SANDIA NATIONAL LABORATORIES
WASTE ISOLATION PILOT PLANT

IMPACT ANALYSIS OF HIGH PLUTONIUM LOADING IN A SINGLE WIPP WASTE PANEL

REVISION 1

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Executive Summary

To comply with Title 40 CFR Part 194.24(d), the Waste Isolation Pilot Plant (WIPP) Performance Assessment (PA) assumes random emplacement of waste. Previous studies have shown that the repository compliance conclusions of the WIPP PA do not depend on the random emplacement assumption. The addition of the large, high-activity dilute and dispose Plutonium waste streams from the Savannah River Site has raised the following question: If a large amount of this waste was placed in one panel, would this panel behave differently from the other waste panels in a way that impacts compliance; specifically, would additional gas generation from brine radiolysis due to the increased activity in this panel increase releases?

Due to the Department of Energy's commitments to legacy waste disposal, it is seen as unlikely that one panel would see a high concentration of the surplus Plutonium waste streams. Despite the unlikeliness of this, a bounding scenario of a panel with a high concentration of surplus Plutonium is defined for this study. Existing PA tools are used to show the impact on repository behavior and release volumes.

The highly loaded waste panel sees a significant increase in predicted gas generation from brine radiolysis. This increase in gas generation leads to a slight increase in waste panel pressure and a decrease in brine saturation. The increase in pressure drives a slight increase in spallings volumes, while the decrease in brine saturation drives a decrease in Direct Brine Release (DBR) volumes.

Due to the uncertainty modeled in WIPP PA calculations and the counteracting increases in some release mechanisms and decreases in others, the impact of the highly loaded waste panel on the long-term performance of the WIPP repository is relatively low. Most significantly, a single waste panel with a large amount of plutonium waste would not change the conclusions of the WIPP PA about compliance with long-term containment requirements.

Revision History

This report was revised based on comments from the DOE. Changes were made throughout the document to improve clarity and readability.

1.0 INTRODUCTION

To comply with Title 40 Code of Federal Regulations (CFR), Part 194.24(d), the Waste Isolation Pilot Plant (WIPP) Performance Assessment (PA) assumes random emplacement of waste in the disposal system. Random emplacement is realized by using a homogeneous waste form in simulated repository representations. Past studies have shown that WIPP compliance is not affected by the assumption of random distribution of waste containers in the repository (Hansen et al. 2003, Casey et al. 2003).

The dilute and dispose surplus plutonium waste streams SR-KAC-HET and SR-KAC-PuOx are large volume, relatively high-activity waste streams new to the WIPP repository. The question has been raised by the EPA (U.S. EPA 2022, Section 10.0): If a single panel were to be loaded with a large amount of the surplus plutonium waste, would additional gas generation from the high concentration of waste activity change the performance of that waste panel and the WIPP repository? Variation in waste panel loading is not currently modeled in the WIPP PA due to the random emplacement assumption. DOE believes that is unlikely that these waste streams would be concentrated in a few waste panels due to commitments to prioritize legacy waste cleanup (State of New Mexico Environment Department, 2023).

This calculation, termed SP5050, examines a scenario that assumes a high concentration of surplus plutonium in a single waste panel. Hereafter, the waste panel with the high concentration of surplus plutonium will be referred to as the highly loaded waste panel. Due to limited capability of existing PA tools to implement heterogeneous waste loading, the other waste panels are assumed to contain the same inventory as the highly loaded panel. Except for inventory parameters described hereafter, models and parameters are the same as in the Replacement Panel Planned Change Request (RPPCR) PA (Hansen et al. 2023).

The SP5050 calculation was carried forward to releases from stochastic futures. The chemical conditions and radionuclide solubilities are dependent on constituents of the waste inventory (e.g. organic ligands), and the highly loaded waste panel would have different concentrations of these constituents. The changes to radionuclide solubility are generally minor compared to the uncertainty modeled in solubility so it is assumed that the waste loading would not significantly impact chemical conditions and radionuclide solubility limits. While the solubility limits are not changed, the PA codes PANEL and NUTS were run because mobile radionuclide concentration can change with the inventory change.

Beyond the SP5050 calculation, this analysis contains two other calculations, MSP5050 and ASP5050. MSP5050 is a calculation where the waste panels contain the inventory not accounted for in a highly loaded waste panel, distributed homogeneously. Direct releases attributable to intrusions into the highly loaded waste panel are compared with direct releases from single panels of two other calculations: the RPPCR and the MSP5050.

The ASP5050 calculation approximates the full heterogenous repository model with one highly loaded waste panel. The ASP5050 calculation is constructed from per-panel releases from the SP5050 and MSP5050 calculations. The calculations used in this report are summarized in Table 1.

Long-term releases through the Culebra are several orders of magnitude less than the direct releases in the RPPCR PA (Brunell and Zeitler 2023). Because of the relatively small effect of one

highly loaded waste panel on total releases, long-term releases through the Culebra are not considered in the SP5050 analysis.

Table 1 – Calculation Names and Descriptions

Calculation Name	Description
RPPCR	The Replacement Panels Planned Change Request (RPPCR) PA performed under AP-204 (Hansen et al. 2023).
SP5050	Analysis with every waste panel loaded with half Surplus Plutonium and half Pit Production waste as defined in Section 2.0. Based on the RPPCR PA with changes only to radionuclide inventory parameters.
MSP5050	Analysis with the waste panels loaded with the WIPP inventory less the inventory amount accounted for in a highly loaded waste panel and scaled by the repository volume over the repository volume minus one panel. Based on the RPPCR PA, with only the EPAUNI and CCDFGF results changed to account for solid waste activity concentration changes.
ASP5050	The sum of the highly loaded panel releases from the SP5050 and releases from all other panels from the MSP5050. Simulates a heterogeneous repository with one highly loaded panel and the remaining RPPCR PA inventory homogeneously distributed among the remaining panels.

This analysis is conducted as a screening or impact analysis and as such is considered a Programmatic Decision analysis as defined by the nuclear waste management procedure NP 9-1 (Nielsen 2020).

2.0 INVENTORY ANALYSIS

2.1 Inventory in a Highly Loaded Panel

The SP5050 analysis focuses on three waste streams: the two dilute and dispose waste streams SR-KAC-HET and SR-KAC-PuOx, and the pit production waste stream SR-CH-PP. Here, we assume that Savannah River is the only site shipping waste and, in addition, that there is an even mix of pit production (SR-CH-PP) and dilute and dispose (SR-KAC-HET, SR-KAC-PuOx) waste. The ratio of the two dilute and dispose plutonium waste streams is determined by their relative total container count.

The SP5050 analysis considers heterogeneity by varying the per-panel concentration of the radionuclides contributing to brine radiolysis, namely Am-241, Pu-238, Pu-239, Pu-240, and Pu-242. All other radionuclides and other waste components (iron-based metals, cellulose, plastic, and rubber (CPR), etc.) are represented as homogeneous throughout the waste.

Table 2 gives the waste volume[1], total activity in curies of the relevant radionuclides, and the total container count for the three waste streams of interest from the RPPCR inventory from Van Soest (2022). From the data in Table 1, the average activity per container is found by dividing the total activity by the container count. The average activity per container for each of the radionuclides of concern is shown in Table 3.

Table 2 – Waste Stream Volumes and Total Activity

Waste Stream ID	Container Type	Estimated Total Container Count	Volume (m3)	Am-241 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-242 (Ci)
SR-CH-PP	55-gal Drum Dir Ld w/o Liner	170,057	3.57E+04	2.02E+05	4.33E+05	4.28E+05	1.42E+05	4.01E+01
SR-KAC-HET	55-gal Drum Dir Ld w/o Liner	2,901	6.09E+02	4.98E+02	8.91E+01	1.22E+03	3.14E+02	1.04E-01
SR-KAC-PuOx	55-gal CCO w/ Liner	72,609	9.29E+02	6.84E+05	9.67E+04	1.15E+06	3.87E+05	1.35E+02

Table 3 – Waste Stream Average Container Activity

Waste Stream ID	Am-241 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-242 (Ci)
SR-CH-PP	1.19E+00	2.55E+00	2.52E+00	8.32E-01	2.36E-04
SR-KAC-HET	1.72E-01	3.07E-02	4.20E-01	1.08E-01	3.60E-05
SR-KAC-PuOx	9.42E+00	1.33E+00	1.59E+01	5.34E+00	1.85E-03

Next, the number of containers in a panel is calculated using several parameters from the WIPP PA parameter database (Table 4). An inherent assumption in these parameter values is an optimal

[1] The projected waste volume is scaled up to meet the WIPP waste volume limit set by the Land Withdrawal Act as described by Van Soest (2022).

loading to the full capacity of the panel. This assumption gives a conservative upper bound on the number of containers, and therefore activity, in the panel.

Table 4 – WIPP PA Parameter Values

Material	Property	Equation Symbol	Description	Value	Units
REFCON	DRROOM	n_d	Number of Drums per room in ideal packing	6804	Drums
REFCON	VROOM	V_R	Volume of a room	3,644.378	m^3
REFCON	VPANELX	V_P	Volume of a standard panel	46,097.65	m^3
REFCON	VREPOS	V_W	Volume of the total waste area of the repository	853,284.89	m^3

With these parameter values, the number of drums per panel can be found with the equation:

$$D_P = n_d \frac{V_P}{V_R} = 86{,}064 \quad (1)$$

For the highly loaded waste panel, half of the drums are assumed to contain the pit production waste stream and the other half contain the two dilute and dispose waste streams. Table 5 gives the resulting waste volumes and activity.

Table 5 – Waste Stream Volumes and Activity for a Highly Loaded Panel

Waste Stream ID	Fraction of Drums	Containers in Panel	Waste Volume (m3)	Am-241 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-242 (Ci)
SR-CH-PP	0.50	43,032	9.04E+03	5.10E+04	1.10E+05	1.08E+05	3.58E+04	1.02E+01
SR-KAC-HET	0.02	1,653	3.47E+02	2.84E+02	5.08E+01	6.95E+02	1.79E+02	5.95E-02
SR-KAC-PuOx	0.48	41,379	5.30E+02	3.90E+05	5.51E+04	6.57E+05	2.21E+05	7.67E+01
Total	1.00	86,064	9.91E+03	4.41E+05	1.65E+05	7.66E+05	2.57E+05	8.69E+01

2.2 Scaling to a Full Repository

The WIPP PA code BRAGFLO currently can only model homogeneous waste throughout the repository. Given this, the highly loaded waste panel inventory described in Section 2.1 is scaled up to the entire repository volume. The scaling factor of 18.51 can be found from the standard panel volume *Vp* and repository volume *Vw* (values in Table 4). This scaling factor is applied to the values in Table 5 to give the full repository inventory in Table 6.

Table 6 – Waste Stream Volumes and Activity Scaled to a Full Repository

Waste Stream ID	Waste Volume (m3)	Am-241 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-242 (Ci)
SR-CH-PP	1.67E+05	9.44E+05	2.03E+06	2.01E+06	6.63E+05	1.88E+02
SR-KAC-HET	6.43E+03	5.25E+03	9.40E+02	1.29E+04	3.32E+03	1.10E+00
SR-KAC-PuOx	9.80E+03	7.21E+06	1.02E+06	1.22E+07	4.09E+06	1.42E+03
Total	1.84E+05	8.16E+06	3.05E+06	1.42E+07	4.75E+06	1.61E+03

In the PA, the total waste inventory is the sum of the contact handled (CH) and remote handled (RH) inventory. The waste streams SR-CH-PP, SR-KAC-HET and SR-KAC-PuOx are all CH waste. To minimize the parameter changes needed for the SP5050 analysis, the RH inventory remains as specified for the RPPCR. The CH inventory for the radionuclides of interest is specified as the totals from Table 6 minus the RPPCR RH inventory. Table 7 gives the CH inventory calculated for the SP5050 analysis, and the RH and CH inventory from the RPPCR. The inventory in Table 7 is an unrealistic inventory for the WIPP, but is useful for evaluating the behavior of a waste panel loaded with the surplus plutonium waste streams as compared to a waste panel loaded with a homogeneous waste material.

Table 7 – Analysis Parameter Specification

Property	Am-241 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-242 (Ci)
INVRHD	1.43E+04	2.11E+04	3.86E+03	3.66E+03	1.94E+01
INVCHD (RPPCR)	1.41E+06	1.28E+06	2.17E+06	6.89E+05	2.45E+02
INVCHD (SP5050)	8.15E+06	3.03E+06	1.42E+07	4.75E+06	1.59E+03

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3.0 ANALYSIS RESULTS

Using the inventory parameter values from Section 2.2, the Salado Flow; Cuttings, Cavings, and Spallings; and the Direct Brine Release calculations for the SP5050 analysis were completed[1]. Beyond the inventory parameters no other changes from the RPPCR PA were made. The calculation was run for the 100 vectors of Replicate 1.

Box and whisker plots are used to display the results. Boxes extend from the 25th percentile to the 75th percentile, also known as the inner quartile range. Whiskers extend out from the box to the full range of the data or to 1.5 times the inner quartile range, whichever is closer to the median. Data points outside of the whiskers are plotted as black diamonds. The black center line in the box is the median value; the mean value is denoted with a white square. Where time-averaged output values are given, the time-averaging is done over all output times, not limited to select times plotted.

3.1 Salado Flow

The results of the Salado Flow simulations are presented and discussed in this section. Loading a panel with a higher amount of plutonium results in an increase in gas generation from brine radiolysis, which in turn affects brine pressure and brine saturation. Results presented here are for the representative waste panel (Waste Panel in Figure 8 of King (2023)). A complete description of the Salado Flow model, conceptual approach, scenarios, and RPPCR results can be found in King (2023).

3.1.1 Gas Generation

Table 8 gives summary statistics for gas generation in the representative panel for the RPPCR and SP5050 analyses. There is a significant increase in both mean and maximum gas generation from brine radiolysis in SP5050 compared to the RPPCR PA, as well as a significant increase in total gas generation. There is a decrease in mean gas generation from iron corrosion and biodegradation in the SP5050, driven by the increased brine consumption by radiolysis. The maximum cumulative gas generation for iron corrosion and biodegradation is limited by inventory and does not change for SP5050 from the RPPCR.

[1] Analysis files and post-processing scripts are archived in the WIPP PA CVS repository at: /data/cvs/CVSLIB/WIPP_EXTERNAL/SP5050

Table 8 – Cumulative Gas Generation Statistics

Quantity (units)	Description	Scenario	Mean 10,000 Year Value[1]		Maximum Individual Vector Value[2]	
			RPPCR	SP5050	RPPCR	SP5050
FEMOL_W (mol)	Gas Generation from Iron Corrosion in the Waste Panel	S1-BF	3.65E+07	3.04E+07	7.23E+07	7.23E+07
		S2-BF	6.35E+07	4.95E+07	7.23E+07	7.23E+07
		S4-BF	3.71E+07	3.16E+07	7.23E+07	7.23E+07
		S6-BF	5.68E+07	4.65E+07	7.23E+07	7.23E+07
CELMOL_W (mol)	Gas Generation from Biodegradation in the Waste Panel	S1-BF	5.57E+06	5.08E+06	3.02E+07	3.02E+07
		S2-BF	8.57E+06	7.92E+06	3.02E+07	3.02E+07
		S4-BF	5.71E+06	5.19E+06	3.02E+07	3.02E+07
		S6-BF	7.90E+06	7.31E+06	3.02E+07	3.02E+07
WAS_HRDC (mol)	Gas Generation from Radiolysis in the Waste Panel	S1-BF	1.19E+07	4.47E+07	8.18E+07	3.33E+08
		S2-BF	2.59E+07	7.70E+07	8.66E+07	3.46E+08
		S4-BF	1.30E+07	5.55E+07	8.66E+07	3.68E+08
		S6-BF	1.92E+07	6.64E+07	7.17E+07	2.15E+08
WAS_HTTC (mol)	Total Gas Generation in the Waste Panel	S1-BF	5.39E+07	8.00E+07	1.61E+08	4.09E+08
		S2-BF	9.76E+07	1.34E+08	1.65E+08	4.25E+08
		S4-BF	5.57E+07	9.22E+07	1.66E+08	4.46E+08
		S6-BF	8.36E+07	1.20E+08	1.55E+08	2.88E+08

Notes:

1 Mean at 10,000 years of 100 Replicate 1 vectors.

2 Maximum at 10,000 years of 100 Replicate 1 vectors.

3.1.1.1 Brine Radiolysis

Figure 1, Figure 2, Figure 3, and Figure 4 show the distributions of cumulative gas generation from brine radiolysis for Scenarios S1-BF, S2-BF, S4-BF, and S6-BF respectively. All scenarios show a significant increase in gas generation in the SP5050 analysis compared to the RPPCR PA.

