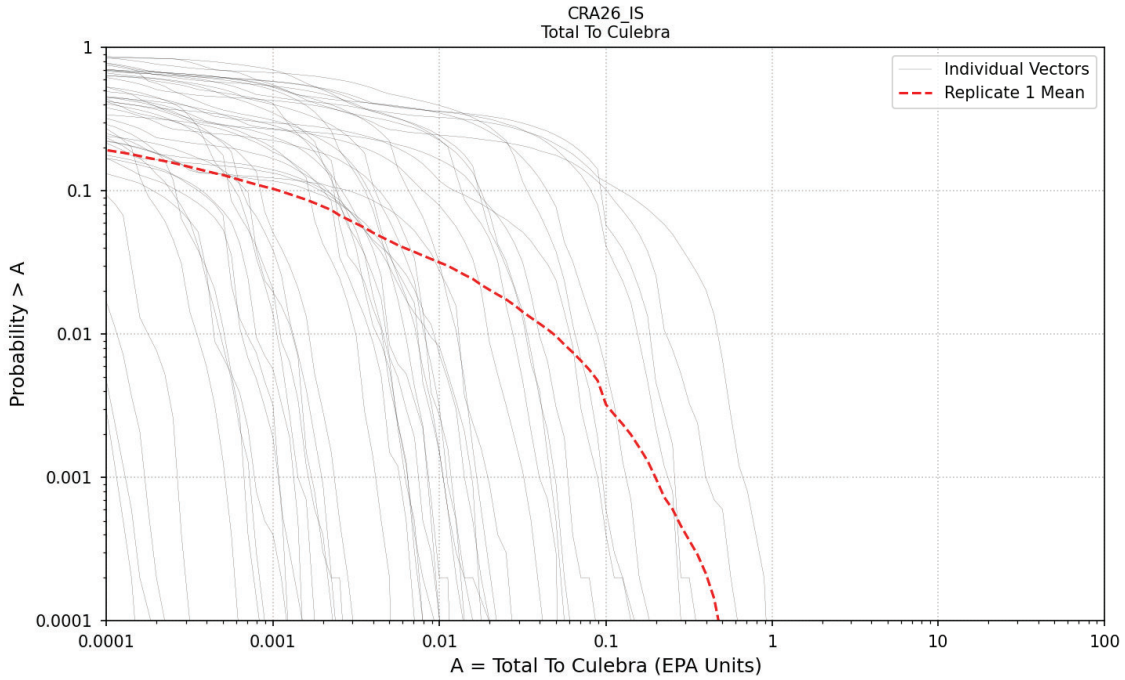


Figure 26. Activity Entering the Culebra for Replicate 1 of the CRA26_IS

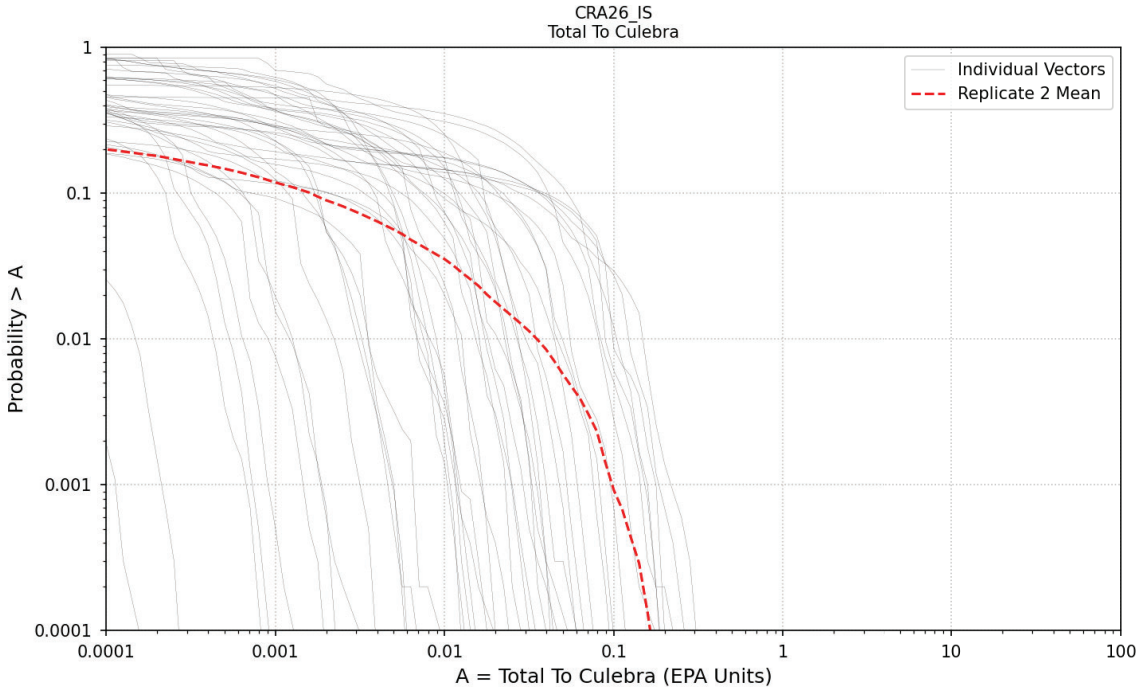


Figure 27. Activity Entering the Culebra for Replicate 2 of the CRA26_IS

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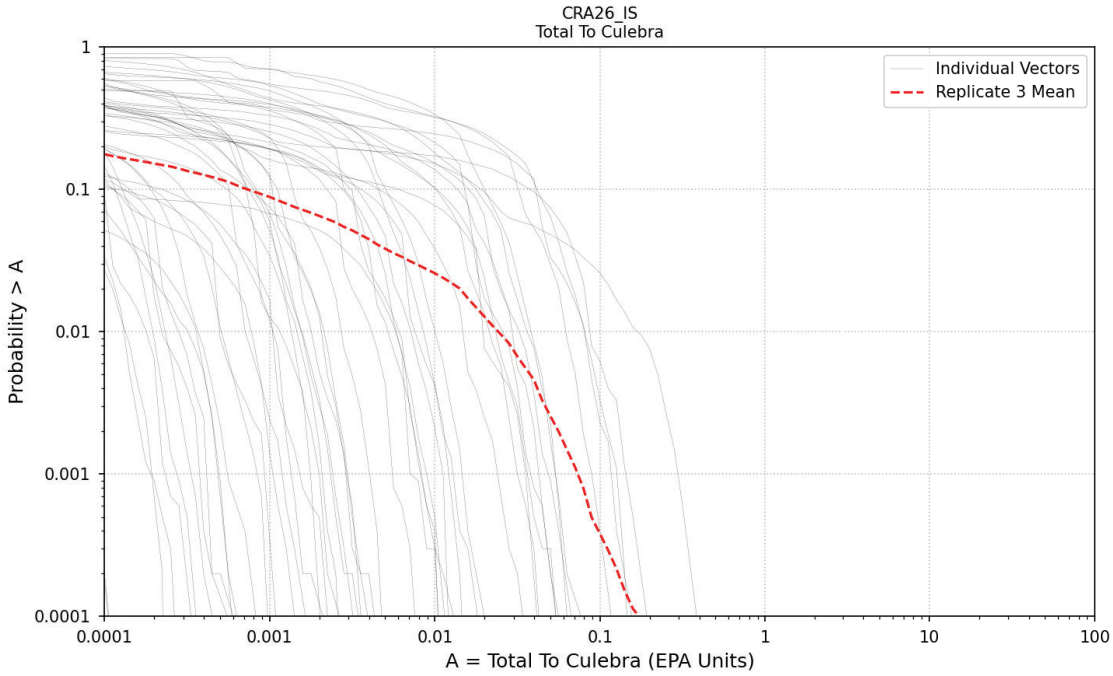


Figure 28. Activity Entering the Culebra for Replicate 3 of the CRA26_IS

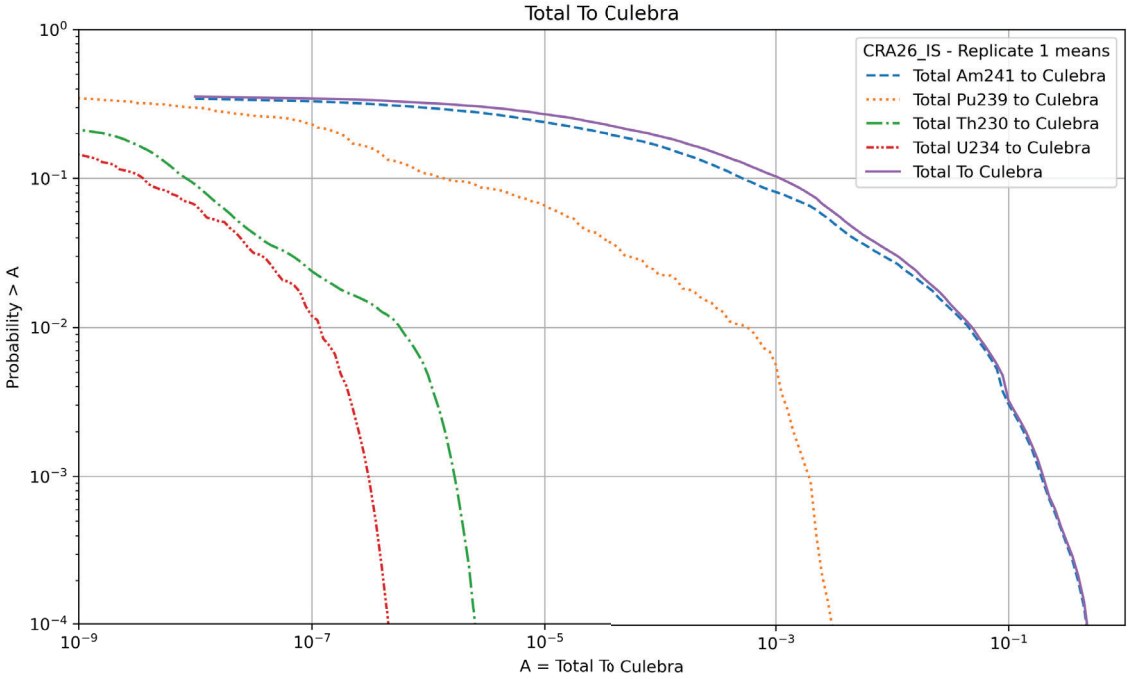


Figure 29. Mean Activity Entering the Culebra by Radionuclide for Replicate 1 of CRA26_IS

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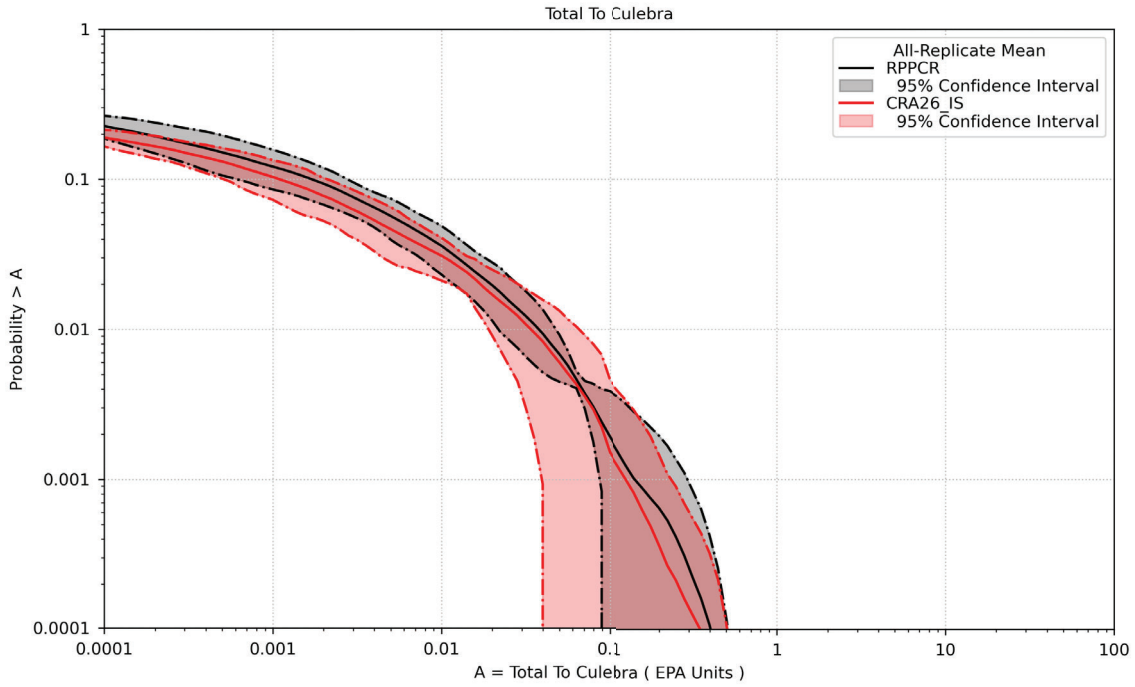


Figure 30. Overall Mean Activity Entering the Culebra

Table 5-16. Statistics on the Overall Mean Activity Entering the Culebra

Analysis	P(R)>0.1 Lower CI (EPA Units)	P(R)>0.1 Mean (EPA Units)	P(R)>0.1 Upper CI (EPA Units)	P(R)>0.1 Release Limit (EPA Units)	P(R)>0.001 Lower CI (EPA Units)	P(R)>0.001 Mean (EPA Units)	P(R)>0.001 Upper CI (EPA Units)	P(R)>0.001 Release Limit (EPA Units)
RPPCR	0.0006	0.0017	0.0028	1	0.0874	0.1429	0.2954	10
CRA26_IS	0.0005	0.0011	0.0021	1	0.0395	0.1263	0.2359	10

5.5.2 Releases through the Culebra

Releases through the Culebra represent the radionuclide activity transported from the Culebra Dolomite Member to the accessible environment. These releases are calculated based on radionuclide transport modeling and are influenced by the activity entering the Culebra, transmissivity fields, and radionuclide decay and sorption processes.

Figure 31, Figure 32, and Figure 33 show the releases through the Culebra for Replicates 1, 2, and 3 of the CRA26_IS, respectively. The x-axis in these figures has been extended to display releases below the normal cutoff of 0.0001 EPA units, highlighting the negligible radionuclide releases through the Culebra for the CRA26_IS across all replicates. Figure 34 shows the mean releases

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through the Culebra by radionuclide and release point for Replicate 1 of CRA26_IS. Despite ^{234}U being the smallest contributor to activity entering the Culebra (Figure 29), it dominates releases through the Culebra. Figure 35 presents the overall mean releases through the Culebra, along with the 95% confidence interval, for the CRA26_IS. However, the mean CRA26_IS results and confidence interval are below the cutoff value of 0.0001 EPA Units and do not appear in Figure 35.

Table 5-17 provides statistics on the overall mean for releases through the Culebra at the compliance limit probabilities. The values in Table 5-17 confirm that releases through the Culebra are effectively zero for the CRA26_IS, even at lower probabilities.

The CRA26_IS repository layout uses only the first and second Culebra release points (CRP 1 and CRP 2), as the interim state repository consists of 12 panels. In contrast, the RPPCR included four release points, with CRP 4 experiencing much higher releases due to westerly flow in the mining-impacted region. The exclusion of CRP 4 from the CRA26_IS significantly reduces the potential for radionuclide releases through the Culebra. The slight change of location for CRP 2 (Section 2.12) has little impact on radionuclide transport in the Culebra (Wilgus and Bethune 2025).

Overall, the CRA26_IS results demonstrate that releases through the Culebra are negligible. These findings highlight the effectiveness of the repository configuration and radionuclide transport mechanisms in minimizing releases through the Culebra.

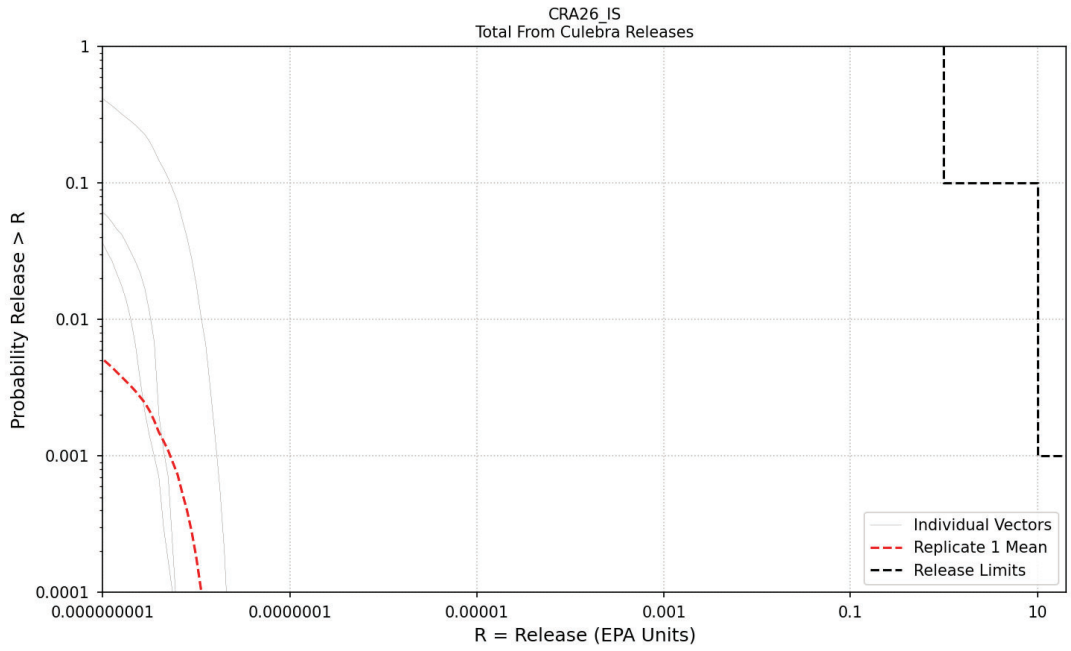


Figure 31. Releases through the Culebra for Replicate 1 of the CRA26_IS

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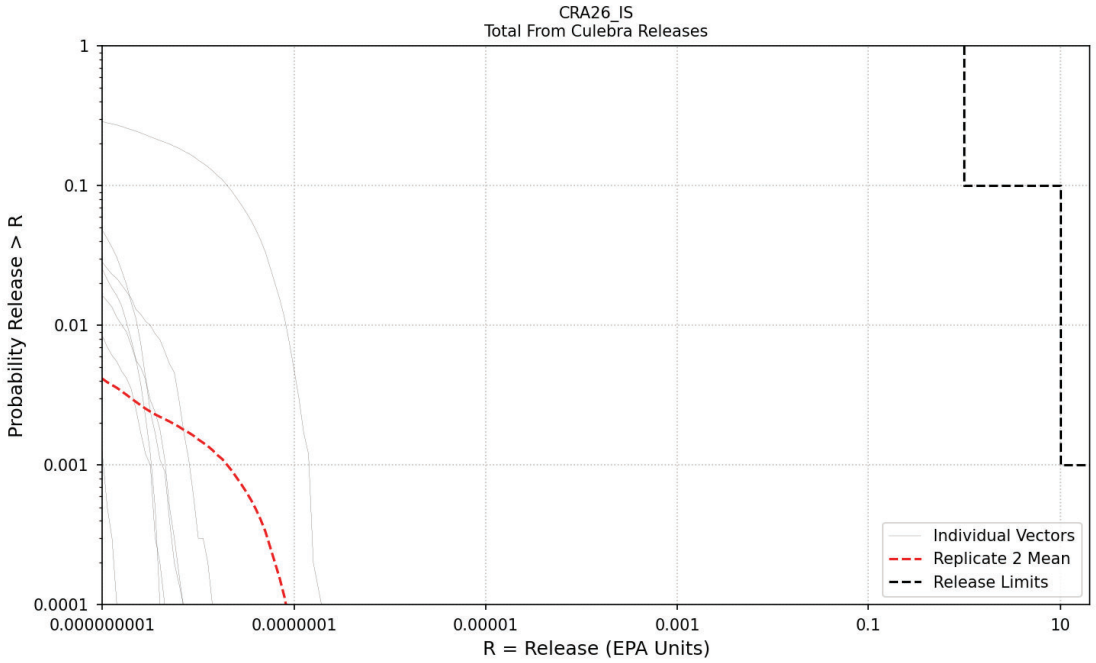


Figure 32. Releases through the Culebra for Replicate 2 of the CRA26_IS

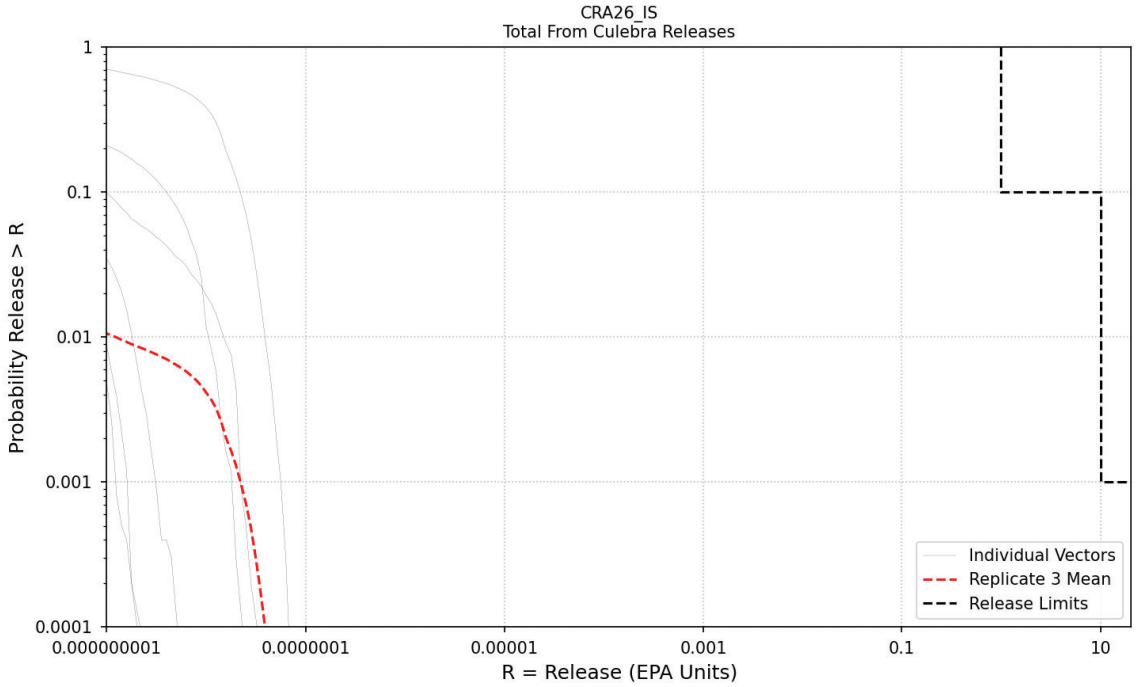


Figure 33. Releases through the Culebra for Replicate 3 of the CRA26_IS

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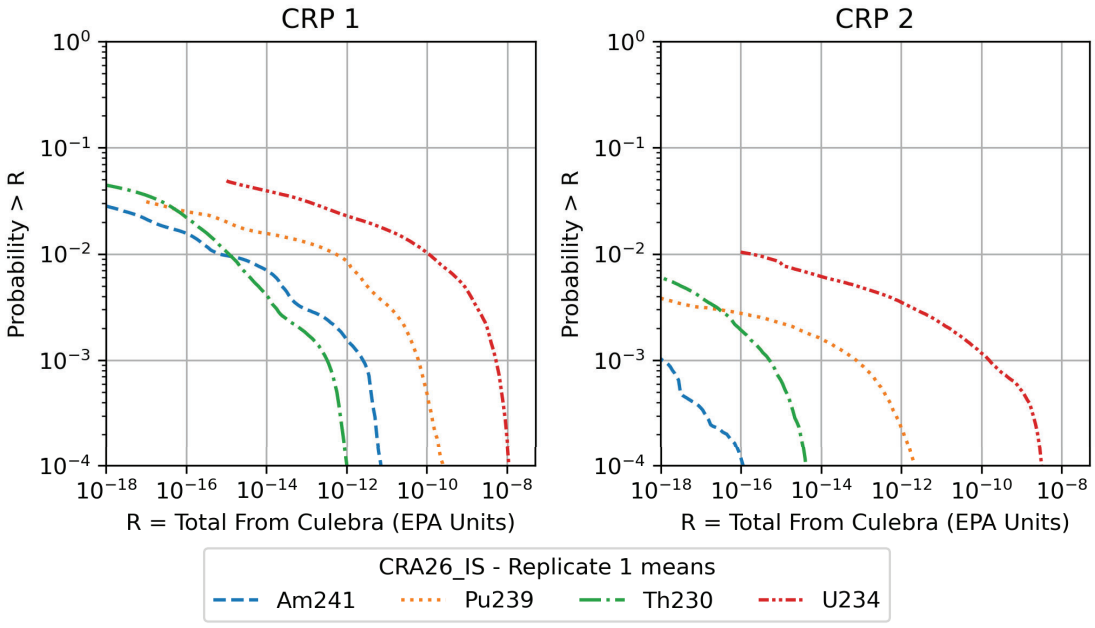