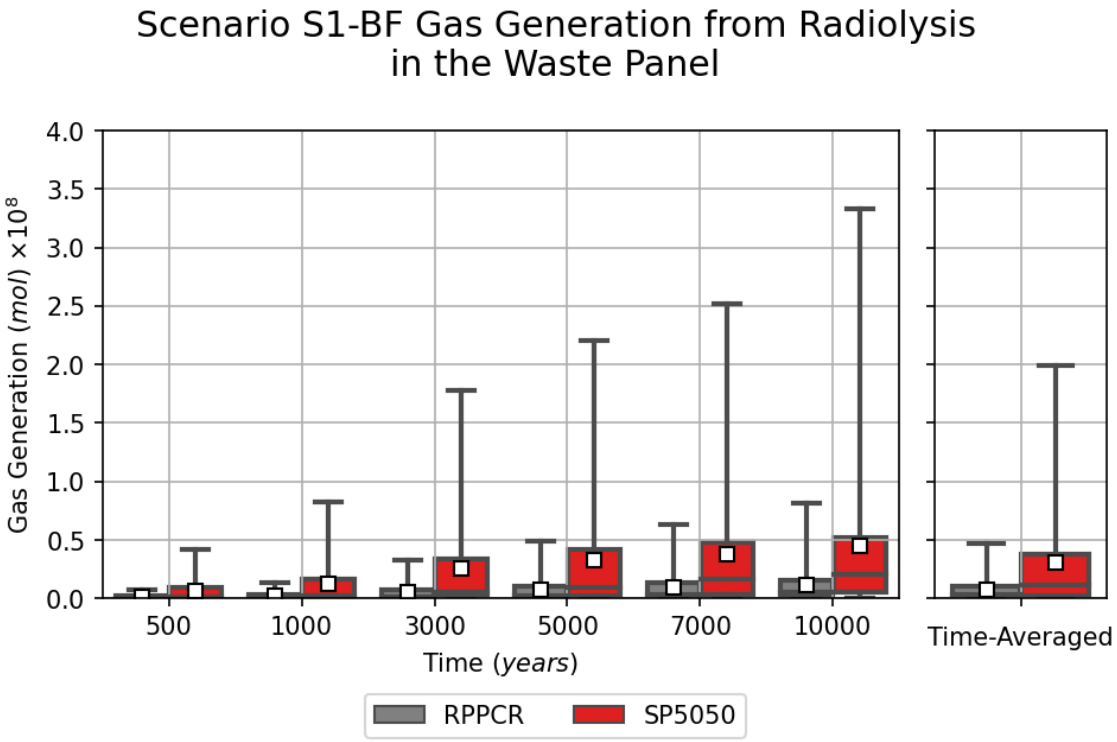

Figure 1 – Gas Generation from Brine Radiolysis in the Waste Panel for Scenario S1-BF

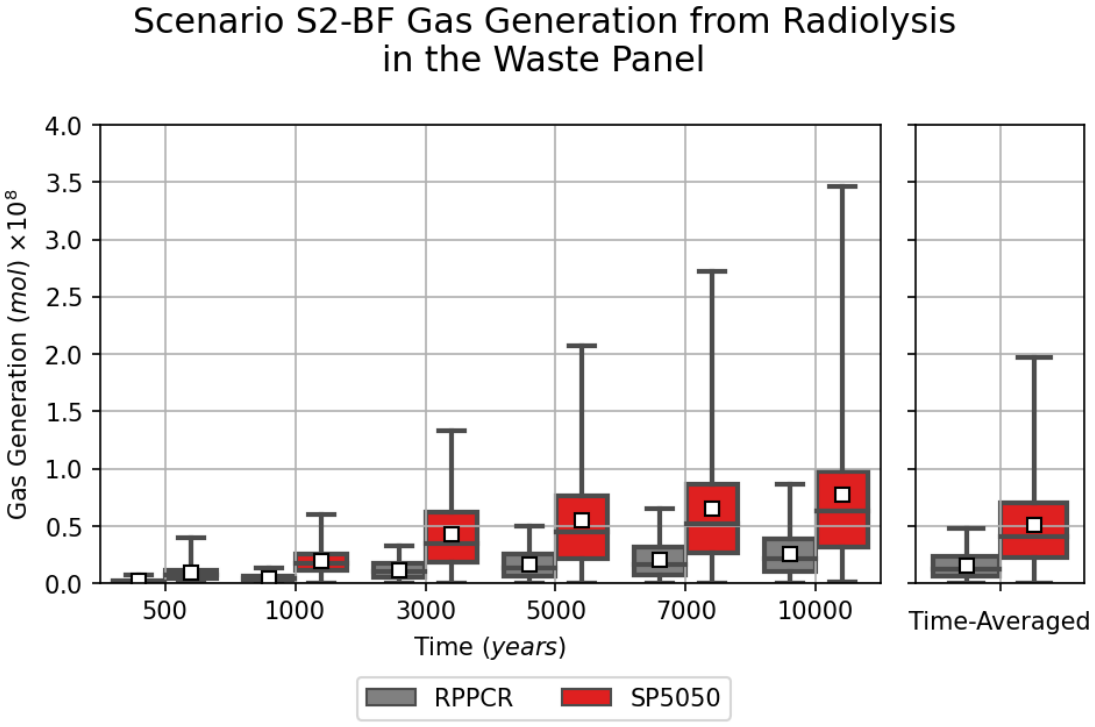

Figure 2 – Gas Generation from Brine Radiolysis in the Waste Panel for Scenario S2-BF

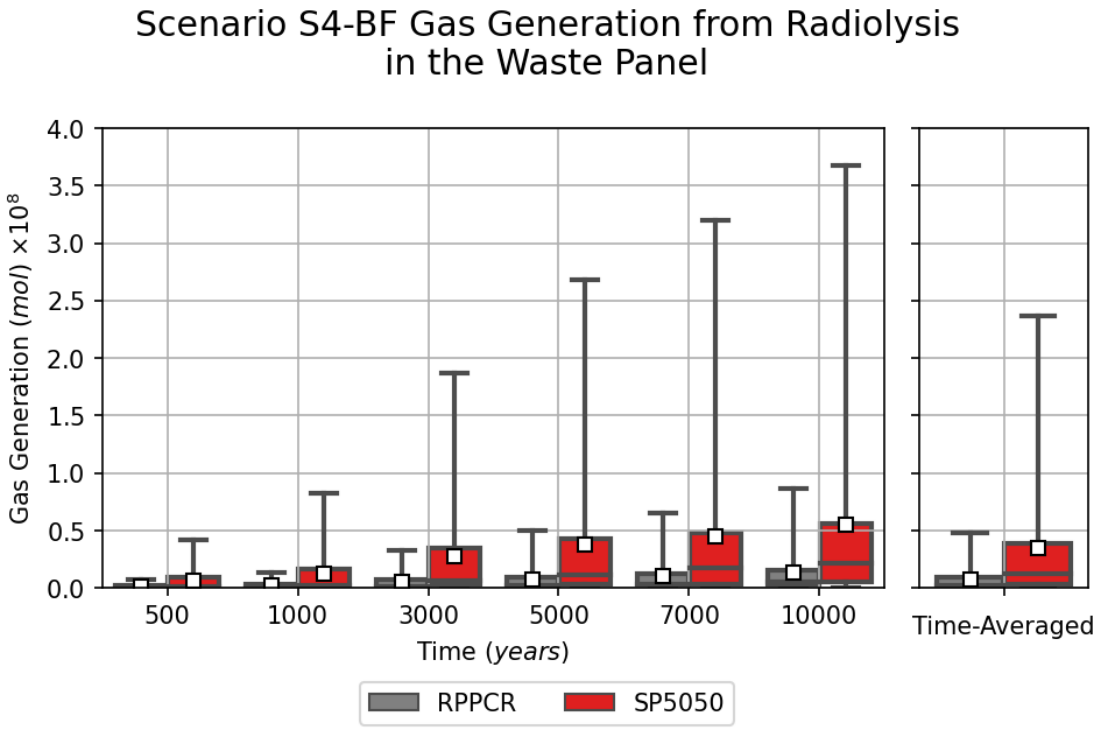

Figure 3 – Gas Generation from Brine Radiolysis in the Waste Panel for Scenario S4-BF

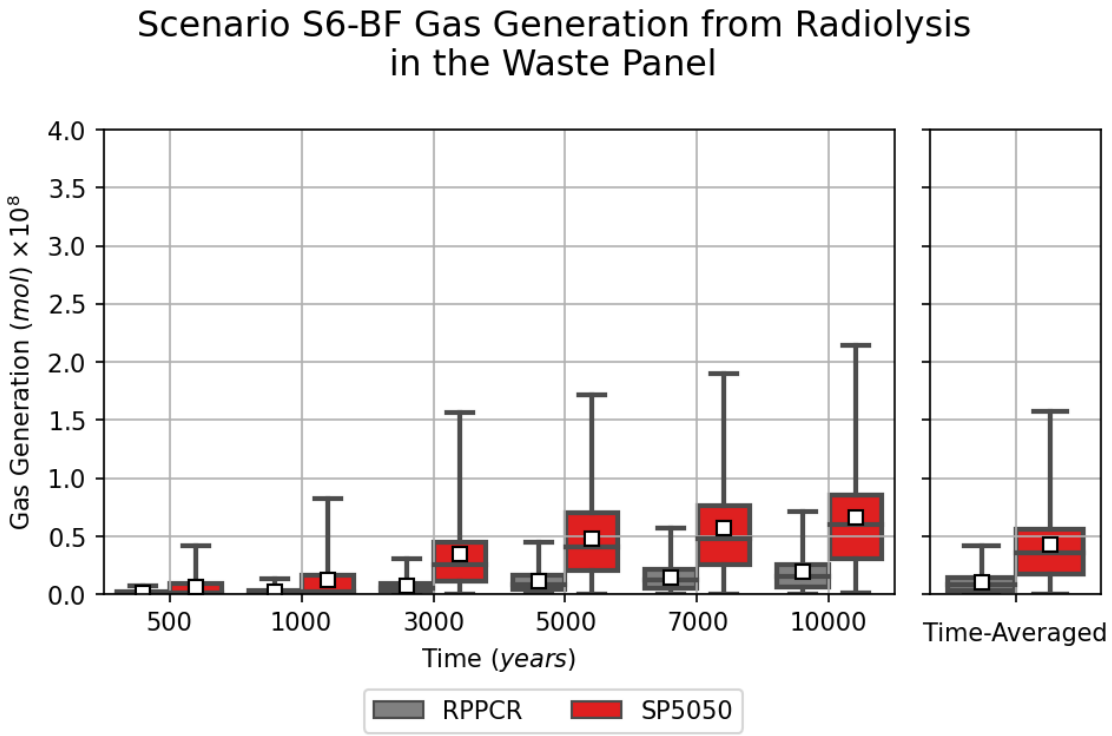

Figure 4 – Gas Generation from Brine Radiolysis in the Waste Panel for Scenario S6-BF

3.1.1.2 Total Gas Generation

Distributions of total gas generation are shown in Figure 5, Figure 6, Figure 7, and Figure 8 for scenarios S1-BF, S2-BF, S4-BF, and S6-BF respectively. Total gas generation in the waste panel has increased in SP5050 compared to the RPPCR PA consistent with the increase in gas generation from brine radiolysis. Notably, the vectors with high total gas generation also show high increases relative to the RPPCR. Mean gas generation by source is shown in Figure 9 and Figure 10 for scenarios S1-BF and S2-BF. For SP5050, brine radiolysis overtakes iron corrosion as the dominant source of gas generation.