Figure 34. Mean Releases Through the Culebra by Radionuclide and Release Point for the Replicate 1 of CRA26_IS

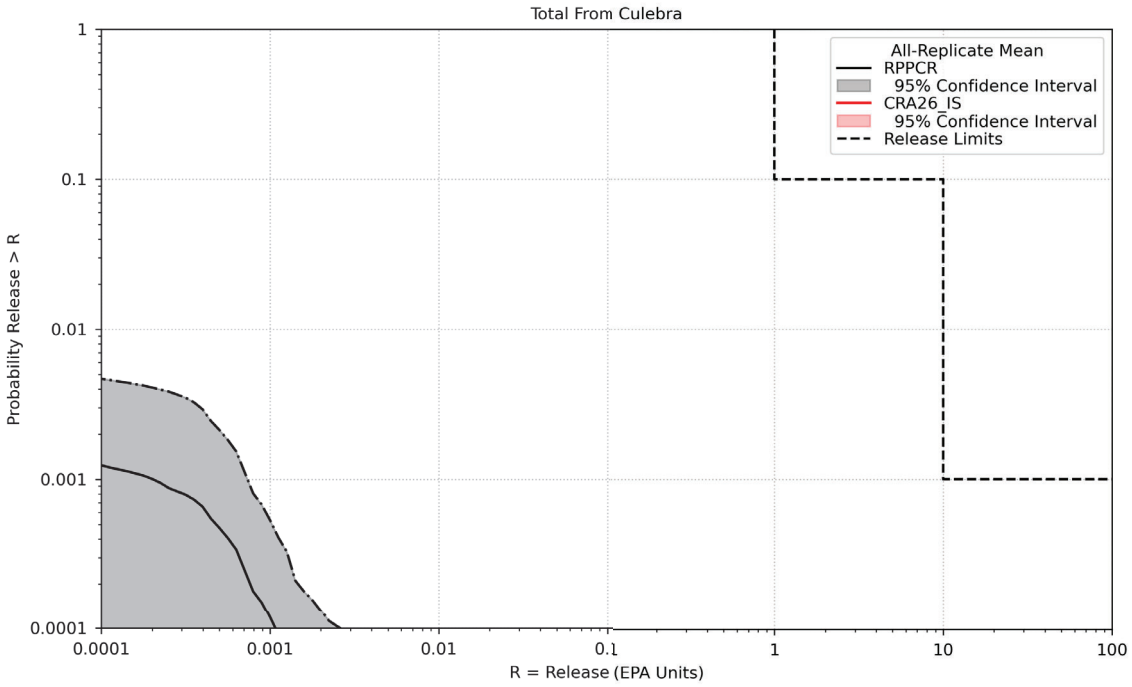


Figure 35. Overall Mean Releases Through the Culebra for the CRA26_IS

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Table 5-17. Statistics on the Overall Mean Releases Through the Culebra

Analysis	P(R)>0.1 Lower CI (EPA Units)	P(R)>0.1 Mean (EPA Units)	P(R)>0.1 Upper CI (EPA Units)	P(R)>0.1 Release Limit (EPA Units)	P(R)>0.001 Lower CI (EPA Units)	P(R)>0.001 Mean (EPA Units)	P(R)>0.001 Upper CI (EPA Units)	P(R)>0.001 Release Limit (EPA Units)
RPPCR	0.0000	0.0000	0.0000	1	0.0000	0.0002	0.0007	10
CRA26_IS	0.0000	0.0000	0.0000	1	0.0000	0.0000	0.0000	10

5.5.3 Sensitivity Analysis for Releases Through the Culebra

The very low releases observed for the CRA26_IS make fitting a regression model to the results difficult, such that the sensitivity analysis does not yield meaningful insights. A large proportion of the vectors in each replicate show either zero releases or values below the cutoff of 0.0001 EPA units, which are considered dominated by numerical error and hence unreliable (Appendix A, Section 8.5.2). For example, as shown in Table 8-3 and Table 8-5, none of the vectors for "Total From Culebra" exceed the cutoff value of 0.0001 EPA Units across all replicates of the CRA26_IS. Similarly, for "Total To Culebra," only 33% to 50% of the vectors exceed the cutoff value for maximum releases, and only 33% to 38% exceed the cutoff for mean releases.

In comparison, the RPPCR results also show very low releases through the Culebra, with similar proportions of vectors below the cutoff value (Table 8-4 and Table 8-6). For "Total From Culebra," none of the vectors exceed the cutoff value for maximum releases, and only 0% to 2% exceed the cutoff for mean releases. For "Total To Culebra," 44% to 50% of the vectors exceed the cutoff for maximum releases, and 30% to 39% exceed the cutoff for mean releases.

Due to the scarcity of credible release values, the STEPWISE code does not yield meaningful results for releases through the Culebra in the CRA26_IS. The large proportion of zero or unreliable values introduces significant challenges in ranking the relative importance of parameters, as the regression analysis cannot effectively capture the variability in the results. Consequently, the STEPWISE results for releases through the Culebra are not shown here.

Figure 34 showed that ^{234}U dominated releases through the Culebra despite being a small component of the activity released to the Culebra. This is attributed to uranium transport, particularly in the U(VI) oxidation state, being less attenuated by diffusion into the matrix pore structure. Figure 36 shows the individual CCDFs of ^{234}U releases from the Culebra for the vectors of Replicate 1 colored by the realized dominant oxidation state of uranium. This plot shows the vectors with the highest releases all sample the U(VI) oxidation state. The largest releases from a vector sampling the U(IV) oxidation state are approximately four orders of magnitude lower than the largest releases from a vector sampling the U(VI) oxidation state, ensuring that the mean release will be dominated by these highest release vectors which sample the U(VI) oxidation state.

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Overall, the negligible releases through the Culebra in the CRA26_IS reflect the effectiveness of the repository configuration and radionuclide transport mechanisms in minimizing radionuclide migration to the accessible environment.

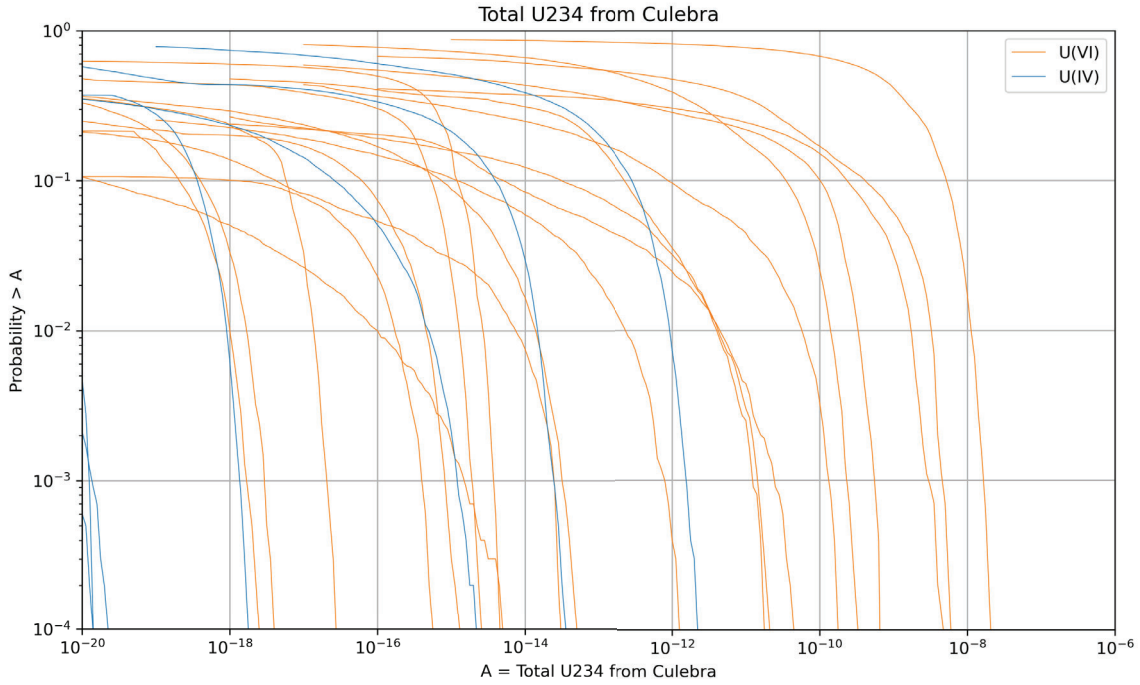


Figure 36. ^{234}U Releases from the Culebra by Oxidation State for Replicate 1 of the CRA26_IS

5.6 Total Releases

5.6.1 Total Releases

Total releases represent the combined radionuclide releases considering all release pathways, including cuttings and cavings, spallings, direct brine releases, and releases through the Culebra. Figure 37, Figure 38, and Figure 39 show the total releases for Replicates 1, 2, and 3 of the CRA26_IS, respectively. Figure 40 presents the overall mean release components for the CRA26_IS, illustrating the relative contributions of each pathway to total releases. Figure 41 shows the overall mean total releases, along with the 95% confidence interval, for the CRA26_IS and the RPPCR.

Table 5-18 provides statistics on the overall mean total release at the compliance limit probabilities. The values in Table 5-18 indicate slightly higher total releases for the CRA26_IS at both compliance limit probabilities.

The increase in total releases for the CRA26_IS is primarily driven by higher contributions from spallings and direct brine releases, as shown in Figure 40. The CRA26_IS incorporates a waste

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inventory with higher activity concentrations and longer half-lived radionuclides, which amplify the impact of spalling releases. Additionally, while the volume of waste is reduced in the CRA26_IS compared to the RPPCR, the waste density (m^3 waste/m^3 repository) has increased. These inventory changes, combined with the increased drilling rate in the CRA26_IS, contribute to the observed increase in total releases compared to the RPPCR.

Despite the increase in total releases, the CRA26_IS results remain well below the regulatory limits of 1 EPA Unit for P(R)>0.1 and 10 EPA Units for P(R)>0.001. These findings demonstrate that the interim state repository continues to comply with containment requirements under 40 CFR Part 191.