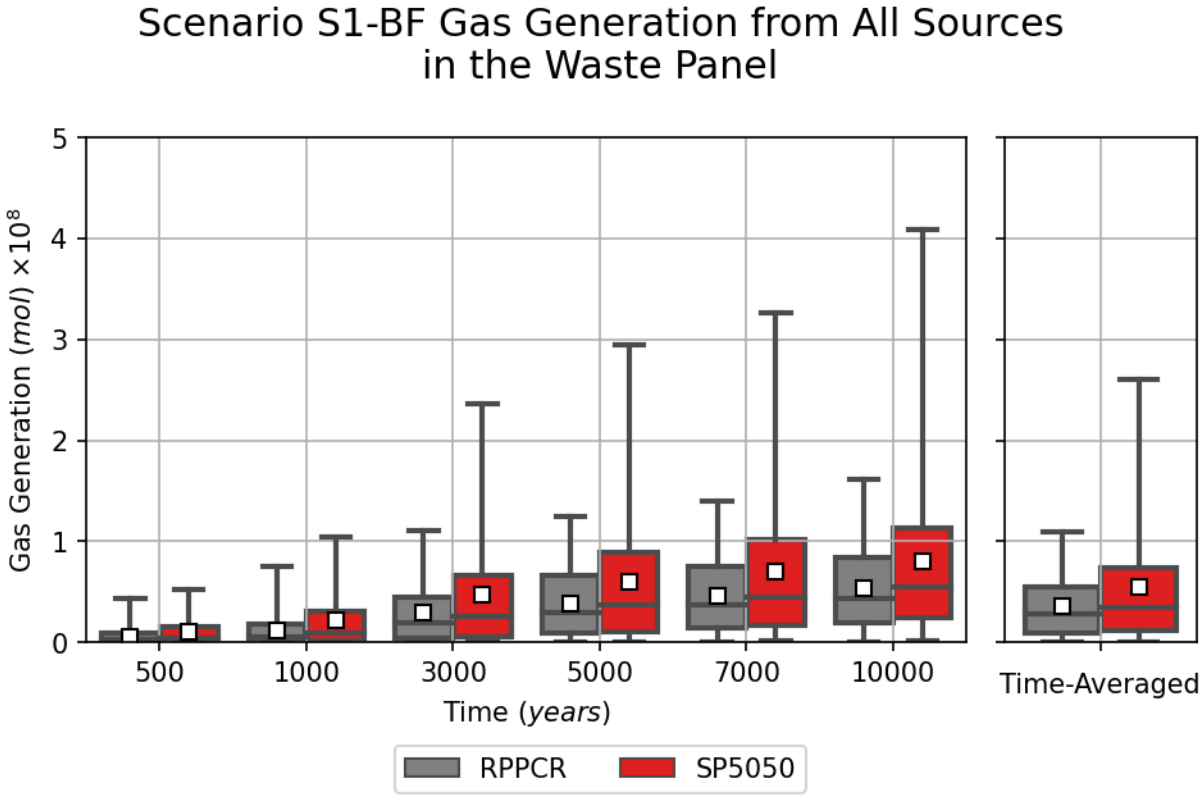

Figure 5 – Total Gas Generation in the Waste Panel for Scenario S1-BF

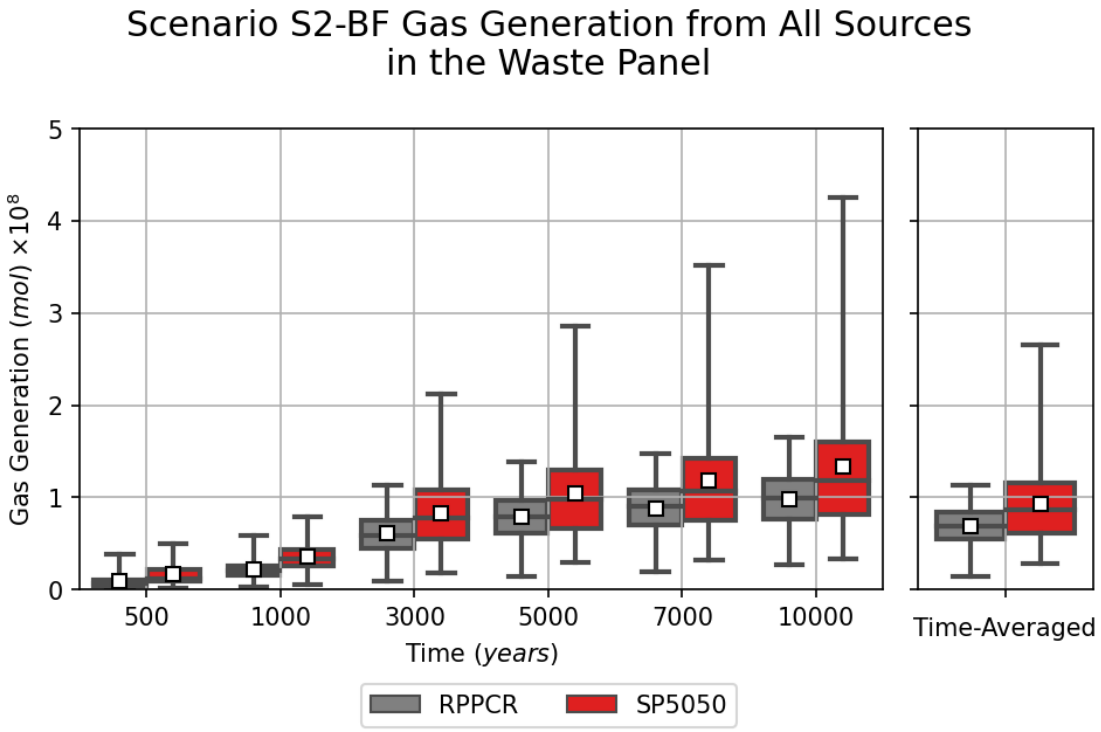

Figure 6 – Total Gas Generation in the Waste Panel for Scenario S2-BF

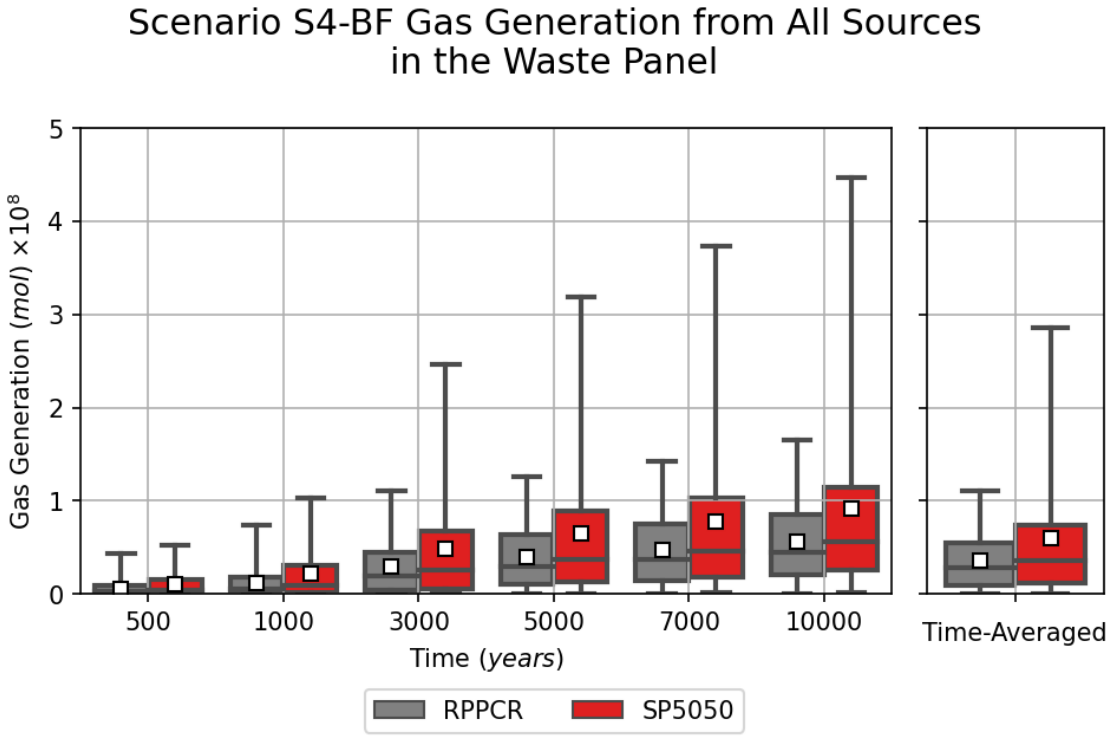

Figure 7 – Total Gas Generation in the Waste Panel for Scenario S4-BF

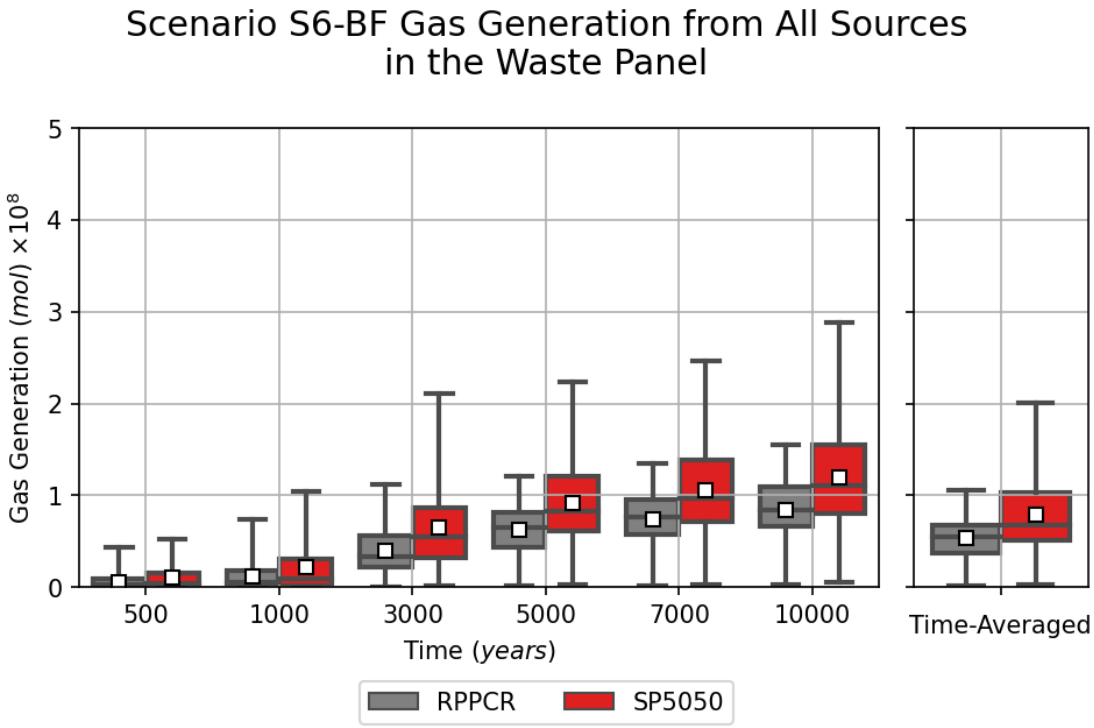

Figure 8 – Total Gas Generation in the Waste Panel for Scenario S6-BF

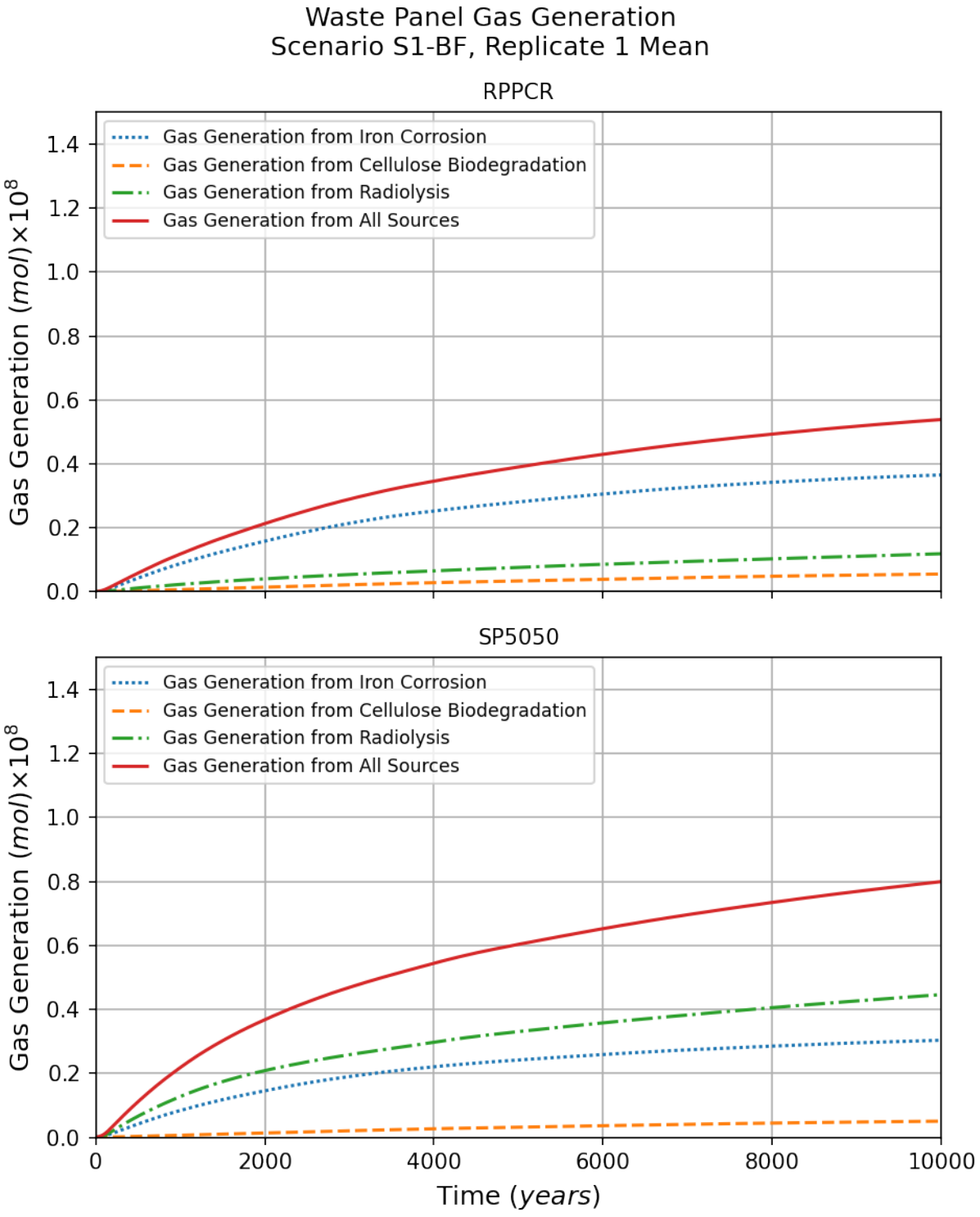

Figure 9 – Mean Total Gas Generation in the Waste Panel by Component for Scenario S1-BF

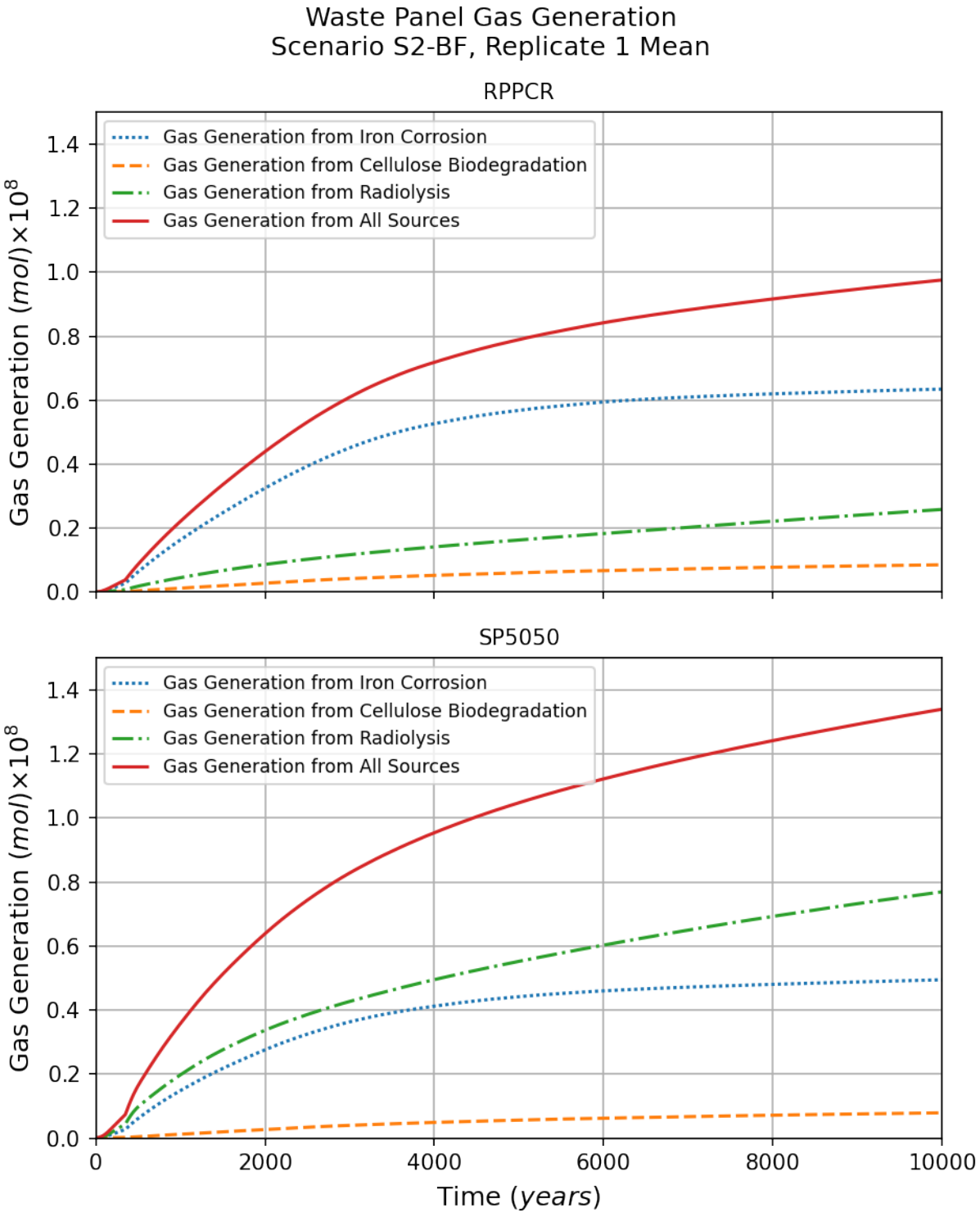

Figure 10 – Mean Total Gas Generation in the Waste Panel by Component for Scenario S2-BF

3.1.2 Waste Panel Brine Pressure

Summary statistics for the waste panel brine pressure are presented in Table 9. Figures 11, 12, 15 and 16 show the waste panel pressure for scenarios S1-BF, S2-BF, S4-BF, and S6-BF at a selection of times up to 10,000 years. Figures 13 and 14 plot pressure versus time for all 100 vectors in Replicate 1 for the S1-BF and S2-BF scenarios. The vector plots also show the mean pressure superimposed in red.

In all scenarios, the waste panel brine pressures are slightly increased in the SP5050 analysis due to the increased gas generation from brine radiolysis resulting from the increased waste activity. With every panel in the repository being modeled with the same waste, this increase in pressure would be an overestimate of pressure in a heterogeneously loaded repository. In the heterogeneous repository, the rest of the repository (all waste areas except for the representative waste panel) would not see an increase in gas generation and therefore would realize a lower pressure. As a result, there would be more fluid flow out of the representative waste panel and its pressure would be lower.

Table 9 – Waste Panel Pressure Statistics for RPPCR and SP5050

Description	Scenario	Average Mean Value[1]		Maximum Mean Value[2]		Maximum Overall Value[3]	
		RPPCR	SP5050	RPPCR	SP5050	RPPCR	SP5050
Brine Pressure in Waste Panel (MPa)	S1-BF	7.4	8.1	8.5	9.2	16.0	16.8
	S2-BF	11.2	11.4	12.6	12.8	15.9	16.6
	S4-BF	6.9	7.7	7.8	8.5	15.8	16.8
	S6-BF	8.8	9.3	10.3	10.8	16.0	16.8

Notes:

1 Average over the time interval (0-10,000 years) of the Replicate 1 mean.

2 Maximum over the time interval (0-10,000 years) for the Replicate 1 mean.

3 Maximum over the time interval (0-10,000 years) and over all 100 Replicate 1 vectors.

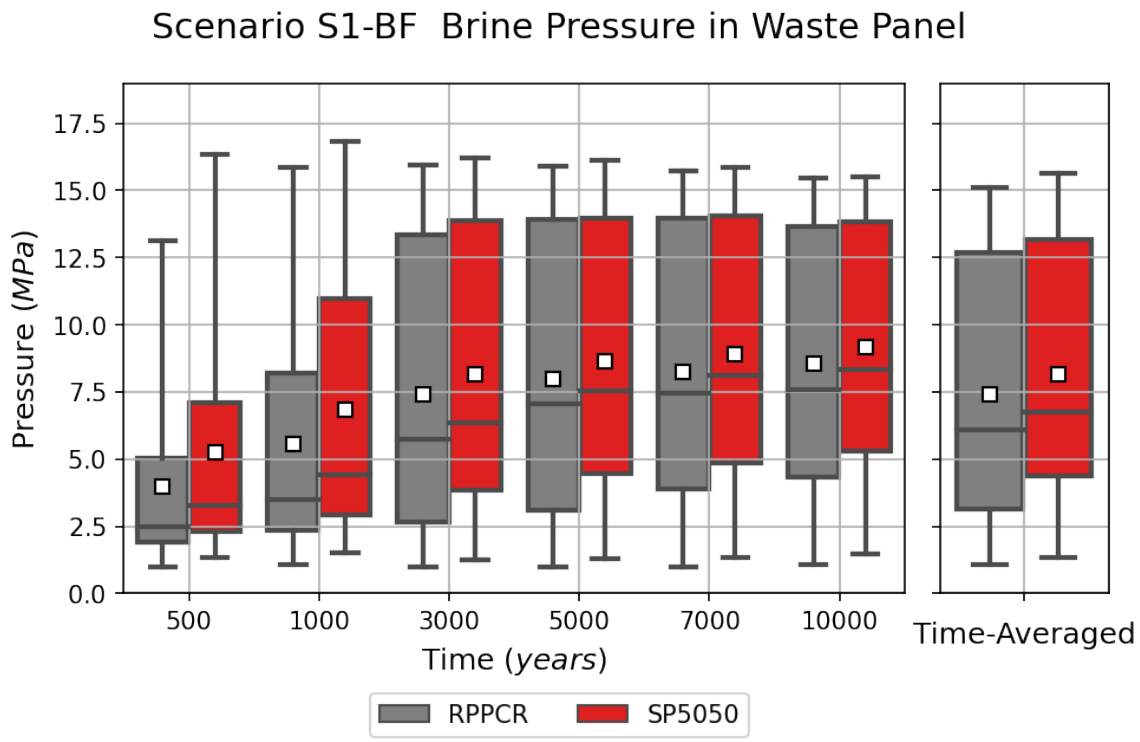

Figure 11 – Brine Pressure in the Waste Panel for Scenario S1-BF

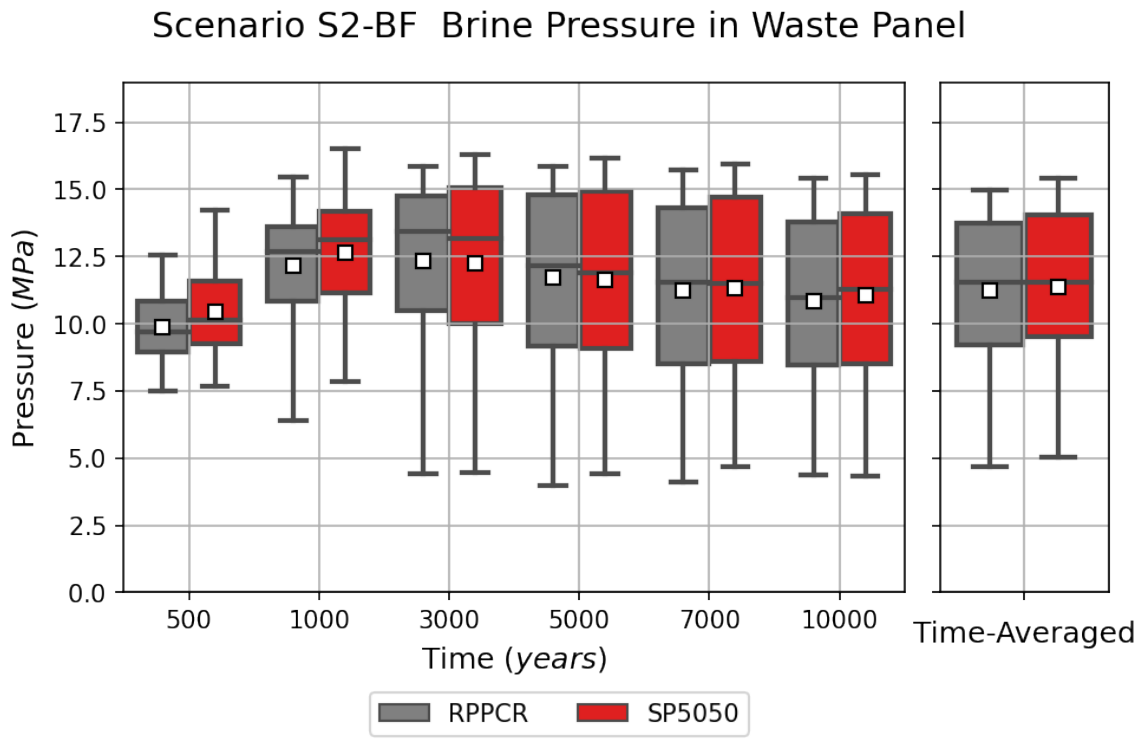

Figure 12 – Brine Pressure in the Waste Panel for Scenario S2-BF

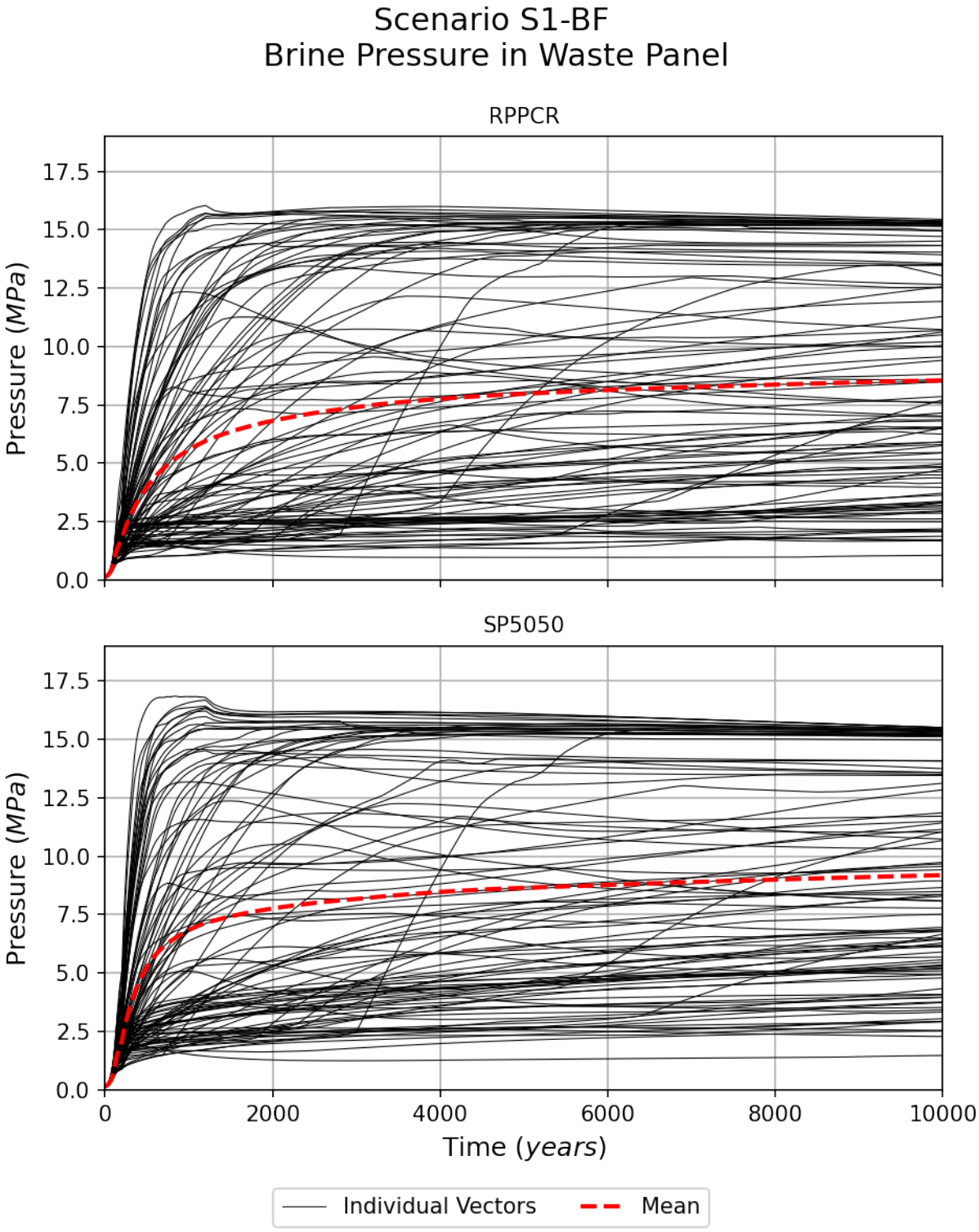

Figure 13 – Brine Pressure in the Waste Panel for Scenario S1-BF

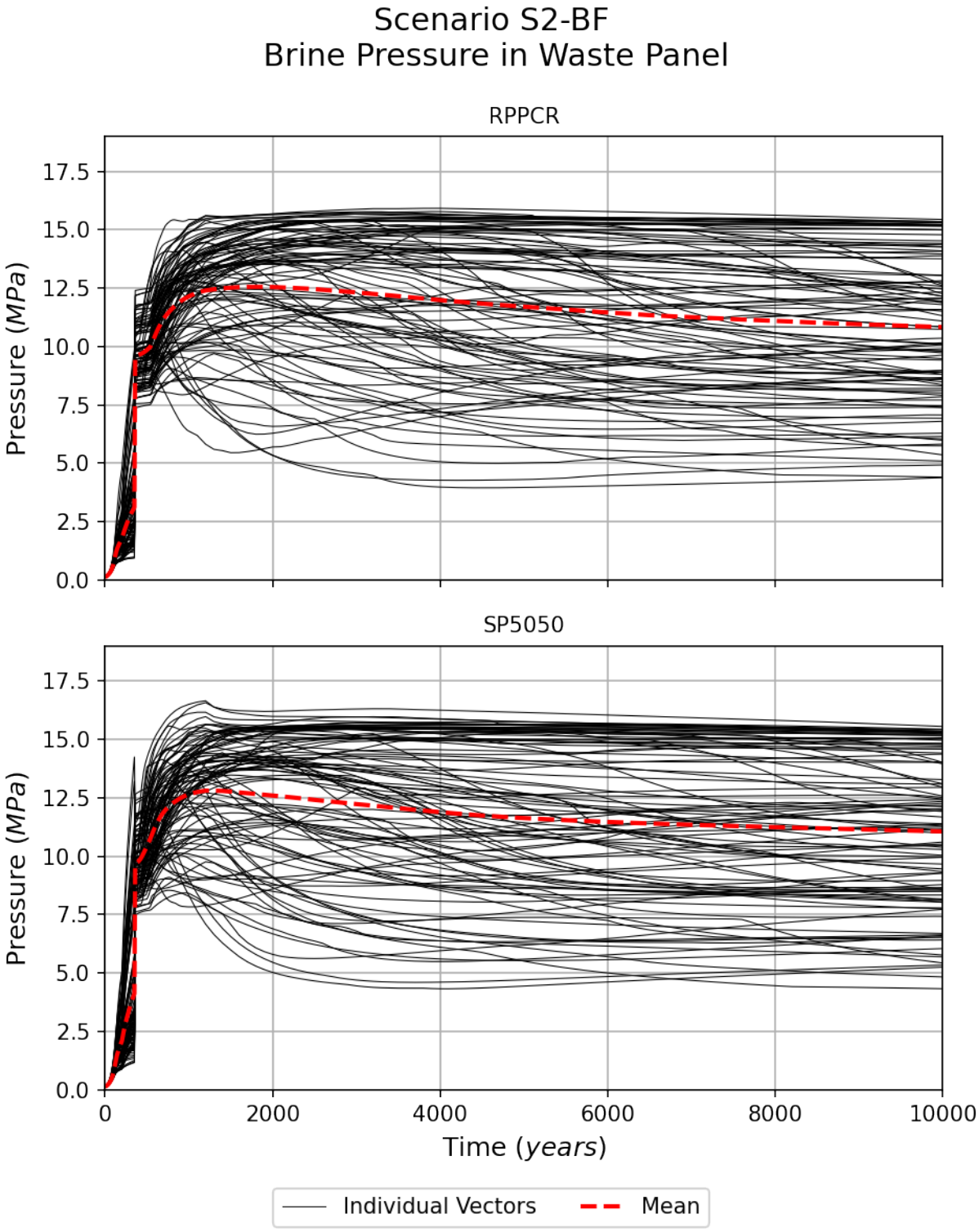

Figure 14 – Brine Pressure in the Waste Panel for Scenario S2-BF

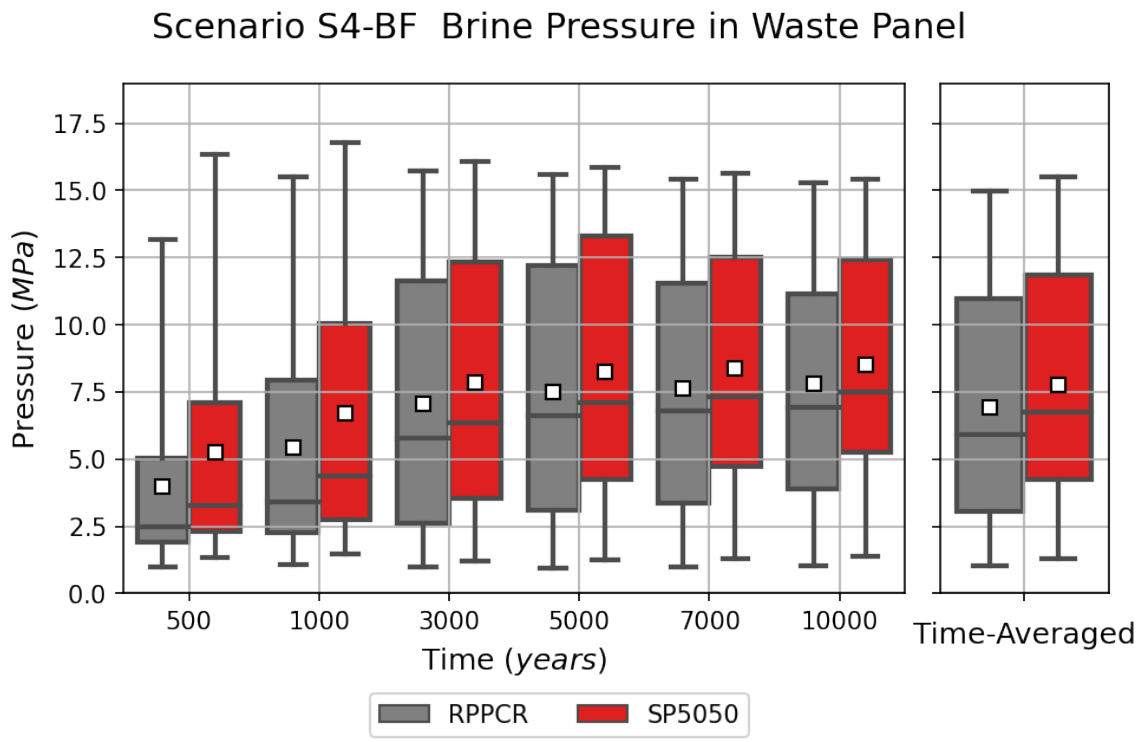

Figure 15 – Brine Pressure in the Waste Panel for Scenario S4-BF

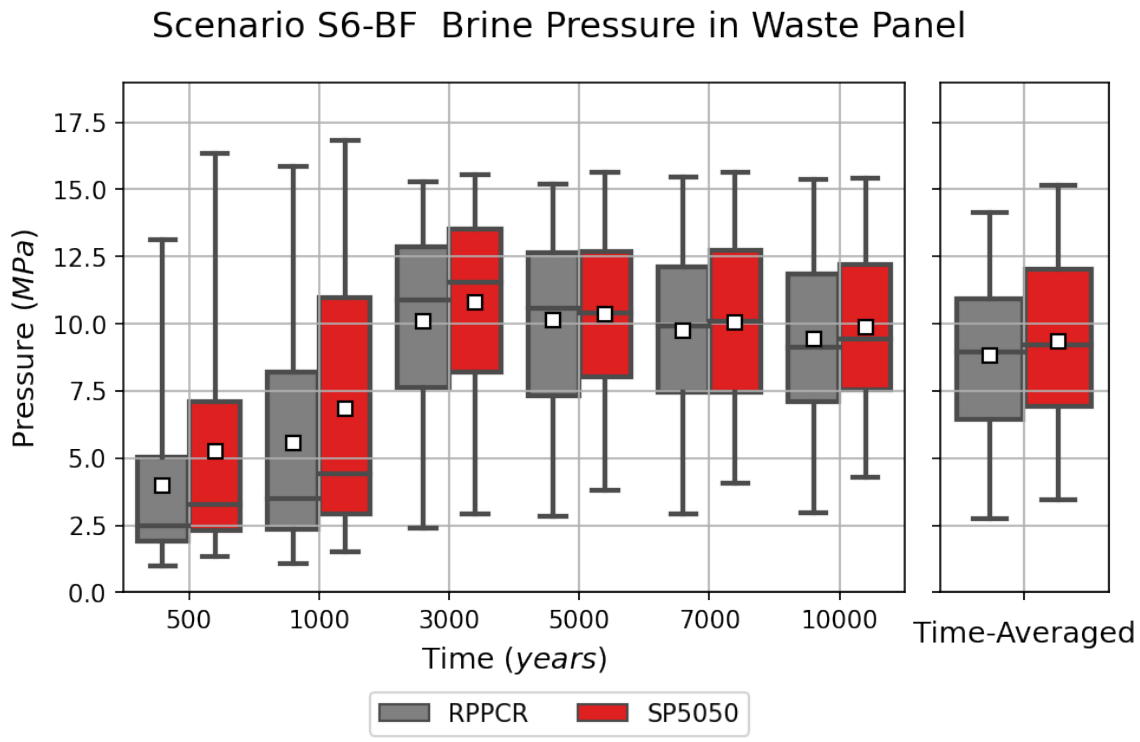

Figure 16 – Brine Pressure in the Waste Panel for Scenario S6-BF

3.1.3 Waste Panel Brine Saturation

Summary statistics for the waste panel brine saturation are presented in Table 10 for scenarios S1-BF, S2-BF, S4-BF, and S6-BF. In all scenarios, the average and maximum mean waste panel brine saturations have decreased in SP5050. Figure 17 through Figure 20 show the distributions of waste panel brine saturations for scenarios S1-BF, S2-BF, S4-BF, and S6-BF. Brine saturation distributions are shifted to lower saturations in SP5050, and to substantially lower saturations at later times. The decrease in brine saturation is driven by the increased brine consumption and gas generation from brine radiolysis caused by the increased waste activity.

Table 10 – Waste Panel Brine Saturation Statistics

Description	Scenario	Average Mean Value[1]		Maximum Mean Value[2]		Maximum Overall Value[3]	
		RPPCR	SP5050	RPPCR	SP5050	RPPCR	SP5050
Brine Saturation in Waste Panel	S1-BF	0.24	0.14	0.32	0.31	1.00	1.00
	S2-BF	0.55	0.28	0.93	0.91	1.00	1.00
	S4-BF	0.27	0.17	0.32	0.31	1.00	1.00
	S6-BF	0.43	0.24	0.63	0.51	1.00	1.00

Notes:

1 Average over the time interval (0-10,000 years) of the Replicate 1 mean.

2 Maximum over the time interval (0-10,000 years) for the Replicate 1 mean.

3 Maximum over the time interval (0-10,000 years) and over all 100 Replicate 1 vectors.

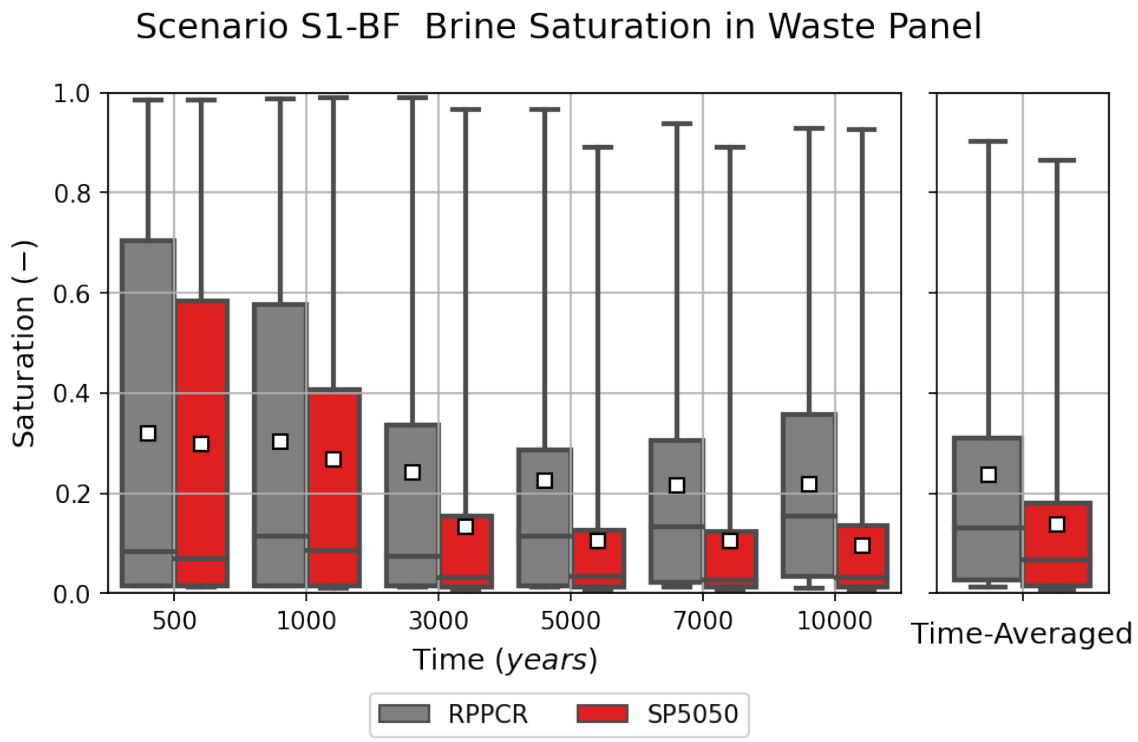

Figure 17 – Brine Saturation in the Waste Panel for Scenario S1-BF

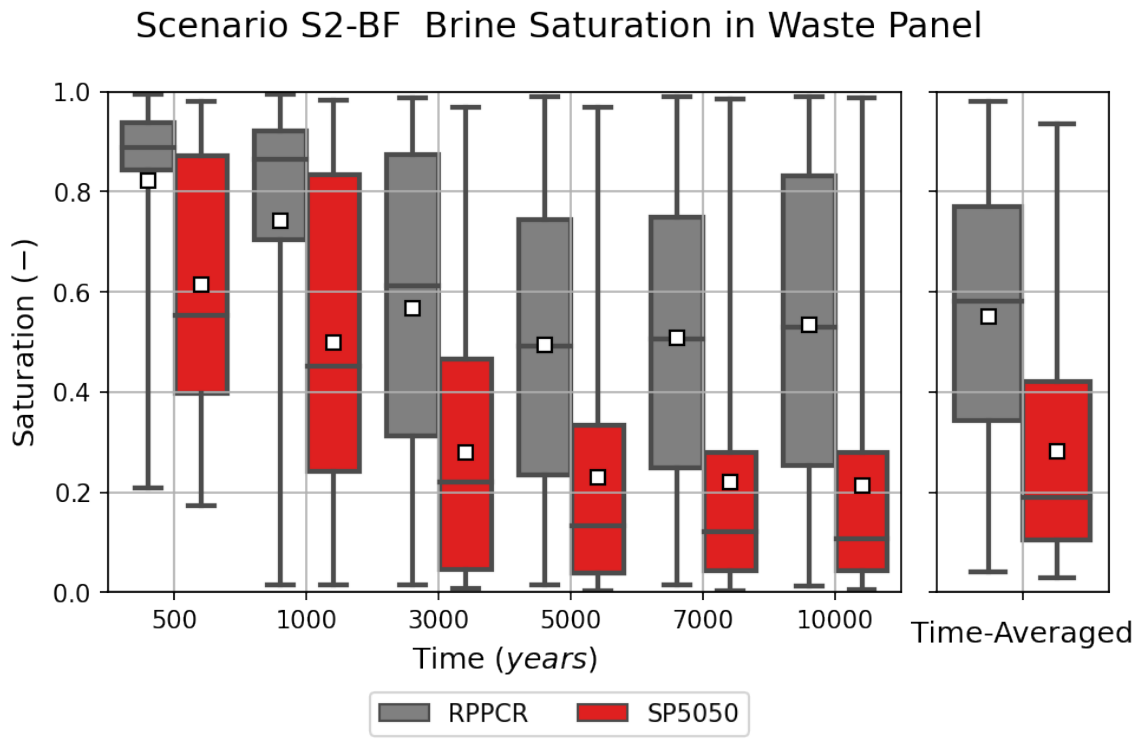

Figure 18 – Brine Saturation in the Waste Panel for Scenario S2-BF

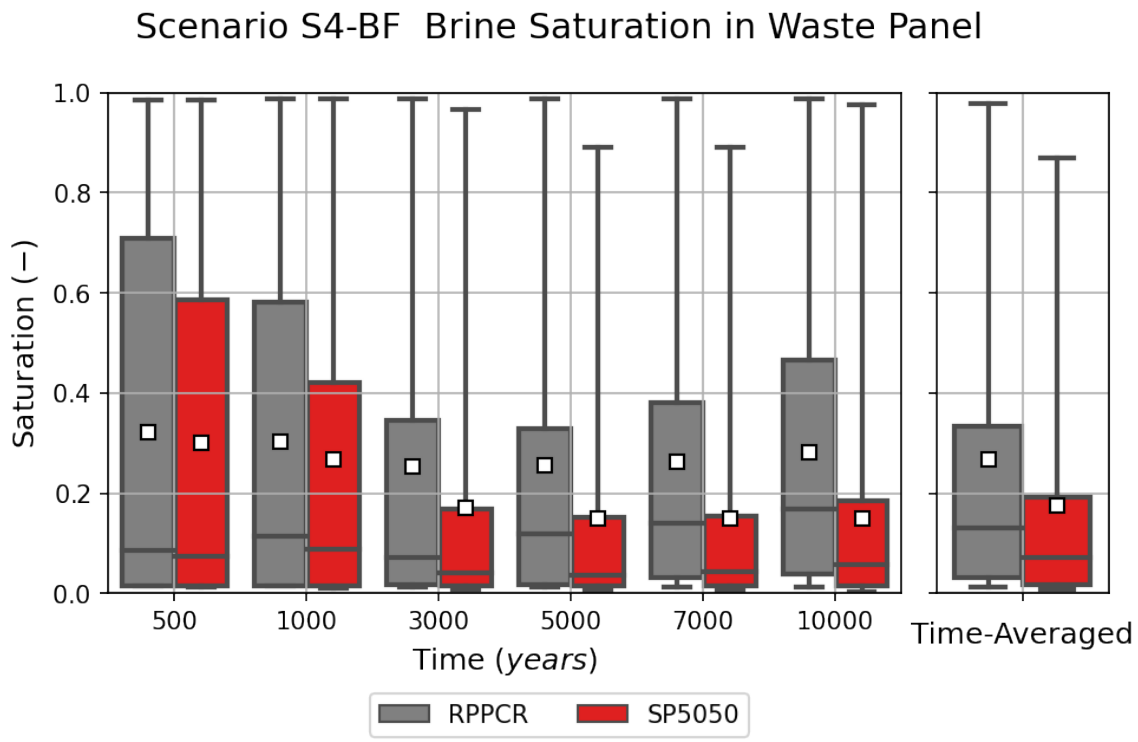

Figure 19 – Brine Saturation in the Waste Panel for Scenario S4-BF

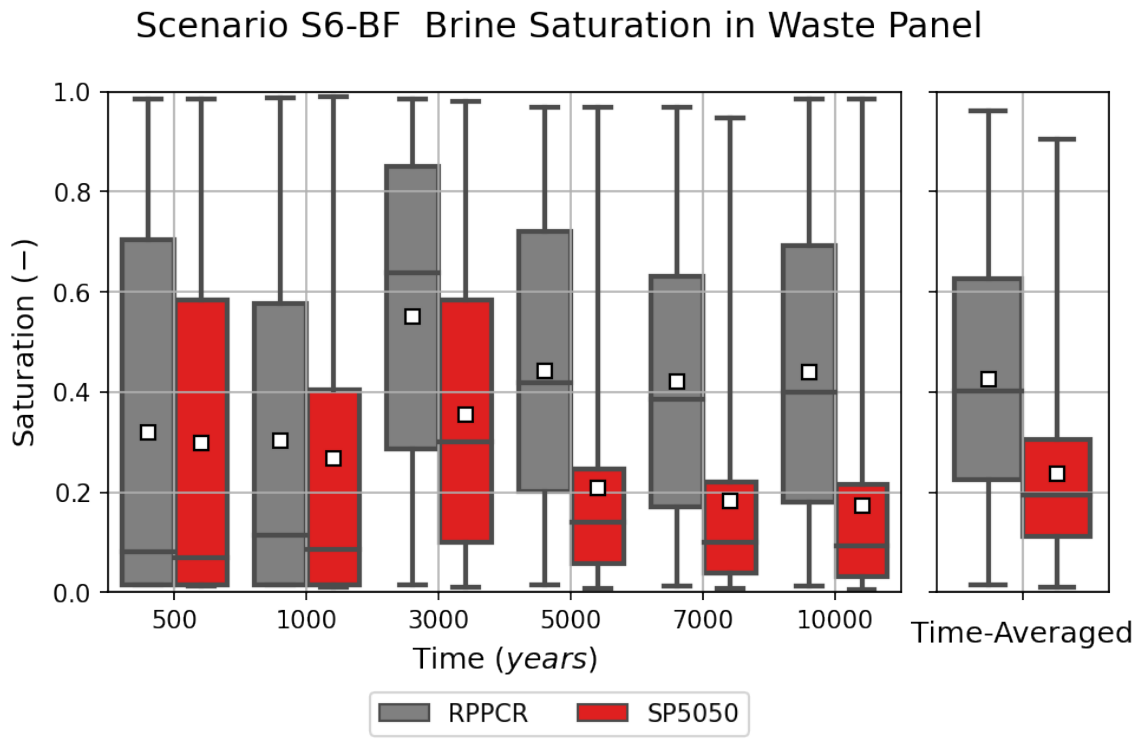

Figure 20 – Brine Saturation in the Waste Panel for Scenario S6-BF

3.2 Cuttings, Cavings and Spallings Volumes

The increases in pressure in the highly loaded waste panel lead to increases in the likelihood of spallings and to increase in spallings volumes. Cuttings and cavings volumes are not dependent on inventory or repository conditions and thus are the same in the SP5050 analysis and the RPPCR PA. A complete description of the cuttings, cavings, and spallings models, conceptual approach, scenarios, and RPPCR PA results can be found in Kicker (2023).

The CUTTINGS_S code was run with the BRAGFLO results for SP5050. Summary statistics for Lower intrusion[2] spallings events are presented in Table 11. The number of Lower intrusion spallings events is plotted in Figure 21 binned by spallings volume. In the SP5050, spallings occur for more intrusions; specifically, Table 11 indicates a 2.7% increase in the number of spallings events. Figure 22 compares the distributions of spallings volumes; Table 11 indicates an 18.0% increase in mean spalled volume from 0.35 m^3 in the RPPCR to 0.46 m^3 in SP5050.

Table 11 – Spallings Volume Summary

Scenario	Mean Spalled Volume (m^3)		Fraction of Simulations with Non-Zero Releases		Mean of Non-Zero Spalled Volume (m^3)	
	RPPCR	SP5050	RPPCR	SP5050	RPPCR	SP5050
S1-DBR	0.28	0.34	15.7%	18.1%	1.8	1.86
S2-DBR	0.54	0.58	48.6%	51.0%	1.12	1.14
S3-DBR	0.44	0.56	45.2%	47.4%	0.98	1.18
S4-DBR	0.21	0.38	17.2%	21.0%	1.23	1.8
S5-DBR	0.3	0.45	20.8%	23.6%	1.43	1.93
All	**0.35**	**0.46**	**29.0%**	**31.7%**	**1.22**	**1.44**

[2] The representative waste panel in the BRAGFLO grid maps to the southernmost, or Lower, waste region in the grid used to calculate direct releases. The Lower intrusion is located in the Lower waste region. See Kicker (2023).

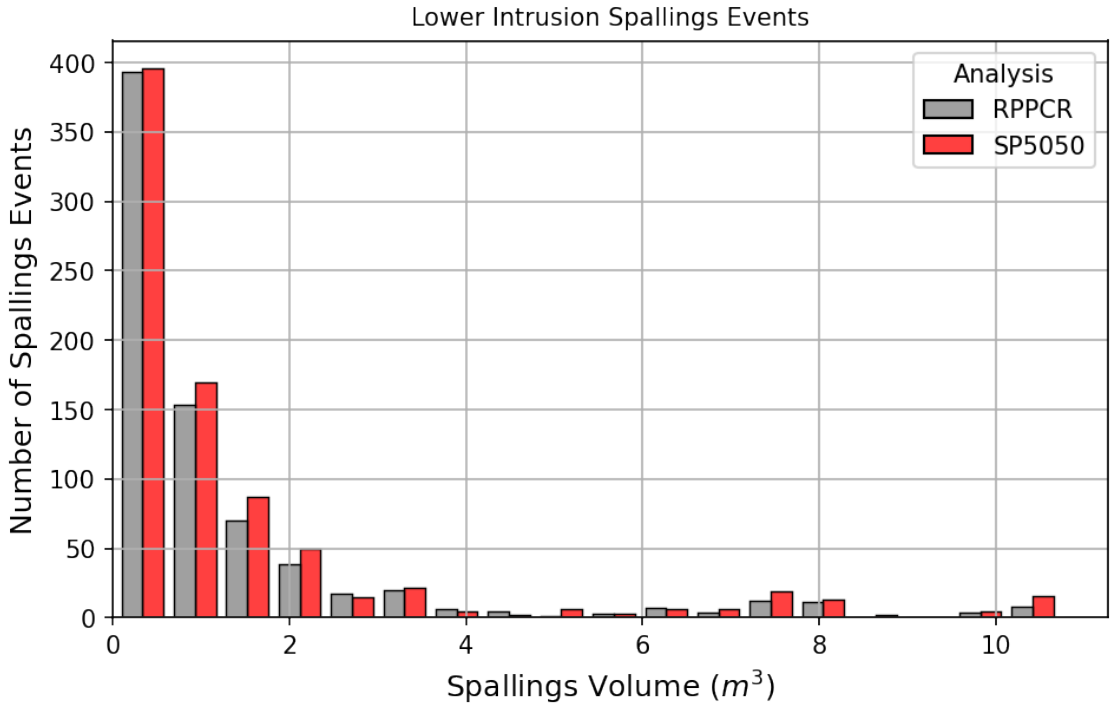

Figure 21 – Histogram of Spalling Events from the Lower Intrusion Location

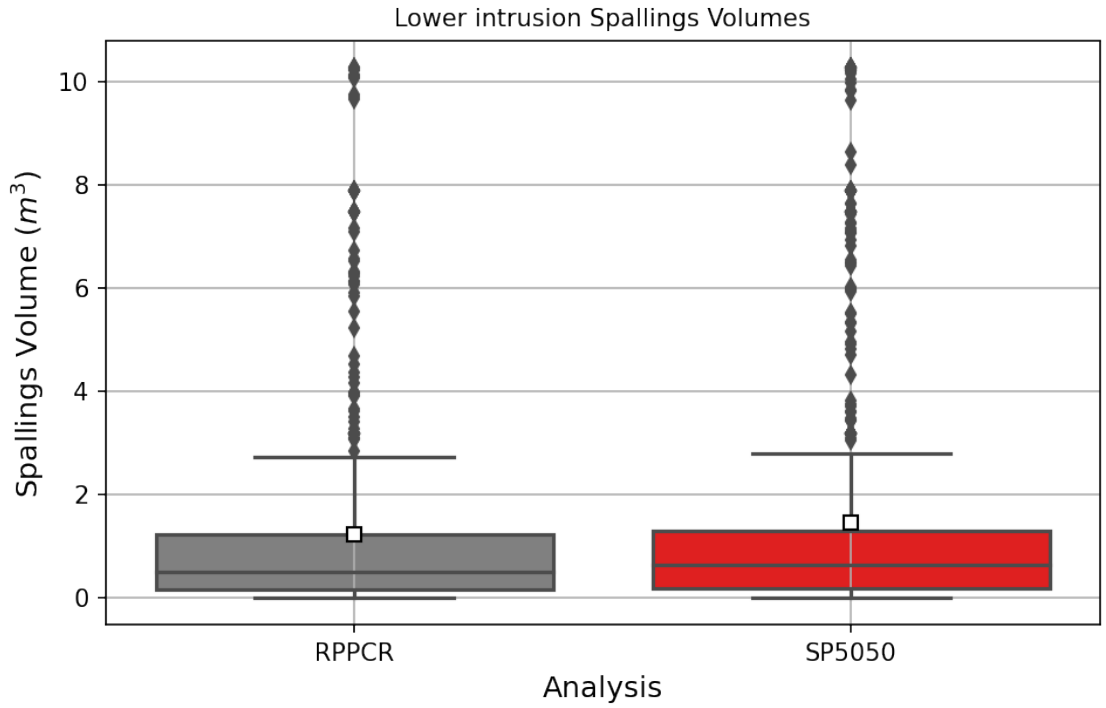

Figure 22 – Spalled Volumes from Lower Intrusions

3.3 Direct Brine Release Volumes

The change in brine pressure and brine saturation in the highly loaded waste panel causes changes in DBR volumes. The BRAGFLO_DBR calculation was run with the Salado Flow results for SP5050. Summary statistics for Lower intrusion DBR events are presented in Table 12. Lower intrusion DBR events and distributions of DBR volumes are presented in Figure 23 and Figure 24.

DBR events and mean DBR volumes are decreased somewhat for intrusions in the highly loaded waste panel, as compared to the RPPCR PA. Table 12 shows the frequency of DBR events decreasing by 9.2% and the mean non-zero DBR volume decreasing by 12.2%. As seen in Figure 24, the maximum DBR volumes from the highly loaded waste panel have somewhat increased. DBR volumes depend on both pressure and brine saturation in the waste panel. The increase in waste pressure would tend to increase DBR volumes, while the decrease in brine saturation would tend to decrease DBR volumes. In the case of the highly loaded waste panel of the SP5050 analysis, the decrease in brine saturation leads to an overall decrease in DBR volumes, despite the increase in brine pressure.

A complete description of the DBR model, conceptual approach, scenarios, and RPPCR PA results can be found in Docherty and King (2023).

Table 12 – Direct Brine Release Volume Summary

Scenario	Mean DBR Volume (m^3)		Fraction of Simulations with Non-Zero DBR Volume		Mean of Non-Zero Brine Volume (m^3)	
	RPPCR	SP5050	RPPCR	SP5050	RPPCR	SP5050
S1-DBR	1.77	1.24	15.2%	11.2%	11.67	11.1
S2-DBR	5.73	2.59	74.6%	57.0%	7.67	4.54
S3-DBR	3.73	1.27	68.0%	44.0%	5.48	2.88
S4-DBR	2.02	2.71	18.4%	19.4%	10.97	13.96
S5-DBR	2.68	2.81	21.4%	18.8%	12.52	14.97
All	**3.13**	**2.09**	**38.6%**	**29.4%**	**8.11**	**7.12**

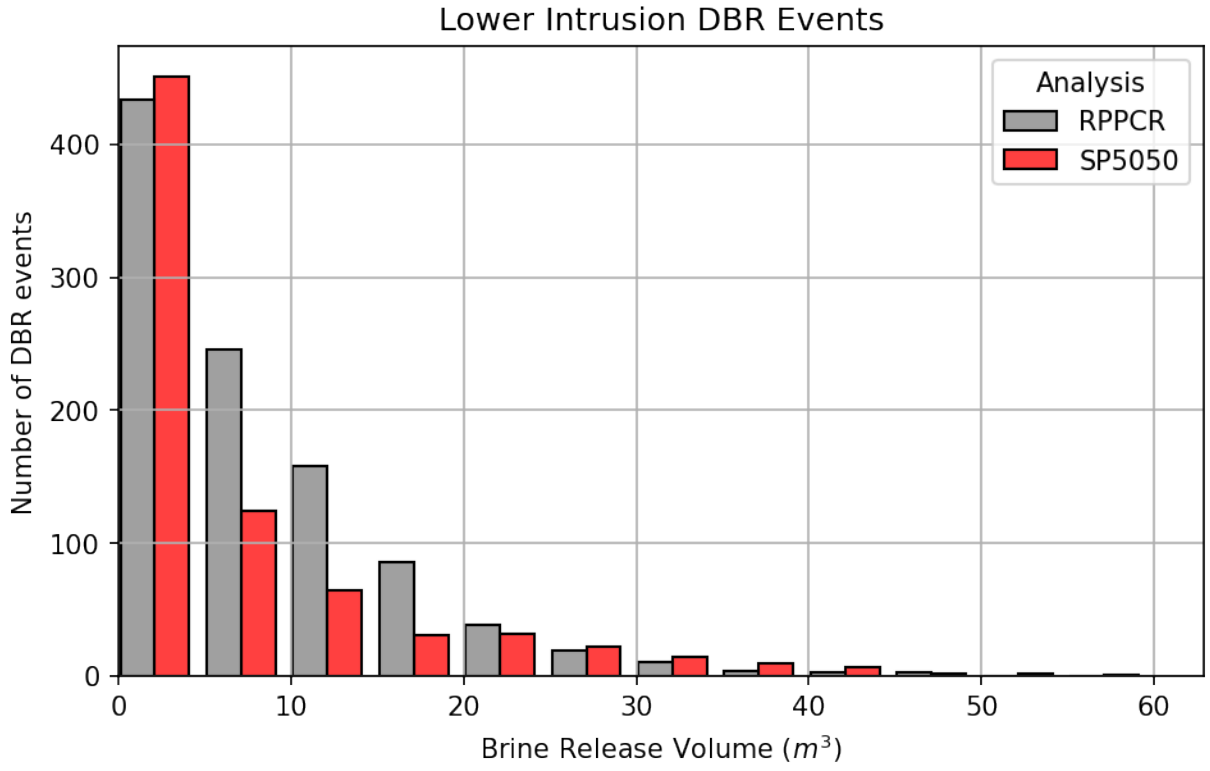

Figure 23 – Number of Events with Non-zero DBR

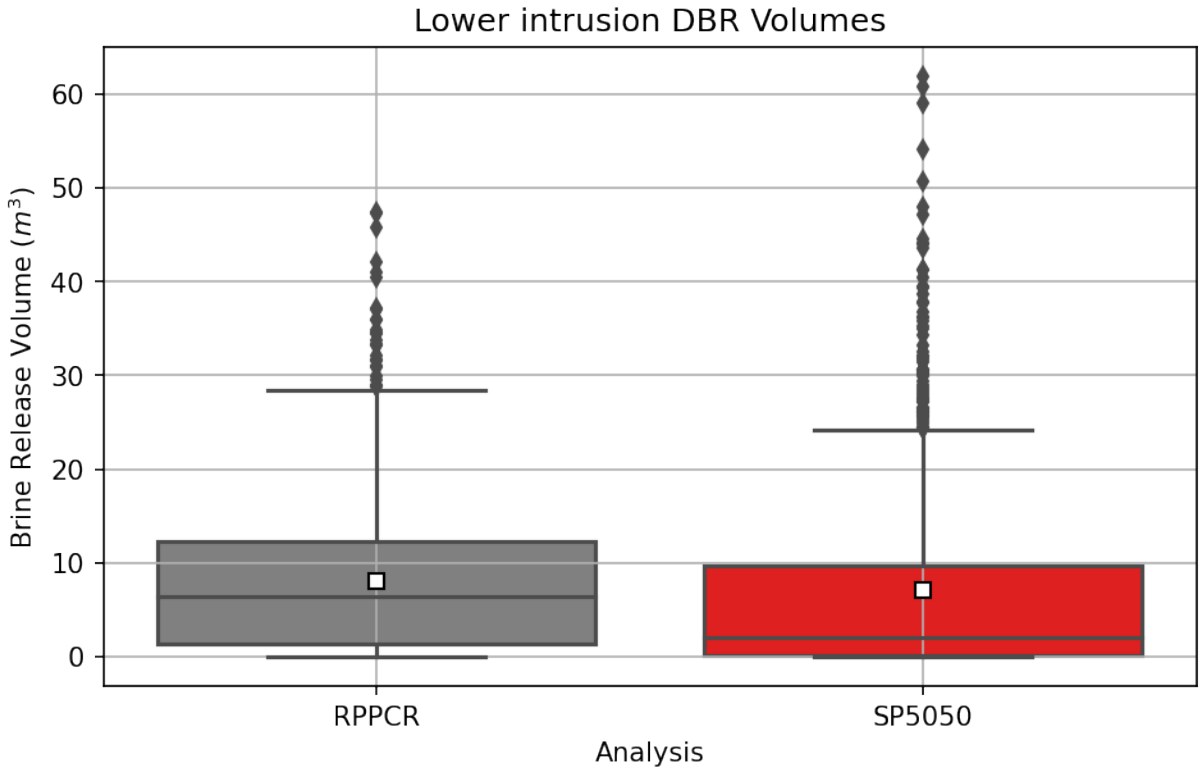

Figure 24 – Direct Brine Release Volumes from Lower Intrusions

3.4 Actinide Mobilization

The actinide mobilization for SP5050 analysis was calculated with the PA code PANEL and the assumption that the waste loading would not significantly impact chemical conditions and radionuclide solubility limits. While the solubility limits are not changed, the mobile radionuclide concentration can change with the inventory change.

Figure 25 shows the total mobile radionuclide concentrations in Castile brine at the minimum brine volume for a DBR. In this figure, the initial concentrations are dominated by Am-241. In the RPPCR, at less than 1,000 years post-closure the Am-241 inventory has decayed to a point where the concentration becomes inventory limited rather than solubility limited. For the SP5050, it is nearly 2,000 years before the concentrations see inventory limitations. After the total concentration becomes dominated by plutonium, some of the vectors with the highest concentrations see lower values in SP5050 due to the change in mole fractions between the plutonium isotopes. See Kim (2023) for a complete description of the actinide mobilization model and the RPPCR results.

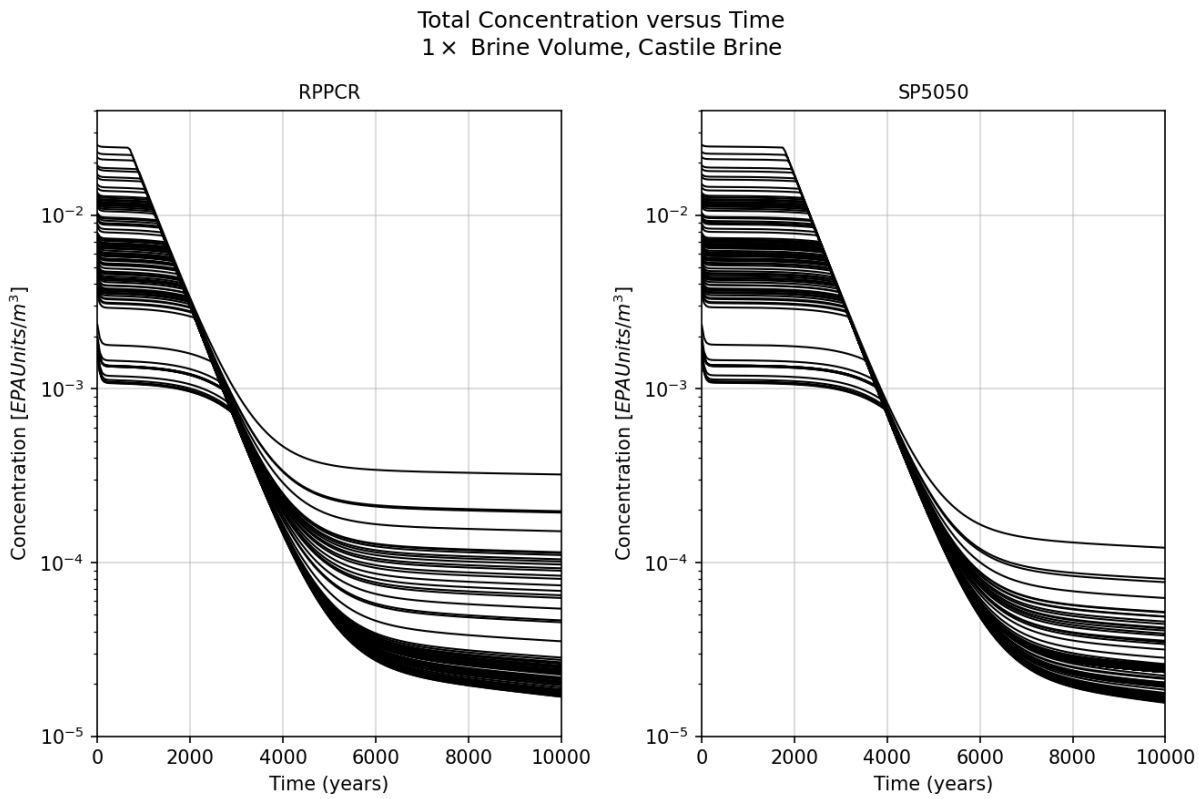

Figure 25 – Total Mobile Radionuclide Concentrations through Time for 1× Brine Volume and Castile Brine.

3.5 Direct Releases

The SP5050 analysis was carried forward to releases from stochastic futures with the assumption that the waste loading would not significantly impact chemical conditions and radionuclide solubility limits. While the solubility limits are not changed, the PA codes PANEL and NUTS were run because mobile radionuclide concentration can change with the inventory change. To construct direct releases for a random future, the highly loaded panel is assumed to be at the location of Panel 11. As all of the unfilled panels in the new west half of the repository have the same footprint, volume, and panel neighboring relationships, releases on average should be the same from each panel. The choice of Panel 11 as the highly loaded waste panel is arbitrary.

First, direct releases attributable to intrusions into the highly loaded waste panel are compared with direct releases from two other single panels: Panel 11 in the RPPCR PA, and Panel 12 in a third calculation (MSP5050) in which panels other than Panel 11 contain the inventory not accounted for in a highly loaded waste panel, distributed homogeneously. Panel 12 results are shown for MSP5050, as representative of all panels except Panel 11.

Second, direct releases from a full repository with one highly loaded waste panel are constructed and compared with direct releases from the RPPCR PA. The full repository model with one highly

loaded waste panel is named ASP5050. A flow chart of analysis used in this report is shown in Figure 26.

Long-term releases through the Culebra are several orders of magnitude less than the direct releases in the RPPCR PA (Brunell and Zeitler, 2023). Because of the relatively small effect of one highly loaded waste panel on total releases, long-term releases through the Culebra are not considered in the SP5050 analysis.

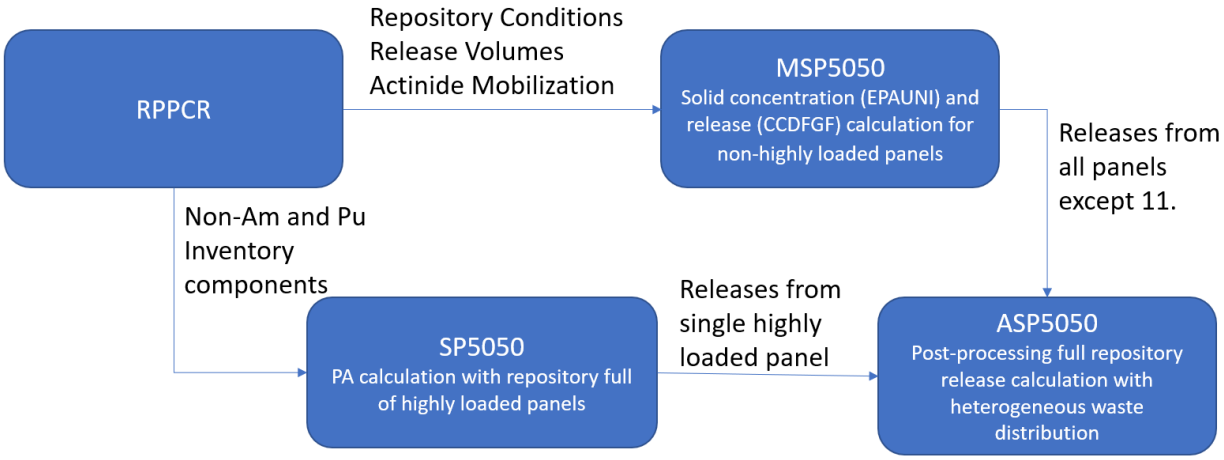

Figure 26 – Flow Chart of Analysis Used in this Study.

3.5.1 Individual Panel Releases

Mean (for Replicate 1) cuttings and cavings releases from a single waste panel are shown in Figure 27. The SP5050 cuttings and caving releases are noticeably larger than the RPPCR PA releases from this panel. As described in Section 3.2, cuttings and cavings volumes are not affected by the repository conditions or waste loading. Therefore, the change in releases is due to the increased activity concentration in the solid waste in the highly loaded panel.

Mean (for Replicate 1) spallings releases from a single waste panel are shown in Figure 28. Like the cuttings and cavings releases, there is a noticeable increase in the spalling releases from the SP5050 analysis. By itself, the small increase in the spalling volume seen in Section 3.2 would result in only a minor increase in spallings releases from the highly loaded waste panel. Similar to the increase in cuttings and cavings releases, the increase in activity concentration is the major driver for the increase in mean spallings releases from the highly loaded panel.

Mean (for Replicate 1) direct brine releases from a single waste panel are shown in Figure 29. Compared with the RPPCR PA, the direct brine releases shown in Figure 29 decrease at higher probabilities and increase at lower probabilities for the highly loaded waste panel. As shown in Section 3.4, for a portion of the regulatory timeframe the activity concentrations in mobile brine are limited by solubility rather than by the waste inventory. When mobile concentrations are solubility limited, the highly loaded panel inventory would not cause a change in mobile concentration from the homogeneous waste loading mobile concentration. Section 3.3 showed a decrease in non-zero DBR events and mean DBR volumes, with an increase in maximum DBR

volumes. These changes in DBR volumes are the primary driver for the change in direct brine releases.

Mean (for Replicate 1) total direct releases from a single waste panel are shown in Figure 30. Mean total releases are noticeably increased due to the increase in cuttings, cavings, and spallings releases. These results indicate that the changes in the activity concentration in solid waste releases are much more impactful to total releases than are changes in the repository conditions resulting from a highly loaded waste panel.

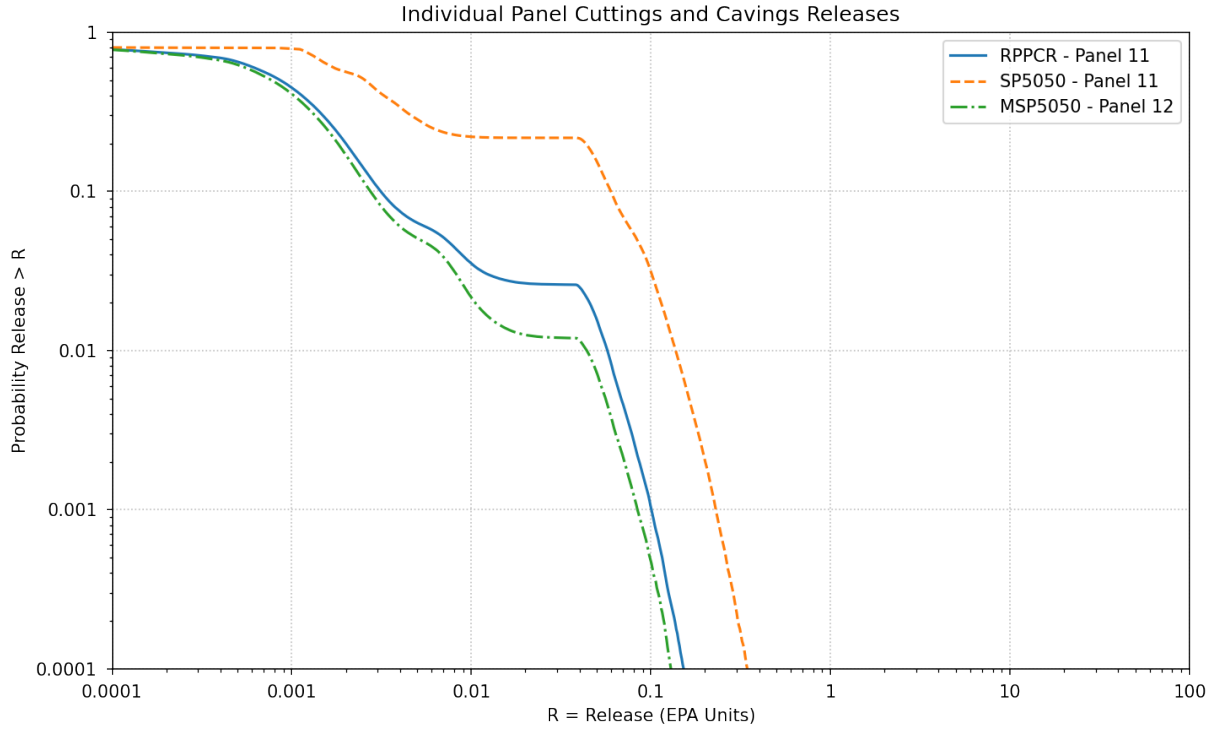

Figure 27 – Mean Cuttings and Cavings Releases from One Waste Panel.