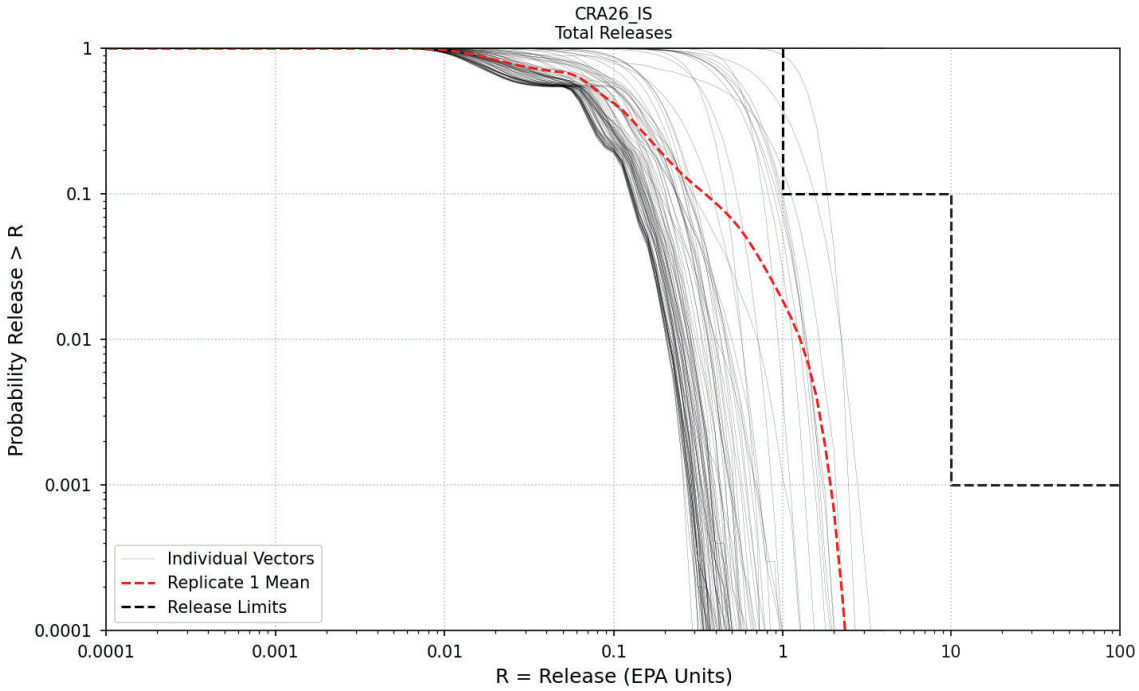


Figure 37. Total Releases for Replicate 1 of the CRA26_IS

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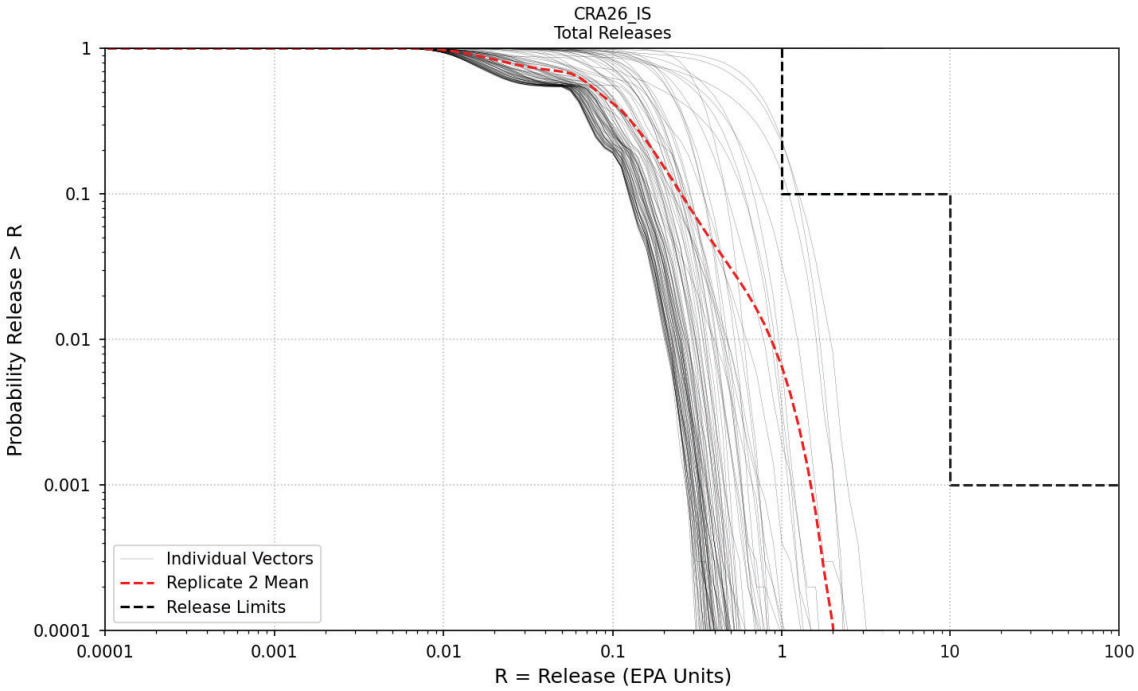


Figure 38. Total Releases for Replicate 2 of the CRA26_IS

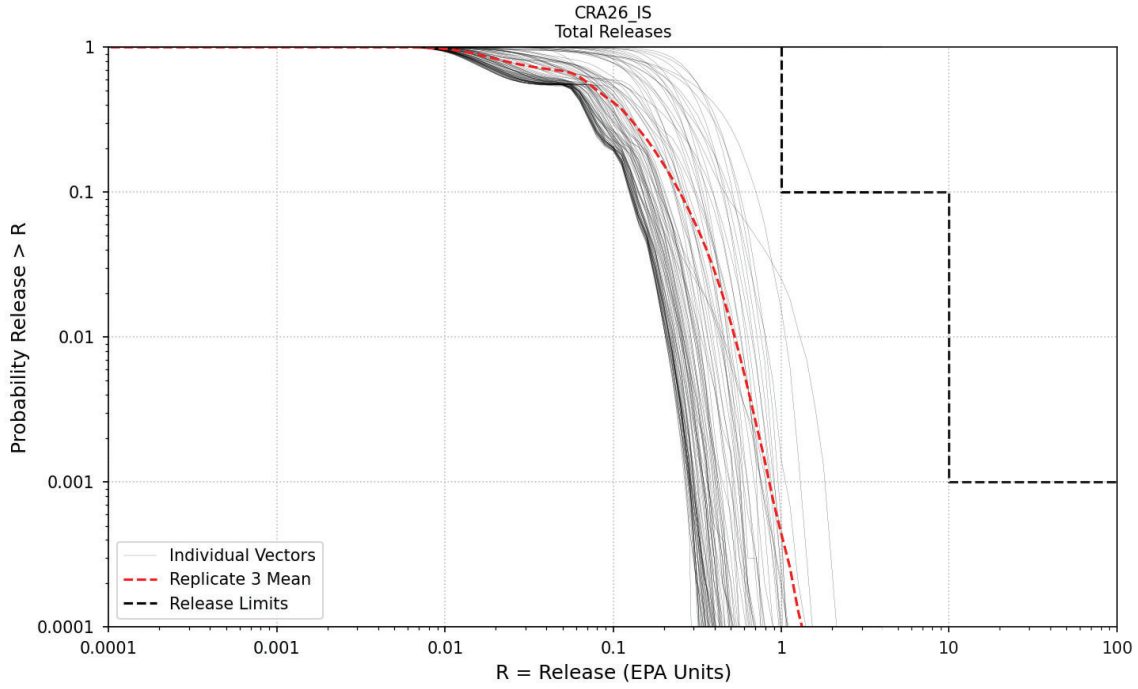


Figure 39. Total Releases for Replicate 3 of the CRA26_IS

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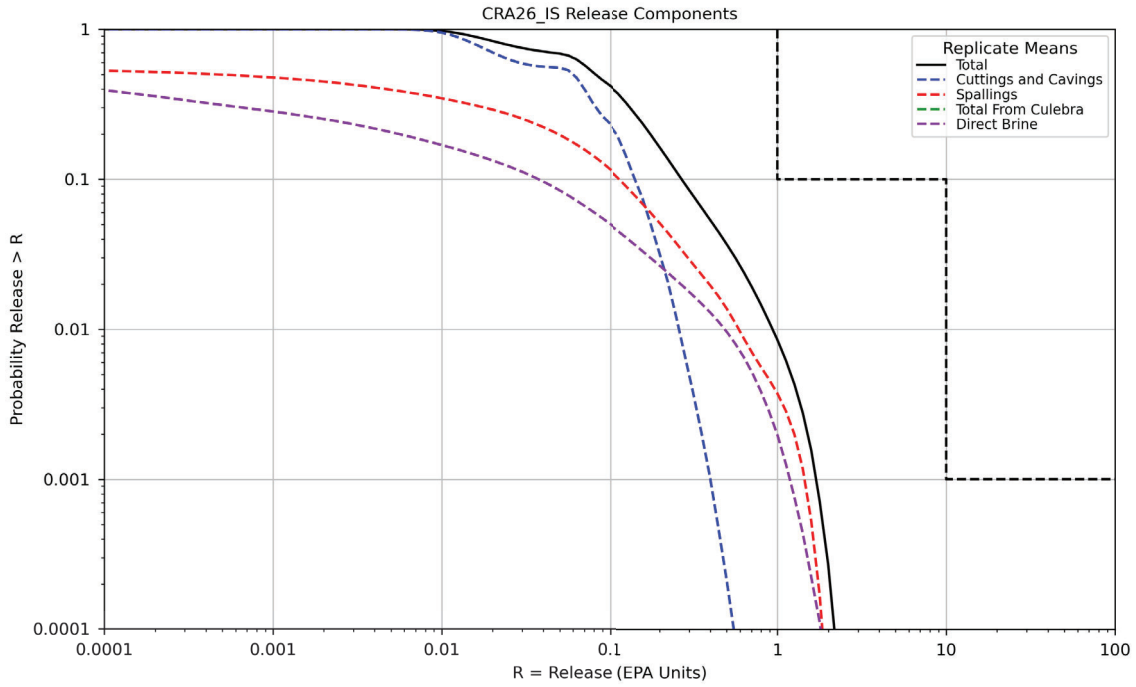


Figure 40. Overall Mean Releases Components for the CRA26_IS

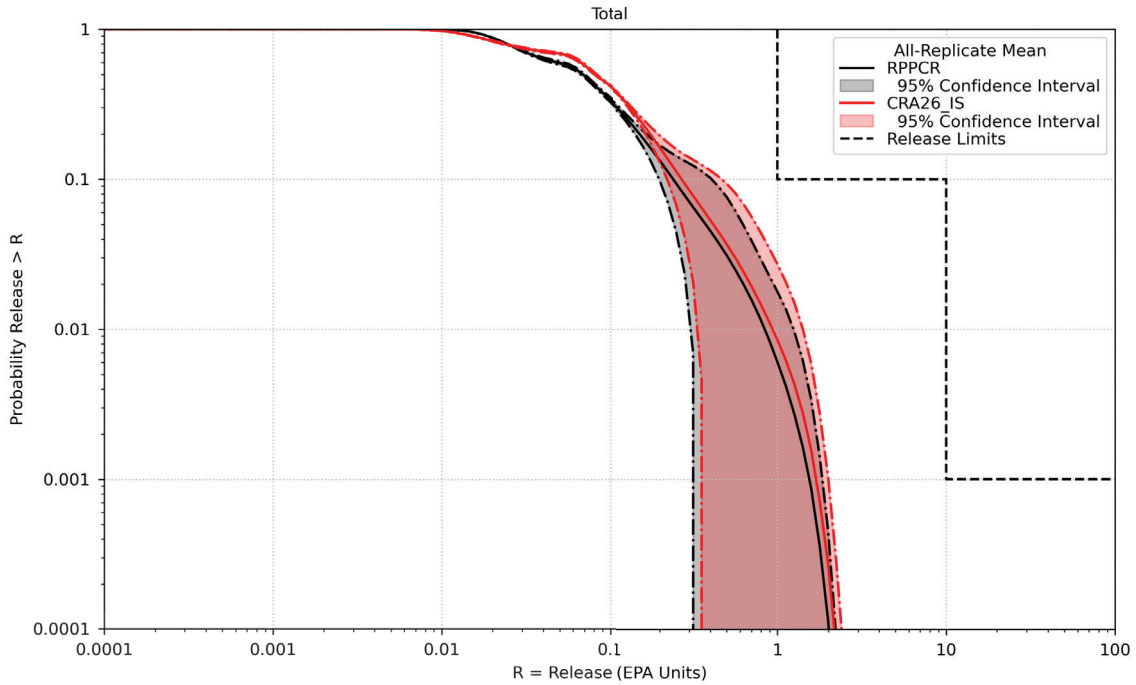


Figure 41. Overall Mean Total Releases for the CRA26_IS

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Table 5-18. Statistics on the Overall Mean for Total Releases

Analysis	P(R)>0.1 Lower CI (EPA Units)	P(R)>0.1 Mean (EPA Units)	P(R)>0.1 Upper CI (EPA Units)	P(R)>0.1 Release Limit (EPA Units)	P(R)>0.001 Lower CI (EPA Units)	P(R)>0.001 Mean (EPA Units)	P(R)>0.001 Upper CI (EPA Units)	P(R)>0.001 Release Limit (EPA Units)
RPPCR	0.1990	0.2418	0.4073	1	0.3360	1.5541	1.8716	10
CRA26_IS	0.2219	0.2713	0.4679	1	0.3678	1.7121	2.0062	10

5.6.2 Sensitivity Analysis for Total Releases

The sensitivity analysis for total releases was conducted using the STEPWISE code to identify the relative influence of uncertain parameters on the means of the CCDFs of releases. Table 5-19, Table 5-20, and Table 5-21 summarize the stepwise ranked regression analysis results for Replicates 1, 2, and 3 of the RPPCR and CRA26_IS.