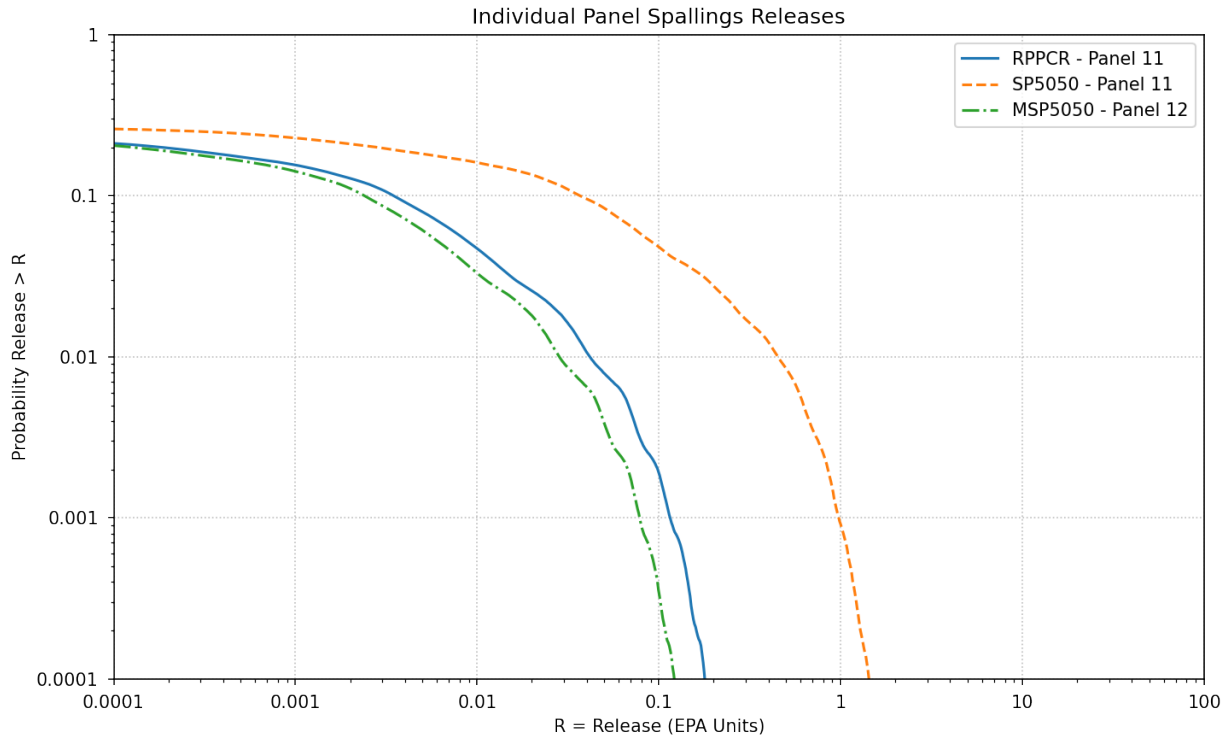

Figure 28 – Individual Panel Spallings Releases

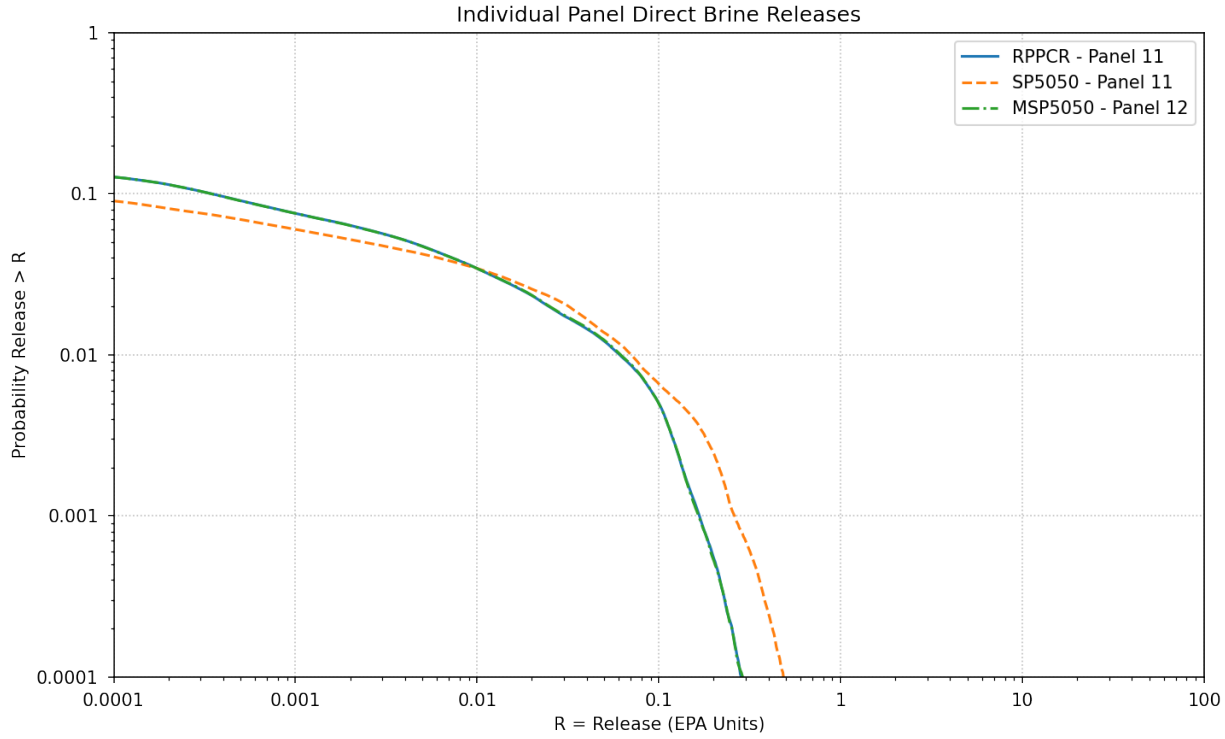

Figure 29 – Individual Panel Direct Brine Releases

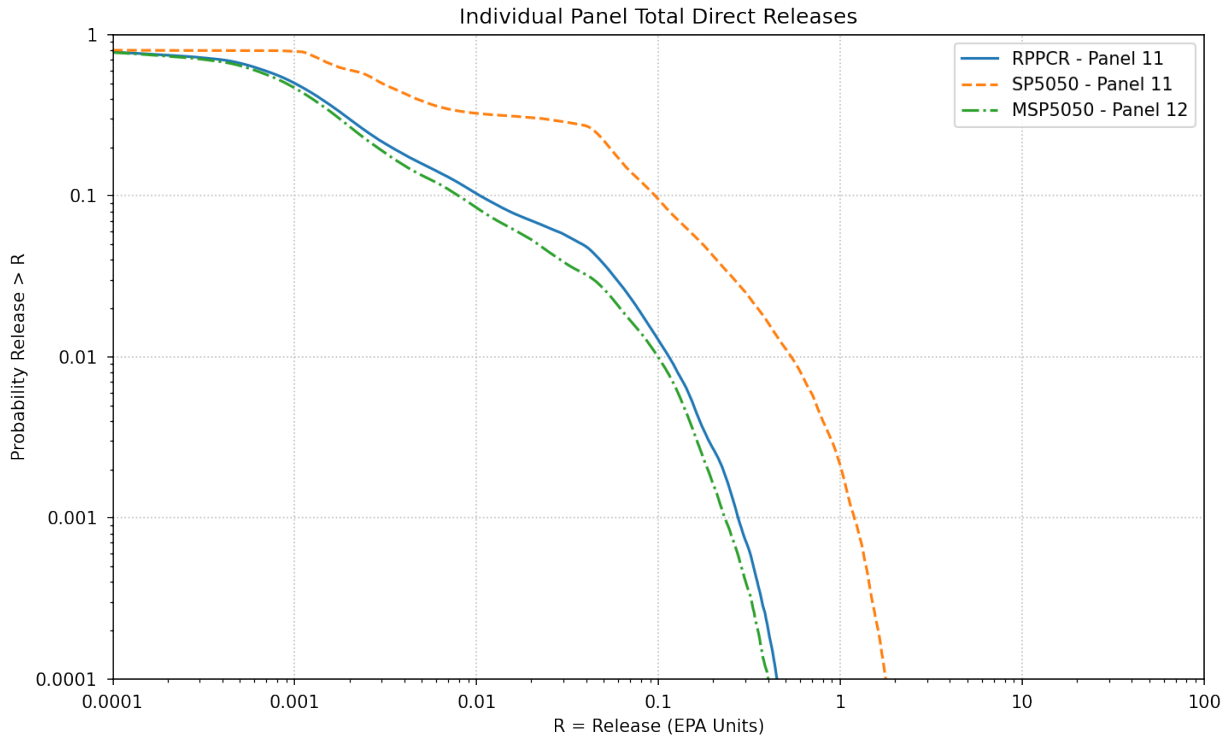

Figure 30 – Individual Panel Total Direct Releases

3.5.2 Repository Releases

Releases from a repository with one highly loaded panel and the remaining waste distributed homogeneously in all other panels are presented in this section. In order to account for the waste emplaced in the highly loaded panel, the solid waste inventory in the EPAUNI input files was adjusted by subtracting the single panel's inventory calculated in Section 2.1 from the RPPCR PA inventory, then scaled by the repository volume divided by the repository volume minus one panel volume. A new calculation, named MSP5050 as mentioned above, was run using EPAUNI and CCDFGF. The RPPCR PA results for all other code executions were used in the MSP5050 calculation. By using the RPPCR PA results for the flow model, the MSP5050 will tend to overestimate gas generation in each panel, but not account for fluid flow from the highly loaded panel into the remaining panels. The SP5050 Panel 11 direct releases are added to the MSP5050 direct releases from all panels except Panel 11 to simulate direct releases from the complete repository. The combined SP5050 and MSP5050 analysis results are termed ASP5050.

Cuttings and caving releases are shown in Figure 31 and Figure 32. Mean releases in ASP5050 are slightly lower at high probabilities and slightly higher at low probabilities compared to the RPPCR PA. This shows that while cuttings and cavings releases from the highly loaded panel are increased, the cuttings and cavings releases from the other panels are decreased leading to little change in the cuttings and cavings releases from the full repository.

Spallings releases are shown in Figure 33 and Figure 34. Mean releases in ASP5050 are slightly higher at low probabilities compared to the RPPCR. Like cuttings and cavings, the increase in spallings releases from the increase in activity concentration of the solid waste is offset by a

decrease in releases from the decrease in the activity concentration in the remaining panels. The increase in spalling volumes from the highly loaded waste panel drives the slight increase in spalling releases at low probability. Note that because the MSP5050 analysis uses the BRAGFLO and CUTTINGS_S calculations from the RPPCR PA, the repository conditions in the remaining panels are not adjusted for the lower waste activity concentration.

Direct brine releases are shown in Figure 35 and Figure 36. Mean releases in the ASP5050 are nearly identical to the mean direct brine releases from the RPPCR PA. The decrease in mean direct brine volume and non-zero simulation scenarios is offset by the increase in maximum direct brine release volume.

Total direct releases are shown in Figure 37 and Figure 38. The mean total direct release in the ASP5050 is slightly increased at low probabilities due to the small increase in spallings releases. The ASP5050 total direct releases is within the 95% confidence interval of the RPPCR total releases shown in Figure 42 of Brunell and Zeitler (2023). That is, the change in releases due to one panel being loaded with only surplus plutonium and pit production waste is within the uncertainty about the mean CCDF of total releases from the finite sample size of Replicate 1.