Across all replicates, S_HALITE:POROSITY (intact halite porosity) consistently emerges as the dominant parameter controlling variability in total releases. For the RPPCR, S_HALITE:POROSITY explains between 27% and 36% of the variability. In the CRA26_IS, S_HALITE:POROSITY accounts for 18% to 27% of the variability. Figure 42 shows the relationship between S_HALITE:POROSITY and mean total releases. Sampling a high halite porosity is a necessary, but not sufficient, condition for driving the largest total releases.

BOREHOLE:TAUFAIL (effective shear strength for erosion) is the second most influential parameter across most replicates. For the RPPCR, BOREHOLE:TAUFAIL explains between 6% and 16% of the variability. In the CRA26_IS, BOREHOLE:TAUFAIL accounts for 6% to 13% of the variability. Figure 43 show the relationship between BOREHOLE:TAUFAIL and mean total releases. Sampling a very low effective shear strength will increase cavings releases which will increase total releases.

SPALLMOD:PARTDIAM (particle diameter for disaggregated waste) also plays a significant role, particularly in the CRA26_IS. SPALLMOD:PARTDIAM explains between 2% and 8% of the variability in the RPPCR and between 5% and 17% in the CRA26_IS. Figure 44 shows the relationship between SPALLMOD:PARTDIAM and mean total releases. Sampling a small particle diameter for disaggregated waste is a necessary, but not sufficient, condition for the largest mean total releases.

Other parameters, such as CASTILER:PRESSURE (initial brine pore pressure in the Castile), SOLMOD3:SOLVAR (solubility multiplier for actinides in the +III oxidation state), and WAS_AREA:BIOGENFC (probability of attaining sampled microbial gas generation rates), contribute less to the variability in total releases but appear consistently across replicates.

Overall, the sensitivity analysis results demonstrate that S_HALITE:POROSITY, BOREHOLE:TAUFAIL, and SPALLMOD:PARTDIAM are the primary drivers of variability in total releases for both the RPPCR and CRA26_IS. The CRA26_IS results show slightly higher variability for SPALLMOD:PARTDIAM, likely due to increased contributions from spallings releases driven by changes in the waste inventory.

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Table 5-19. Stepwise Ranked Regression Analysis for Mean Total Releases for Replicate 1 of the RPPCR and CRA26_IS

	RPPCR Replicate 1			CRA26_IS Replicate 1		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	S_HALITE:POROSITY	0.35	0.57	S_HALITE:POROSITY	0.27	0.49
2	BOREHOLE:TAUFAIL	0.41	-0.26	SPALLMOD:PARTDIAM	0.33	-0.25
3	CASTILER:PRESSURE	0.47	0.25	BOREHOLE:TAUFAIL	0.39	-0.23
4	SOLMOD3:SOLVAR	0.50	0.17	CASTILER:PRESSURE	0.43	0.22
5	STEEL:CORRMCO2	0.53	-0.19	STEEL:CORRMCO2	0.47	-0.22
6	WAS_AREA:PROBDEG	0.56	0.16	WAS_AREA:PROBDEG	0.49	0.17
7	DRZ_1:PRMX_LOG	0.58	0.16	SOLMOD3:SOLVAR	0.52	0.16
8	SPALLMOD:PARTDIAM	0.60	-0.14	SPALLMOD:REPIPERM	0.54	0.15
9	S_MB139:PRMX_LOG	0.62	0.14			

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

Table 5-20. Stepwise Ranked Regression Analysis for Mean Total Releases for Replicate 2 of the RPPCR and CRA26_IS

	RPPCR Replicate 2			CRA26_IS Replicate 2		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	S_HALITE:POROSITY	0.36	0.61	S_HALITE:POROSITY	0.24	0.51
2	BOREHOLE:TAUFAIL	0.43	-0.28	BOREHOLE:TAUFAIL	0.31	-0.28
3	CASTILER:PRESSURE	0.51	0.28	GLOBAL:PBRINE	0.37	0.26
4	GLOBAL:PBRINE	0.56	0.22	CASTILER:PRESSURE	0.42	0.23
5	DRZ_1:PRMX_LOG	0.58	0.17	SPALLMOD:PARTDIAM	0.47	-0.23
6	WAS_AREA:BIOGENFC	0.60	0.14	WAS_AREA:BIOGENFC	0.50	0.19
7	SOLMOD3:SOLVAR	0.62	0.14	BH_SAND:PRMX_LOG	0.53	-0.15
8	SPALLMOD:PARTDIAM	0.64	-0.14	SOLMOD3:SOLVAR	0.55	0.16
9	BH_SAND:PRMX_LOG	0.66	-0.12	WAS_AREA:GRATMICI	0.58	0.16
10				STEEL:CORRMCO2	0.60	-0.14

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

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Table 5-21. Stepwise Ranked Regression Analysis for Mean Total Releases for Replicate 3 of the RPPCR and CRA26_IS

	RPPCR Replicate 3			CRA26_IS Replicate 3		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable	R^2	SRRC
1	S_HALITE:POROSITY	0.27	0.49	S_HALITE:POROSITY	0.18	0.39
2	BOREHOLE:TAUFAIL	0.43	-0.39	SPALLMOD:PARTDIAM	0.35	-0.38
3	SPALLMOD:PARTDIAM	0.51	-0.28	BOREHOLE:TAUFAIL	0.48	-0.35
4	CASTILER:PRESSURE	0.55	0.20	(Composite):MKD_U	0.51	-0.15
5	SOLMOD3:SOLVAR	0.58	0.17	CASTILER:PRESSURE	0.54	0.18
6	(Composite):MKD_U	0.61	-0.18	WAS_AREA:SAT_WICK	0.57	0.14
7	WAS_AREA:SAT_WICK	0.64	0.17	WAS_AREA:GRATMICH	0.59	0.15
8	DRZ_PCS:PRMX_LOG	0.66	-0.14	WAS_AREA:BIOGENFC	0.61	0.15
9				SPALLMOD:REPIPOR	0.63	-0.14
10				S_HALITE:PRESSURE	0.64	-0.13
11				GLOBAL:PBRINE	0.66	0.13

[a] Steps in stepwise regression analysis
[b] Variables listed in order of selection
[c] Cumulative R^2 value with entry of each variable into regression model
[d] Standardized Rank Regression Coefficient

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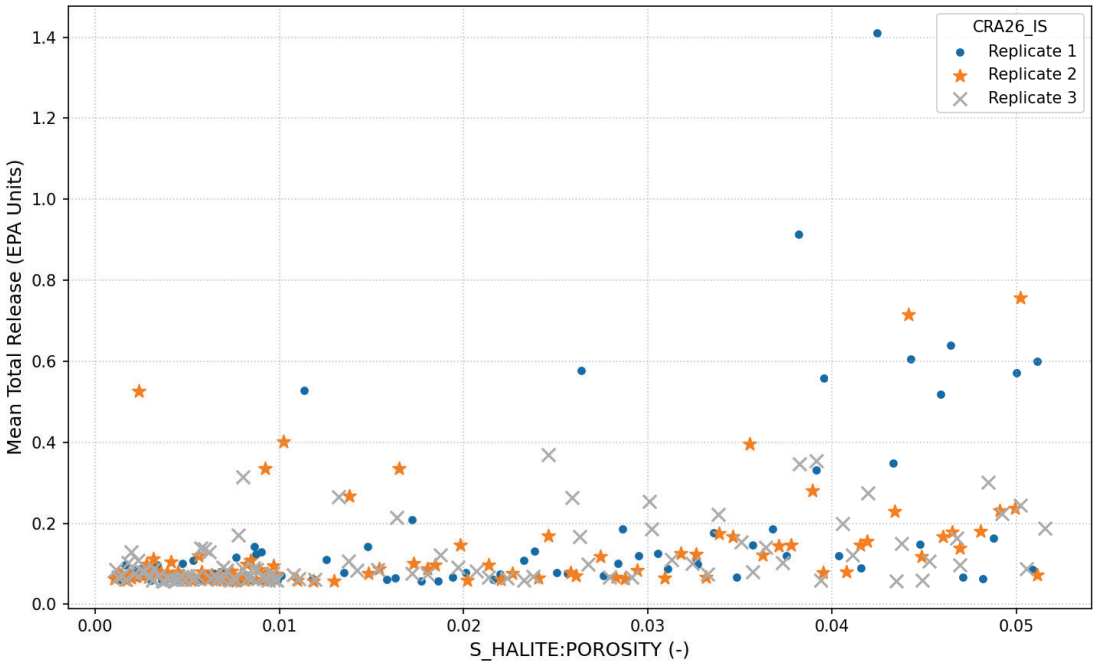


Figure 42. S_HALITE:POROSITY versus Mean Total Releases for CRA26_IS

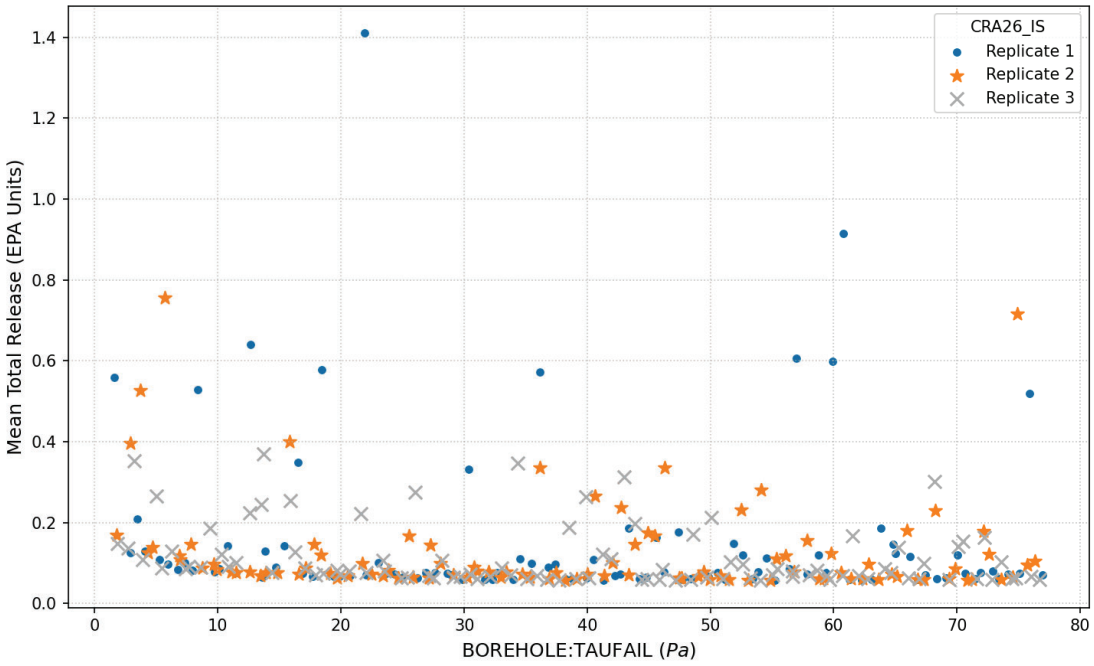


Figure 43. BOREHOLE:TAUFAIL versus Mean Total Releases for CRA26_IS

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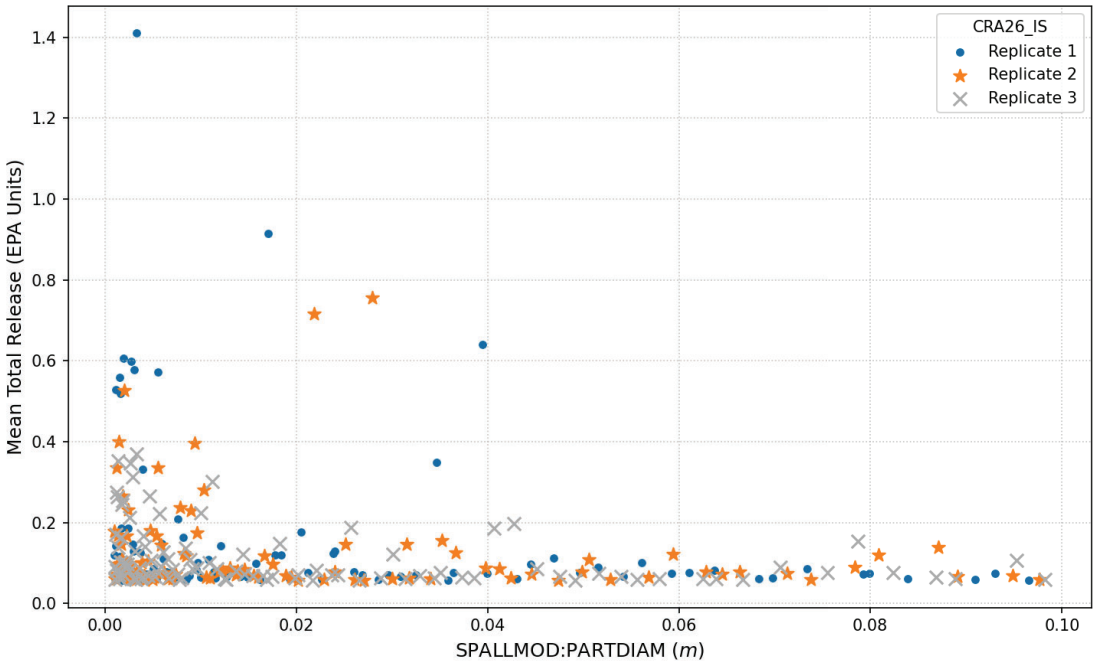


Figure 44. SPALLMOD:PARTDIAM versus Mean Total Releases for CRA26_IS

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6.0 SUMMARY

The CRA26_IS analysis evaluates the performance of the interim state repository configuration for the Waste Isolation Pilot Plant (WIPP) and demonstrates compliance with containment requirements under 40 CFR Part 191. This analysis incorporates updates to repository design, waste inventory, and modeling parameters relative to the RPPCR, reflecting the interim state 12-panel repository layout.

Key findings from the CRA26_IS analysis include:

1. Cuttings and Cavings Releases: The CRA26_IS results show slightly higher cuttings and cavings releases compared to the RPPCR, driven by increased radionuclide activity concentrations in the waste inventory.
2. Spallings Releases: Spallings releases are higher in the CRA26_IS due to increases in the waste activity concentrations. Changes in the repository pressure, drilling rate, and repository footprint also contribute to changes in spallings releases.
3. Direct Brine Releases: Direct brine releases are lower at higher probabilities in the CRA26_IS compared to the RPPCR, reflecting the smaller repository footprint. At lower probabilities, direct brine releases are slightly higher due to increased mobile radionuclide concentrations.
4. Activity Entering the Culebra: Activity entering the Culebra is reduced in the CRA26_IS due to the smaller repository footprint and changes in radionuclide inventory. These reductions limit the potential for radionuclide transport through the Culebra.
5. Releases Through the Culebra: Releases through the Culebra are negligible in the CRA26_IS, with results effectively zero across all replicates. The exclusion of CRP 4 and updated transmissivity fields further minimize radionuclide transport through the Culebra.
6. Total Releases: Total releases in the CRA26_IS are slightly higher than those in the RPPCR, primarily due to increased contributions from spallings and direct brine releases. Despite these increases, total releases remain well below regulatory limits, demonstrating compliance with containment requirements.

The sensitivity analysis results highlight the importance of parameters such as S_HALITE:POROSITY, BOREHOLE:TAUFAIL, and SPALLMOD:PARTDIAM in controlling variability across release pathways. The sensitivity analysis for the CRA26_IS has findings consistent with the sensitivity analysis for the RPPCR. Changes in repository pressures, waste inventory, and drilling rates amplify the influence of these parameters in the CRA26_IS.

Overall, the CRA26_IS analysis confirms that the interim state repository configuration continues to meet regulatory requirements for containment. The findings demonstrate the effectiveness of the repository design, radionuclide transport mechanisms, and updated modeling parameters in ensuring long-term safety and compliance.

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8.0 APPENDIX A – PARAMETER SENSITIVITY ANALYSIS METHODOLOGY

In this appendix, the conceptual approach, mathematical model, and limitations of the STEPWISE sensitivity analysis are discussed.

8.1 STEPWISE Code

The STEPWISE code is used as part of the sensitivity analysis to determine the relative importance of uncertainty in the sampled parameters in the CRA26_IS analysis. STEPWISE receives sampled input parameter values and calculated outputs, such as a mean release across 10,000 futures, that correspond to those input parameters on a vector basis.

Calculations for the CRA26_IS were performed on the WIPP PA HPC/Linux Cluster, which consists of Dell PowerEdge C6420 hardware running CentOS7 (Long 2025). The STEPWISE code v2.23 was used in CRA26_IS calculations. No changes to the hardware or STEPWISE code have been made since the RPPCR.

8.2 Conceptual Approach for the CRA26_IS

No changes have been made to the conceptualization of parameter sampling since the RPPCR. Under the standard approach, a determination is first made as to which parameters are epistemically uncertain and parameter distributions are defined for those parameters and entered into the WIPP PA Parameter Database (ParamDB) (Feng and Kicker 2025). Uncertain parameters are sampled from these defined distributions using a Latin Hypercube sampling design for three replicates of 100 sets of sampled parameters (King and Zeitler 2025). Following the execution of WIPP PA codes for 100 realizations (“vectors”) (each of which uses one set of specified parameters) of each replicate, calculated releases are entered into the WIPP PA Results Database (PA_Results). A stepwise linear multiple regression (“sensitivity”) analysis is then performed to determine the relative importance of the sampled parameters on the calculated mean releases. The sensitivity analysis is used to resolve the question of which *sampled* parameters contribute the most to the variability (uncertainty) observed in the mean releases by vector. Not all variables are included in the analysis for all release types in order to reduce the number of spurious correlations (see Table 8-2 for mapping variable to material:property). In most cases, the variables included in the analysis for a given release type are those that could potentially impact the release type. The sensitivity analysis performed using stepwise regression cannot be used to explain sensitivity of the results to the changes implemented in the models, fixed parameters, or inventory components of a WIPP PA analysis.

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Table 8-1. Variables Included in Sensitivity Analysis for Each Release Pathway

Cuttings and Cavings Releases	Spallings Releases	Direct Brine Volume	Direct Brine Releases	Activity Entering the Culebra	Releases From Culebra	Total Releases
DOMEGA	ANHBCEXP	ANHBCEXP	ANHBCEXP	ANHBCEXP	ANHBCEXP	ANHBCEXP
WTAUFAIL	ANHBCVGP	ANHBCVGP	ANHBCVGP	ANHBCVGP	ANHBCVGP	ANHBCVGP
ANHBCEXP*	ANHPRM	ANHPRM	ANHPRM	ANHPRM	ANHPRM	ANHPRM
ANHBCVGP*	ANRBRSAT	ANRBRSAT	ANRBRSAT	ANRBRSAT	ANRBRSAT	ANRBRSAT
ANHPRM*	BHPERM	BHPERM	BHPERM	BHPERM	BHPERM	BHPERM
ANRBRSAT*	BPINTPRS	BPINTPRS	BPINTPRS	BPINTPRS	BPINTPRS	BPINTPRS
BHPERM*	BPPRM	BPPRM	BPPRM	BPPRM	BPPRM	BPPRM
BPCOMP*	DOMEGA	DRZPCPRM	DRZPCPRM	DRZPCPRM	CCLIMSF	CCLIMSF
BPINTPRS*	DRZPCPRM	DRZPRM	DRZPRM	DRZPRM	CFRACPOR	CFRACPOR
BPPRM*	DRZPRM	GDEPFAC	GDEPFAC	GDEPFAC	CFRACSP	CFRACSP
DRZPCPRM*	GDEPFAC	HALPOR	HALPOR	HALPOR	CMKDAM3	CMKDAM3
DRZPRM*	HALPOR	HALPRM	HALPRM	HALPRM	CMKDTH4	CMKDTH4
GDEPFAC*	HALPRM	PBRINE	PBRINE	PBRINE	CMTRXPOR	CMTRXPOR
HALCROCK*	PBRINE	PLGPRM	PLGPRM	PLGPRM	DRZPCPRM	DOMEGA
HALPOR*	PLGPRM	SALPRES	SALPRES	SALPRES	DRZPRM	DRZPCPRM
HALPRM*	REPIPERM	SHLPRM2	SHLPRM2	SHLPRM2	GDEPFAC	DRZPRM
PLGPRM*	SALPRES	SHLPRM3	SHLPRM3	SHLPRM3	HALPOR	GDEPFAC
REPIPERM*	SHLPRM2	SHUPRM	SHUPRM	SHUPRM	HALPRM	HALPOR
SALPRES*	SHLPRM3	SHURBRN	SHURBRN	SHURBRN	PBRINE	HALPRM
SHLPRM2*	SHUPRM	SHURGAS	SHURGAS	SHURGAS	PLGPRM	PBRINE
SHLPRM3*	SHURBRN	STHUMCOR	STHUMCOR	STHUMCOR	SALPRES	PLGPRM
SHUPRM*	SHURGAS	T1PDIS	T1PDIS	T1PDIS	SHLPRM2	REPIPERM
SHURBRN*	SPLPTDIA	T1POROS	T1POROS	T1POROS	SHLPRM3	SALPRES
SHURGAS*	SPLRPOR	T1PRMX	T1PRMX	T1PRMX	SHUPRM	SHLPRM2
SPLPTDIA*	STHUMCOR	T1SRBRN	T1SRBRN	T1SRBRN	SHURBRN	SHLPRM3
SPLRPOR*	T1PDIS	T1SRGAS	T1SRGAS	T1SRGAS	SHURGAS	SHUPRM
STHUMCOR*	T1POROS	T2P2PERM	T2P2PERM	T2P2PERM	STHUMCOR	SHURBRN
T1PDIS*	T1PRMX	T2POROS	T2POROS	T2POROS	T1PDIS	SHURGAS
T1POROS*	T1SRBRN	T3POROS	T3POROS	T3POROS	T1POROS	SPLPTDIA
T1PRMX*	T1SRGAS	WASTWICK	WASTWICK	WASTWICK	T1PRMX	SPLRPOR
T1SRBRN*	T2P2PERM	WBIOGENF	WBIOGENF	WBIOGENF	T1SRBRN	STHUMCOR
T1SRGAS*	T2POROS	WBRUITEC	WBRUITEC	WBRUITEC	T1SRGAS	T1PDIS
T2P2PERM*	T3POROS	WBRUITEH	WBRUITEH	WBRUITEH	T2P2PERM	T1POROS
T2POROS*	TENSLSTR	WBRUITES	WBRUITES	WBRUITES	T2POROS	T1PRMX