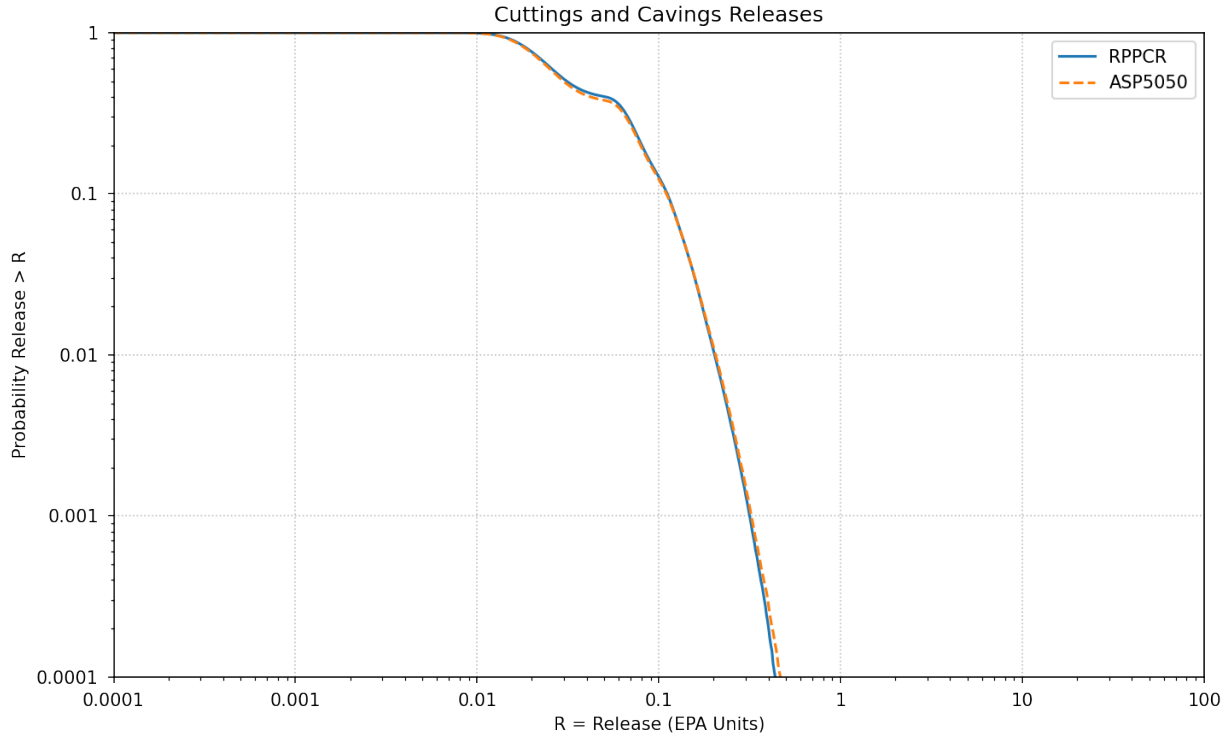

Figure 31 – Mean Cuttings and Cavings Releases

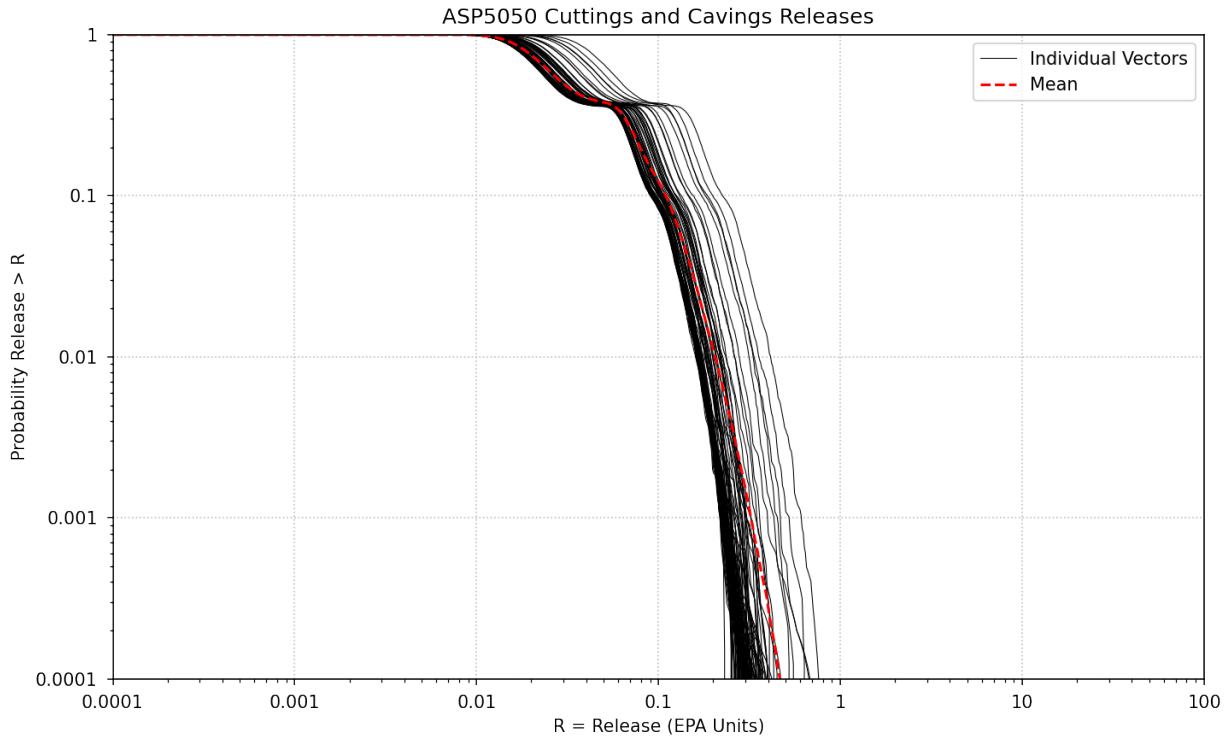

Figure 32 –Cuttings and Cavings Releases in the ASP5050 Analysis

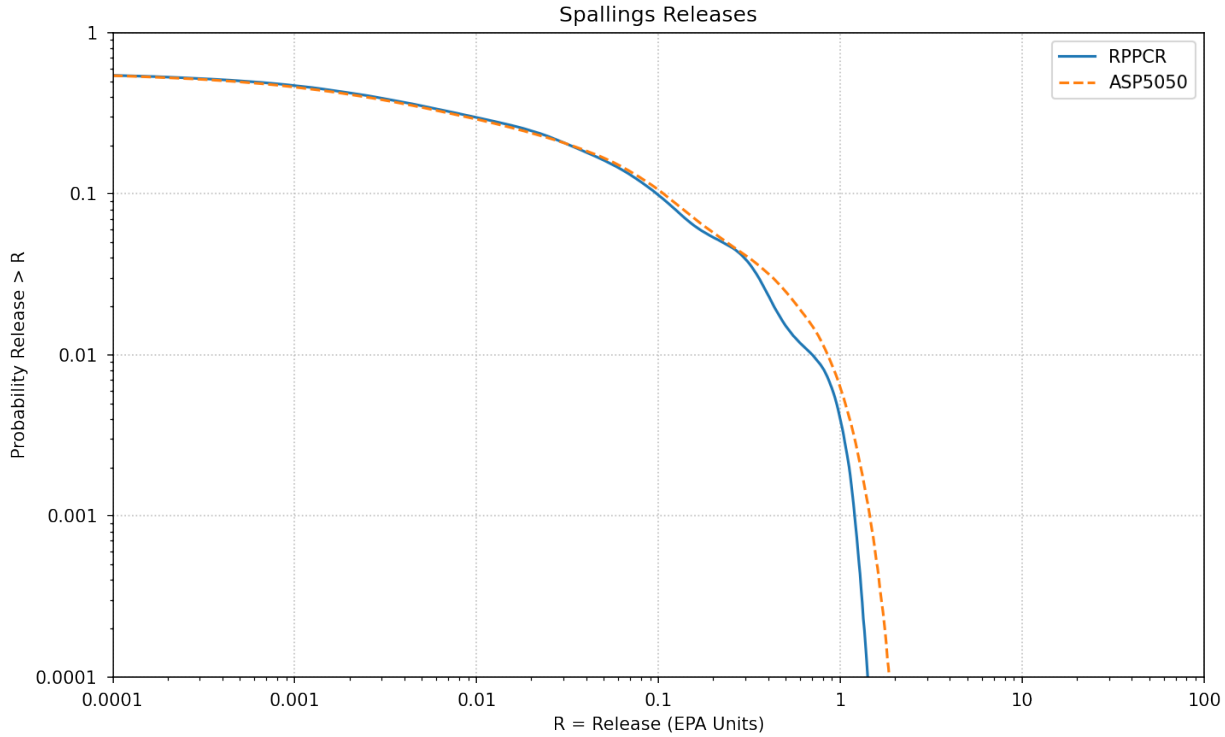

Figure 33 – Mean Spallings Releases

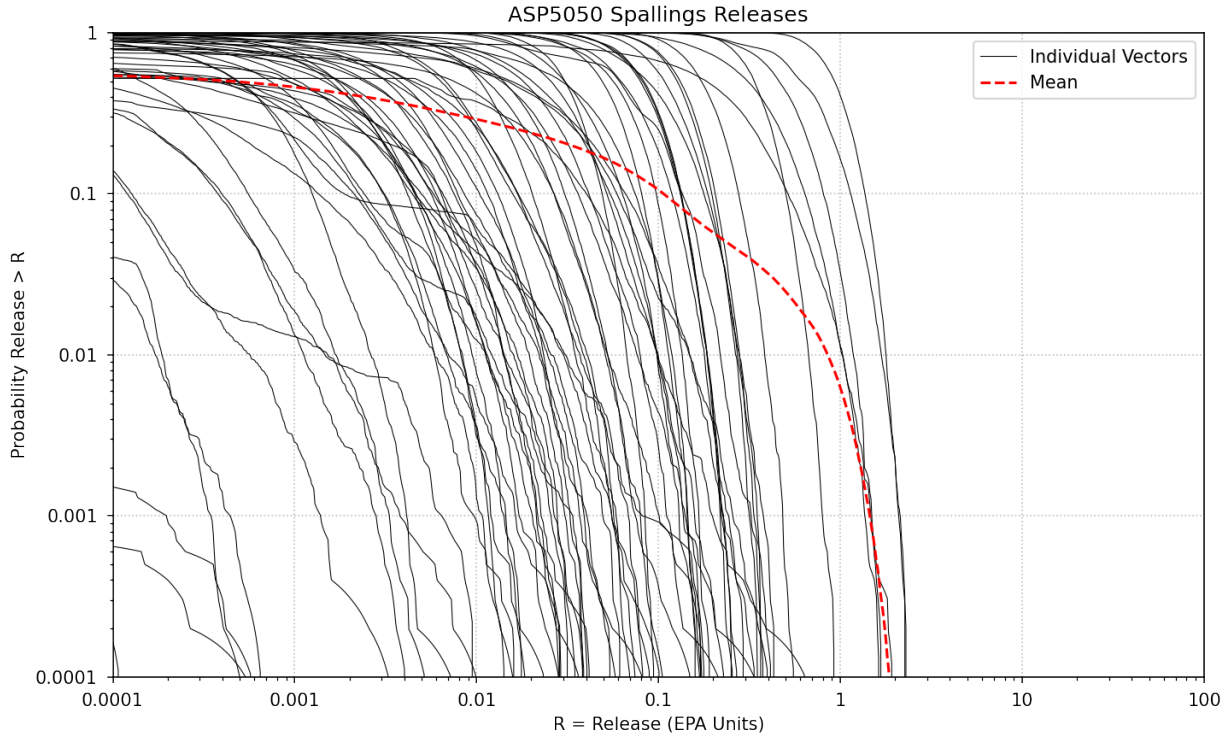

Figure 34 –Spallings Releases in the ASP5050 Analysis

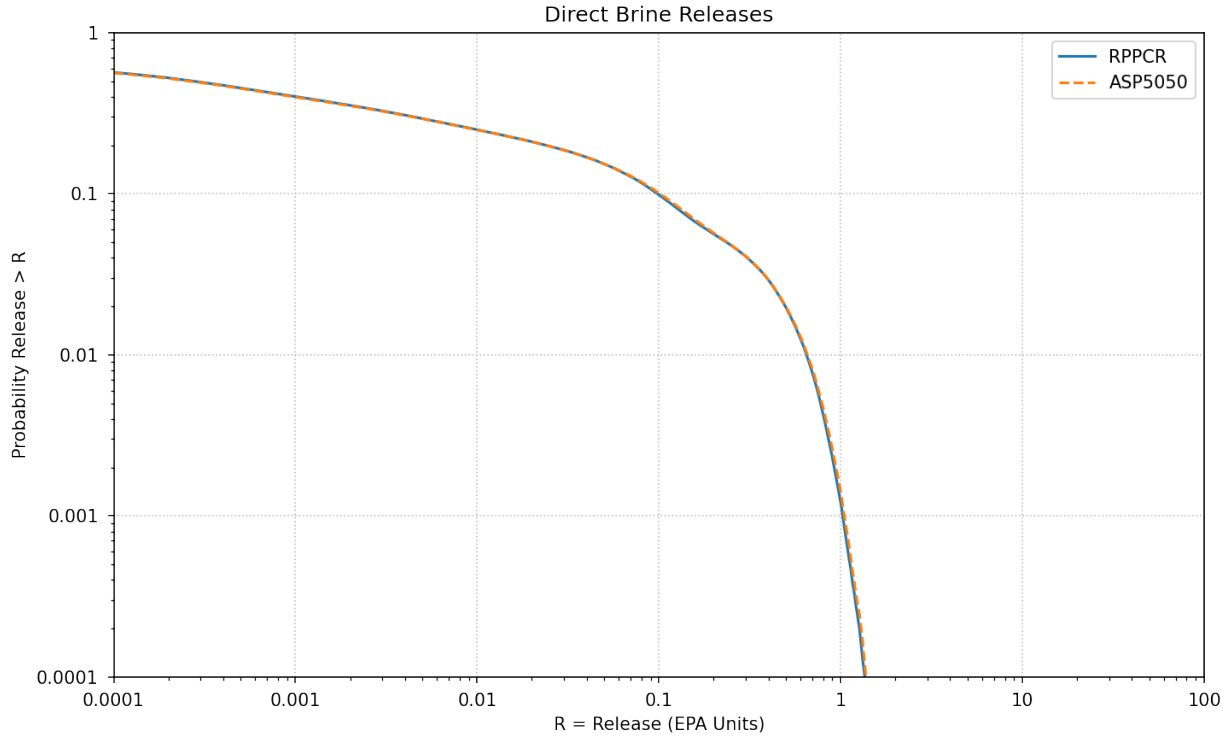

Figure 35 – Mean Direct Brine Releases

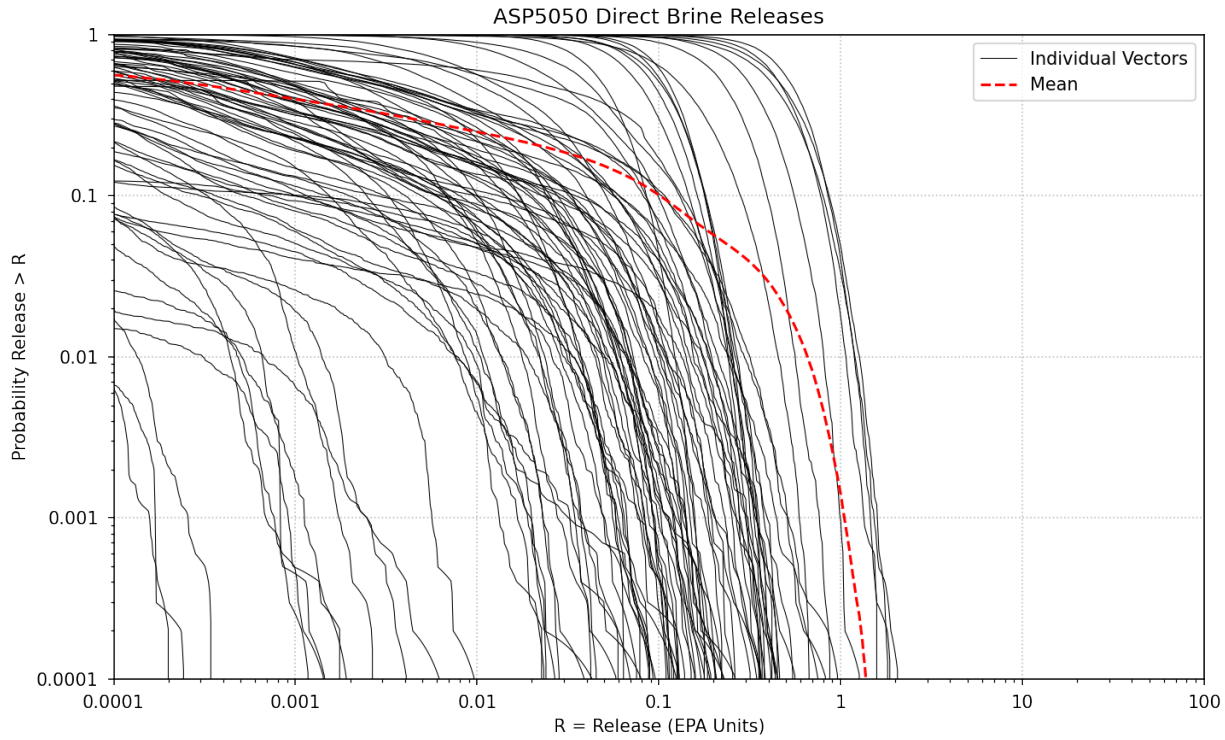

Figure 36 –Direct Brine Releases in the ASP5050

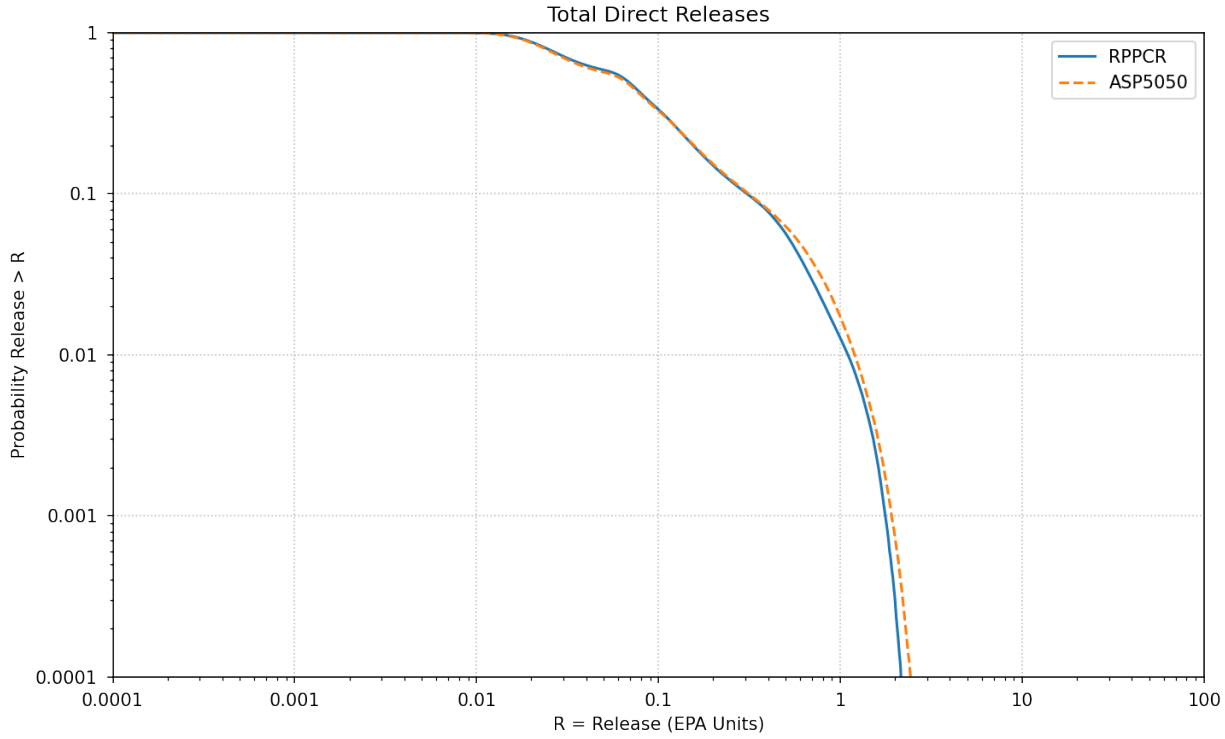

Figure 37 – Mean Total Direct Releases

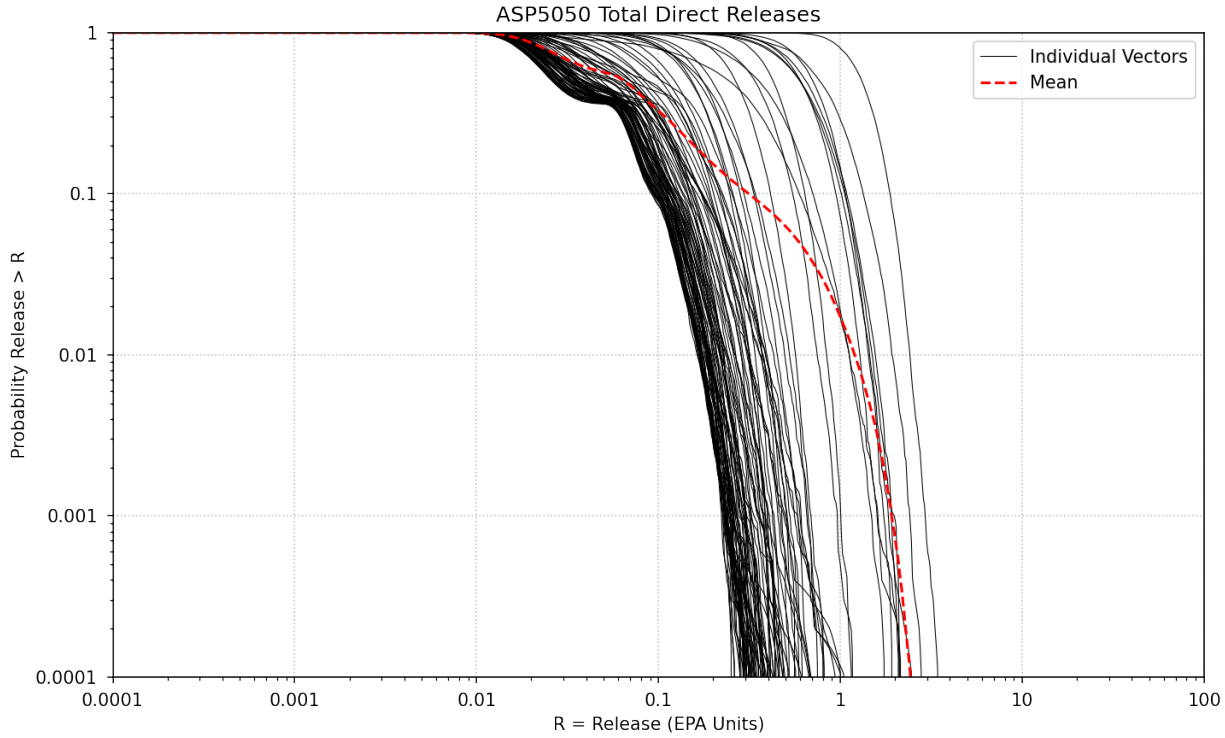

Figure 38 –Total Direct Releases in the ASP5050 Analysis.

4.0 SUMMARY

Because of DOE's commitments to cleaning up legacy TRU waste and shipping logistics, it is not expected that any one waste panel will see a disproportionate loading of the surplus plutonium waste streams. Even though a highly loaded waste panel is unlikely, an analysis was performed to quantify the performance of the repository with a single highly loaded waste panel.

The analysis assumes that only the Savannah River Site would be shipping waste for a period of time sufficient to load a single panel, and that the waste would be an equal split of surplus plutonium and pit production waste. Optimal loading of the waste panel is assumed, and the total activity of the waste in the highly loaded waste panel was calculated. Because the current WIPP PA codes do not support heterogeneous waste materials, the inventory in the highly loaded waste panel was scaled to fill the whole repository. The assumptions of optimal loading of the panel and scaling to a homogeneous repository will overestimate the impact on repository-scale gas generation and repository pressure resulting from the higher loading in a waste panel.

The Salado flow, spallings, and DBR volume models were calculated with this updated inventory without any other changes from the RPPCR PA. In the representative waste panel, a significant increase in gas generation from brine radiolysis is seen. Brine radiolysis accounts for more gas generation than iron corrosion in the highly loaded panel. The increase in gas generation results in a slight increase in waste panel pressure and a decrease in waste panel brine saturation.

The increase in pressure results in a 2.7% increase in the number of spalling events and an 18.0% increase in mean spalled volume. For DBRs, the increase in pressure is counteracted by the decrease in brine saturations, resulting in an overall decrease in DBR volumes. Frequency of DBR events decrease by 9.2% and mean non-zero DBR volumes decrease by 12.2%.

The analysis is carried forward to calculate direct releases from a single waste panel for randomly generated futures. Cuttings, cavings, and spallings releases from the highly loaded panel increase significantly due to the higher solid waste activity concentration in the highly loaded panel. When the solid waste activity concentration in the other panels is adjusted downward to account for the waste in the highly loaded panel, mean total releases from the complete repository shows a small increase. This small increase in mean total releases is within the 95% confidence interval of the RPPCR releases, meaning a highly loaded waste panel has no significant impact on mean releases for the WIPP repository.

Due to the uncertainty modeled in WIPP PA calculations and the counteracting effects on brine pressure and saturation, these results indicate that a highly loaded waste panel does not have the potential to significantly impact long-term performance of the WIPP repository with the RPPCR model. That is, a single waste panel with a disproportionate amount of surplus plutonium and pit production waste would not change the conclusions of the RPPCR PA about WIPP's compliance with long-term containment requirements.

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