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Cuttings and Cavings Releases	Spallings Releases	Direct Brine Volume	Direct Brine Releases	Activity Entering the Culebra	Releases From Culebra	Total Releases
T3POROS*	WASTWICK	WGRCOR	WGRCOR	WGRCOR	T3POROS	T1SRBRN
TENSLSTR*	WBIOGENF	WGRMICH	WGRMICH	WGRMICH	WASTWICK	T1SRGAS
WASTWICK*	WBRUITEC	WGRMICI	WGRMICI	WGRMICI	WBIOGENF	T2P2PERM
WBIOGENF*	WBRUITEH	WHYMAGC	WHYMAGC	WHYMAGC	WBRUITEC	T2POROS
WBRUITEC*	WBRUITES	WMICDFLG	WMICDFLG	WMICDFLG	WBRUITEH	T3POROS
WBRUITEH*	WGRCOR	WRBRNSAT	WRBRNSAT	WRBRNSAT	WBRUITES	TENSLSTR
WBRUITES*	WGRMICH	WRGSSAT	WRGSSAT	WRGSSAT	WGRCOR	WASTWICK
WGRCOR*	WGRMICI	WSOLVAR3	WSOLVAR3	WSOLVAR3	WGRMICH	WBIOGENF
WGRMICH*	WHYMAGC	WSOLVAR4	WSOLVAR4	WSOLVAR4	WGRMICI	WBRUITEC
WGRMICI*	WMICDFLG	OXSTAT	OXSTAT	OXSTAT	WHYMAGC	WBRUITEH
WHYMAGC*	WRBRNSAT	BPCOMP*	BPCOMP*	BPCOMP*	WMICDFLG	WBRUITES
WMICDFLG*	WRGSSAT	HALCROCK*	HALCROCK*	HALCROCK*	WRBRNSAT	WGRCOR
WRBRNSAT*	WSOLVAR3				WRGSSAT	WGRMICH
WRGSSAT*	WSOLVAR4				WSOLVAR3	WGRMICI
	WTAUFAIL				WSOLVAR4	WHYMAGC
	OXSTAT				DTRKCRP1	WMICDFLG
	BPCOMP*				DTRKCRP2	WRBRNSAT
	HALCROCK*				CMKDPU	WRGSSAT
					CMKDU	WSOLVAR3
					BPCOMP*	WSOLVAR4
					HALCROCK*	WTAUFAIL
					DTRKCRP3*	DTRKCRP1
					DTRKCRP4*	DTRKCRP2
						CMKDPU
						CMKDU
						OXSTAT
						BPCOMP*
						HALCROCK*
						DTRKCRP3*
						DTRKCRP4*

* Included in the RPPCR sensitivity analysis but not the CRA26_IS sensitivity analysis.

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8.3 Stepwise Linear Multiple Regression

WIPP PA employs stepwise linear multiple regression to evaluate the relative importance of the various sampled parameters on the estimates of potential releases. In the forward stepwise approach used by the STEPWISE code, a regression model is constructed by sequentially selecting the predictors, starting with the input parameter that has the strongest simple correlation with the output variable. Partial correlations between the output and the remaining variables are then computed. The partial correlations remove the effects of variables already included in the model. The variable having the largest significant partial correlation coefficient is added next, and the partial correlations for the remaining input variables are recomputed. Stepwise regression is applied to ranked input parameters and output variables.

8.3.1 Determination of Significance

Significance is determined using an F-test, and the significance level for adding an input variable to the model is 1 - α_{in}, where α_{in} is the significance level for a Type I error that is set by the analyst. The F-test compares the variability contributed by the variable to the variability not accounted for by the regression, i.e., the variability of the residuals. By default, the STEPWISE code sets α_{in} = 0.05, so that one is 95% confident that there is a partial correlation between the input and output variables. This process is repeated until no remaining variables have significant correlations with the output variable. Variables excluded from the regression model contribute no significant information in relation to the unexplained variability and hence the results are judged to be relatively insensitive to those parameters. The method does not guarantee that the relative contributions of model parameters to the R^2 (coefficient of determination) will always be smaller with increasing rank, but this is often the case.

8.3.2 Regression Coefficients

Input variables that are added to the regression model are not necessarily retained at later iterations. For an input variable to be retained, its regression coefficient (i.e., the linear contribution of an input to the prediction of the output variable) must be statistically distinguishable from zero. A t-test is used to determine whether a regression coefficient is significantly different than zero. The t-test evaluates the null hypothesis that the regression coefficient is zero. The hypothesis is not rejected when random effects can give rise to the observed regression coefficient with probability α_{out}. The random effects are caused by the stochastic variability contributed by the input variables not in the regression model. In other words, the hypothesis is rejected, and the variable is included in the model when the 1 - α_{out} confidence interval of the regression coefficient does not encompass zero.

By default, the α_{out} value used by the STEPWISE code for allowing a variable to exit the regression model is 0.05. Thus, in the default case, one is 95% confident that the input variables make a linear contribution to the response of the output variable. The user may specify different α-values in the input control file. However, the value allowing a variable to enter the model, α_{in}, must be less than or equal to the value by which a variable is allowed to leave the model, α_{out}, to avoid looping. In

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the sensitivity analysis calculations performed for the CRA26_IS analysis, α_{in} was 0.05, and α_{out} was 0.05.

8.3.3 Predicted Error Sum of Squares

The predicted error sum of squares (PRESS) is computed to detect over-fitting of the regression model to the data. Over-fitting can occur when the regression methodology causes the fit to favor specific points rather than the general shape of the data curve. In such a case the minimum value of PRESS may occur earlier than the last step in the regression analysis. No such condition was observed in any of the rank correlation analyses reported herein.

8.4 Parameters Sampled for the CRA26_IS

The input files for STEPWISE use short names for input parameters rather than material:property designations used in other WIPP PA codes. These short names are required because of a limitation in the length of variable names in the STEPWISE code. Table 8-2 associates these names with the material and property names. For each sampled parameter in the CRA26_IS analysis, there is an assigned variable.

In addition, three variables are created in STEPWISE through transformation of the GLOBAL:OXSTAT parameter, the indicator variable for actinide oxidation states. The GLOBAL:OXSTAT parameter is sampled as a uniform distribution with range [0,1], but is treated in the BRAGFLO, PANEL, and SECOTP2D codes as a Bernoulli distribution (a distribution having only two discrete states). The computed variable WOXSTAT is assigned 0 if GLOBAL:OXSTAT is less than 0.25 and is assigned 1 otherwise. WOXSTAT follows the oxidation state distribution for Pu oxidation state as Pu is the most impactful of the multi-valance state radionuclide in the WIPP PA.

Two other computed variables represent the K_ds for the different oxidation states of uranium and plutonium considered in WIPP PA. A K_d value represents the matrix:water partitioning coefficient. If GLOBAL:OXSTAT is less than 0.5, then the CMKDU variable is assigned the sampled value of U+4:MKD_U, i.e., the K_ds for the +IV oxidation state of uranium, otherwise it is assigned the sampled value of U+6:MKD_U, i.e., the K_ds for the +VI oxidation state of uranium. Similarly, if GLOBAL:OXSTAT is less than 0.25 then, CMKDPU is assigned the sampled value of PU+3:MKD_PU, i.e., the K_ds for the +III oxidation state of plutonium, otherwise, the CMKDPU is assigned PU+4:MKD_PU, i.e., the K_ds for the +IV oxidation state of plutonium. This is done because some sampled parameter values used in WIPP PA calculations depend on the sampled value of the GLOBAL:OXSTAT parameter. In the discussion below, these variables are referenced as (Composite):MKD_U and (Composite):MKD_PU in order to denote their status as composites of pairs of sampled parameters.

Additionally, two variables were created for travel times from Culebra release points to the Land Withdrawal Boundary (see discussion in Wilgus and Bethune 2025). The two new variables (dtrkcrp1, dtrkcrp2) represent the travel times from each Culebra release point to the LWB of a non-sorbing particle for each realization of the transmissivity field. The new variables were added to properly assess any correlations between particle travel time and releases.

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Table 8-2. Material and Property Names Associated with Variable Names Used in the RPPCR and CRA26_IS Sensitivity Analyses

Material	Property	Variable Name	Description
AM+3	MKD_AM	CMKDAM3	Americium III, matrix partition coefficient for americium
BH_SAND	PRMX_LOG	BHPERM	Borehole filled with silty sand, log of intrinsic permeability, x-direction
BOREHOLE	DOMEGA	DOMEGA	Borehole and fill, drill string angular velocity (0)
BOREHOLE	TAUFAIL	WTAUFAIL	Borehole and fill, effective shear strength for erosion
CASTILER	COMP_RCK	BPCOMP	Castile brine reservoir, bulk compressibility
CASTILER	PRESSURE	BPINTPRS	Castile brine reservoir, brine far-field pore pressure
CASTILER	PRMX_LOG	BPPRM	Castile brine reservoir, log of intrinsic permeability, x-direction
CONC_PLG	PRMX_LOG	PLGPRM	Concrete plug, surface and rustler, log of intrinsic permeability, x-direction
CULEBRA	APOROS	CFRACPOR	Culebra member of the rustler formation, Culebra advective porosity
CULEBRA	DPOROS	CMTRXPOR	Culebra member of the rustler formation, diffusive porosity for Culebra dolomite
CULEBRA	HMBLKLT	CFRACSP	Culebra member of the rustler formation, Culebra half matrix-block length
CULEBRA	MINP_FAC	CTRANSFM	Culebra member of the rustler formation, mining transmissivity multiplier
DRZ_1	PRMX_LOG	DRZPRM	Disturbed rock zone during the time period that begins with facility closure (0 years) and ends when DRZ healing is complete, log of intrinsic permeability, x-direction
DRZ_PCS	PRMX_LOG	DRZPCPRM	DRZ directly above the panel closure system, log of intrinsic permeability, x-direction

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Material	Property	Variable Name	Description
GLOBAL	CLIMTIDX	CCLIMSF	Information that applies globally, climate index
GLOBAL	GDEPFAC	GDEPFAC	Information that applies globally, energy deposition probability for wetted solid radionuclides
GLOBAL	OXSTAT	WOXSTAT	Information that applies globally, index for the oxidation state
GLOBAL	PBRINE	PBRINE	Information that applies globally, probability that drilling intrusion in excavated area encounters pressurized brine
GLOBAL	TRANSIDX	CTRAN	Information that applies globally, index for selecting realizations of the transmissivity field
PCS_T1	PORE_DIS	T1PDIS	Panel closure system for an initial time duration, Brooks-Corey pore distribution parameter
PCS_T1	POROSITY	T1POROS	Panel closure system for an initial time duration, effective porosity
PCS_T1	PRMX_LOG	T1PRMX	Panel closure system for an initial time duration, log of intrinsic permeability, x-direction
PCS_T1	SAT_RBRN	T1SRBRN	Panel closure system for an initial time duration, residual brine saturation
PCS_T1	SAT_RGAS	T1SRGAS	Panel closure system for an initial time duration, residual gas saturation
PCS_T2	POR2PERM	T2P2PERM	Panel closure system for a secondary time duration, distribution used to calculate permeability from sampled porosity values
PCS_T2	POROSITY	T2POROS	Panel closure system for a secondary time duration, effective porosity
PCS_T3	POROSITY	T3POROS	Run-of-mine panel closure system, tertiary time period, effective porosity
PU+3	MKD_PU	CMKDPU3	Plutonium III, matrix partition coefficient for plutonium

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Material	Property	Variable Name	Description
PU+4	MKD_PU	CMKDPU4	Plutonium IV, matrix partition coefficient for plutonium
S_HALITE	COMP_RCK	HALCROCK	Salado halite, intact, bulk compressibility
S_HALITE	POROSITY	HALPOR	Salado halite, intact, effective porosity
S_HALITE	PRESSURE	SALPRES	Salado halite, intact, brine far-field pore pressure
S_HALITE	PRMX_LOG	HALPRM	Salado halite, intact, log of intrinsic permeability, x-direction
S_MB139	PORE_DIS	ANHBCEXP	Salado marker bed 139, intact and fractured, Brooks-Corey pore distribution parameter
S_MB139	PRMX_LOG	ANHPRM	Salado marker bed 139, intact and fractured, log of intrinsic permeability, x-direction
S_MB139	RELP_MOD	ANHBCVGP	Salado marker bed 139, intact and fractured, model number, relative permeability model
S_MB139	SAT_RBRN	ANRBRSAT	Salado marker bed 139, intact and fractured, residual brine saturation
SHFTL_T1	PRMX_LOG	SHLPRM2	Lower portion of simplified shaft from 0 - 200 years, log of intrinsic permeability, x-direction
SHFTL_T2	PRMX_LOG	SHLPRM3	Lower portion of simplified shaft from 200 - 10,000 years, log of intrinsic permeability, x-direction
SHFTU	PRMX_LOG	SHUPRM	Upper portion of simplified shaft, log of intrinsic permeability, x-direction
SHFTU	SAT_RBRN	SHURBRN	Upper portion of simplified shaft, residual brine saturation
SHFTU	SAT_RGAS	SHURGAS	Upper portion of simplified shaft, residual gas saturation
SOLMOD3	SOLVAR	WSOLVAR3	Oxidation state III model, solubility multiplier

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Material	Property	Variable Name	Description
SOLMOD4	SOLVAR	WSOLVAR4	Oxidation state IV model, solubility multiplier
SPALLMOD	PARTDIAM	SPLPTDIA	Material developed for DRSPALL, particle diameter of disaggregated waste
SPALLMOD	REPIPERM	REPIPERM	Material developed for DRSPALL, waste permeability to gas local to intrusion borehole
SPALLMOD	REPIPOR	SPLRPOR	Material developed for DRSPALL, waste porosity at time of drilling intrusion
SPALLMOD	TENSLSTR	TENSLSTR	Material developed for DRSPALL, tensile strength of waste
STEEL	CORRMCO2	WGRCOR	Generic steel in waste, inundated corrosion rate for steel without CO2 present
STEEL	HUMCORR	HUMCORR	Generic steel in waste, humid corrosion rate for steel
TH+4	MKD_TH	CMKDTH4	Thorium IV, matrix partition coefficient for thorium
U+4	MKD_U	CMKDU4	Uranium IV, matrix partition coefficient for uranium
U+6	MKD_U	CMKDU6	Uranium VI, matrix partition coefficient for uranium
WAS_AREA	BIOGENFC	WBIOGENF	Waste emplacement area and waste, probability of attaining sampled microbial-gas-generation rates
WAS_AREA	BRUCITEC	WBRUITEC	Waste emplacement area and waste, MgO inundated hydration rate in ERDA-6 brine
WAS_AREA	BRUCITEH	WBRUITEH	Waste emplacement area and waste, MgO humid hydration rate
WAS_AREA	BRUCITES	WBRUITES	Waste emplacement area and waste, MgO inundated hydration rate in GWB brine
WAS_AREA	GRATMICH	WGRMICH	Waste emplacement area and waste, humid biodegradation rate for cellulose
WAS_AREA	GRATMICI	WGRMICI	Waste emplacement area and waste, inundated biodegradation rate for cellulose

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Material	Property	Variable Name	Description
WAS_AREA	HYMAGCON	WHYMAGC	Waste emplacement area and waste, rate of conversion of hydromagnesite to magnesite
WAS_AREA	PROBDEG	WMICDFLG	Waste emplacement area and waste, probability of plastics and rubber biodegradation in event of microbial gas generation
WAS_AREA	SAT_RBRN	WRBRNSAT	Waste emplacement area and waste, residual brine saturation
WAS_AREA	SAT_RGAS	WRGSSAT	Waste emplacement area and waste, residual gas saturation
WAS_AREA	SAT_WICK	WASTWICK	Waste emplacement area and waste, index for computing wicking
Composite	OXSTAT	OXSTAT [a]	Transformation for uniform [0,1] sample of WOXSTAT to discrete (0, 1) realization of Pu oxidation state (low=0, high=1)
Composite	MKD_PU	CMKDPU [a]	Composite parameter of the realized Pu matrix partition coefficient based on the sampling of CMKDPU3, CMKDPU4, and WOXSTAT
Composite	MKD_U	CMKDU [a]	Composite parameter for the realized U matrix partition coefficient based on the sampling of CMKDU4, CMKDU6, and WOXSTAT
CRP1	Travel Time	dtrkcrp1 [b]	Particle travel time from Culebra release point 1 to Land Withdrawal Boundary
CRP2	Travel Time	dtrkcrp2 [b]	Particle travel time from Culebra release point 2 to Land Withdrawal Boundary

a – Material and property for this variable do not correlate to a material and property in the WIPP Parameter Database; instead, this variable is created dynamically from other STEPWISE variables.

b – Material and property for this variable do not correlate to a material and property in the WIPP Parameter Database; instead, this variable is taken from the output of the DTKRMF code (Wilgus and Bethune 2025).

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8.5 Limitations of the Stepwise Analysis

For clarity on the scope of the sensitivity analysis, some details on the limitations of the analysis are laid out in the subsections below.

8.5.1 Linear Regression Model

The STEPWISE sensitivity analysis constructs a multivariate linear regression model. One of the assumptions of this statistical model is that the dependent (output) variable shows a linear response to the independent (input) variables. In cases where the response is non-linear but monotonic, replacing the values of the data with their ranks tends to linearize the response curves and standardizes the variability in the outputs and parameters by mapping the data into identical ranges. The sensitivity analyses performed for this analysis used ranked variables, which reduces the impact of a non-linear response between input and output variables on the analysis results.

The rank of a value is an integer representing its position in the sorted list of the values. Ranking also tends to de-emphasize the impact of "outliers," which are points having considerably larger or smaller values than the remainder of the sample population. Although the use of ranks precludes using the model to predict values of an output variable given an input variable, the results are usually well suited for ranking the importance of the contributions of the input variables to the response of the output variable. A previous analysis using ranked regression showed stronger correlations than the regressions based on the unranked data, which suggested that there are non-linear relationships between the dependent and independent variables, but it does not eliminate the possibility that there are also non-monotonic relationships (Kirchner 2013).

8.5.2 Scarcity of Data

There are also cases (e.g., releases from the Culebra and spallings releases) where large proportions of the vectors in each replicate show no credible release values (values < 0.0001 EPA units) or zero releases (Table 8-3 through Table 8-6). Values less than 0.0001 EPA units are considered to be dominated by numerical error and hence often unreliable. In terms of ranking the relative importance of the parameters, the issue of a large proportion of zeros or unreliable values is problematic. In such cases, results are examined visually, and stepwise regression is not performed to avoid conclusions based on spurious correlations.

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Table 8-3. Percentage of Vectors with Maximum Release Exceeding 0 and 0.0001 EPA Units for CRA26_IS

CRA26_IS	Replicate 1		Replicate 2		Replicate 3	
Release Type	>0	$>10^{-4}$	>0	$>10^{-4}$	>0	$>10^{-4}$
Cuttings and Cavings	100	100	100	100	100	100
Direct Brine	93	90	94	88	96	86
Spallings	69	69	69	69	68	67
Total	100	100	100	100	100	100
Total From Culebra	90	0	89	0	94	0
Total To Culebra	90	44	89	43	94	50

Table 8-4. Percentage of Vectors with Maximum Release Exceeding 0 and 0.0001 EPA Units for RPPCR

RPPCR	Replicate 1		Replicate 2		Replicate 3	
Release Type	>0	$>10^{-4}$	>0	$>10^{-4}$	>0	$>10^{-4}$
Cuttings and Cavings	100	100	100	100	100	100
Direct Brine	98	94	97	96	98	98
Spallings	66	66	67	67	66	66
Total	100	100	100	100	100	100
Total From Culebra	86	0	87	2	92	2
Total To Culebra	86	45	87	44	92	50

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Table 8-5. Percentage of Vectors with Mean Release Exceeding 0 and 0.0001 EPA Units for CRA26_IS

CRA26_IS	Replicate 1		Replicate 2		Replicate 3	
Release Type	>0	$>10^{-4}$	>0	$>10^{-4}$	>0	$>10^{-4}$
Cuttings and Cavings	100	100	100	100	100	100
Direct Brine	93	70	94	69	96	67
Spallings	69	66	69	65	68	63
Total	100	100	100	100	100	100
Total From Culebra	90	0	89	0	94	0
Total To Culebra	90	33	89	38	94	33

Table 8-6. Percentage of Vectors with Mean Release Exceeding 0 and 0.0001 EPA Units for RPPCR

RPPCR	Replicate 1		Replicate 2		Replicate 3	
Release Type	>0	$>10^{-4}$	>0	$>10^{-4}$	>0	$>10^{-4}$
Cuttings and Cavings	100	100	100	100	100	100
Direct Brine	98	84	97	80	98	85
Spallings	66	63	67	63	66	59
Total	100	100	100	100	100	100
Total From Culebra	86	0	87	0	92	1
Total To Culebra	86	36	87	39	92	30

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8.5.3 Spurious Correlations

Setting the STEPWISE parameter α_{out} to α_{in} (see Section 8.3.1) maximizes the number of variables in the model (as requested by EPA in C-23-18, U.S. EPA 2004) but can increase the number of spurious correlations (Kirchner 2004a; Kirchner 2004b). A spurious correlation implies a linear relationship exists between two variables but, in reality, no such relationship exists. For the CRA26_IS, not all variables are included in the analysis for all release types in order to reduce the number of spurious correlations. In most cases, the variables included in the analysis for a given release type are those that could potentially impact the release type.

Parameters that contribute minimally to the R^2 value often explain very little of the variability in the output variable. Such parameters may appear in the regression model by chance due to random correlations. Many of these parameters, which account for only a small percentage of variability in one replicate, may show different rankings or be absent entirely in another replicate. As a result, it is difficult to assess the importance of parameters that provide only minor improvements to the regression model, and they may have no meaningful impact on the results. Therefore, the discussion focuses exclusively on parameters that have significant and meaningful impacts on the regression model.

8.5.4 Statistical Significance

Most of the regression models produced by the STEPWISE code do not include all the input variables, even after ranking the data. This simply indicates that the uncertainties in many of the parameters have statistically insignificant effects on the output variable. Statistical insignificance can arise because the output variable has a low functional response to the input variable or because the variability in the output is dominated by factors not captured by the sampled input parameters. In some cases, both conditions may contribute to the exclusion of certain variables from the regression models. This is not to say that these non-significant variables have no influence on the releases. Their exclusion from the tables may reflect the inability of this statistical technique to rank their importance with an acceptable degree of confidence. For example, if the response of the output variable to an input variable was non-monotonic then the regression analysis might fail to properly identify that variable's importance.

The release pathways that contribute to total releases are driven by different factors on a vector basis, such that the uncertainty in mean total releases may not be consistently described by a few parameters. For example, the mean total releases for some vectors are dominated by spallings or DBRs, while others may be dominated by cuttings and cavings releases. In the former case, uncertainty in halite porosity is significant, while waste shear strength is significant in the latter case. In the CRA26_IS analysis, 54% to 66% of the variability in the total releases has been accounted for by the stepwise regression models as measured by the R^2 value (Table 8-7).

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Table 8-7. Maximum Proportion of the Variability in Releases Accounted for in Stepwise Rank Regression

Release Type	RPPCR			CRA26_IS		
	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
Total	0.62	0.66	0.66	0.54	0.60	0.66
Cuttings and Cavings	0.73	0.78	0.71	0.73	0.74	0.67
Spallings	0.59	0.63	0.71	0.59	0.61	0.74
Direct Brine	0.70	0.70	0.60	0.69	0.72	0.67
From Culebra	0.44	0.61	0.22	0.58	0.48	0.30

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