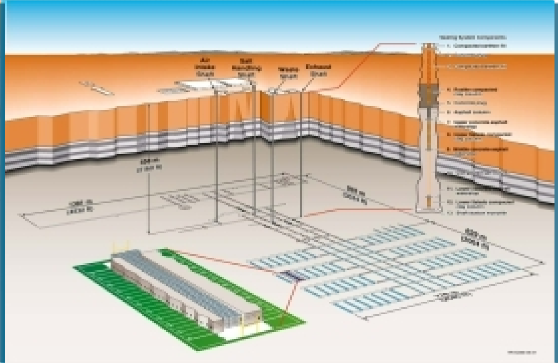
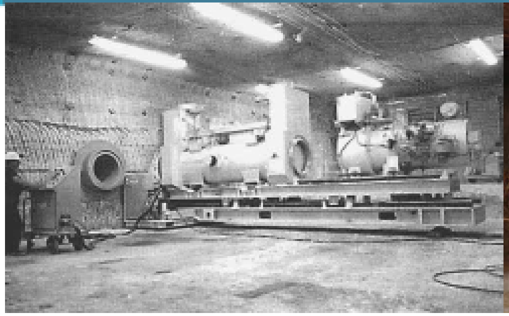
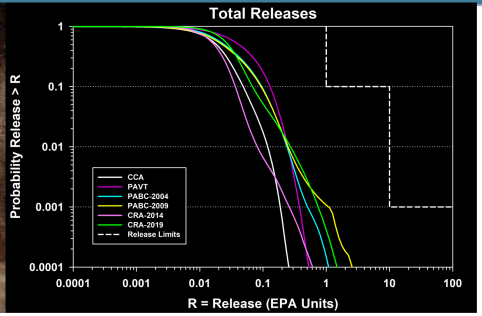
SAND2021-8578PE

Sandia National Laboratories

The Additional Panels Performance Assessment







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July 20, 2021

U.S. DEPARTMENT OF ENERGY NNSA

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Objectives/Outline

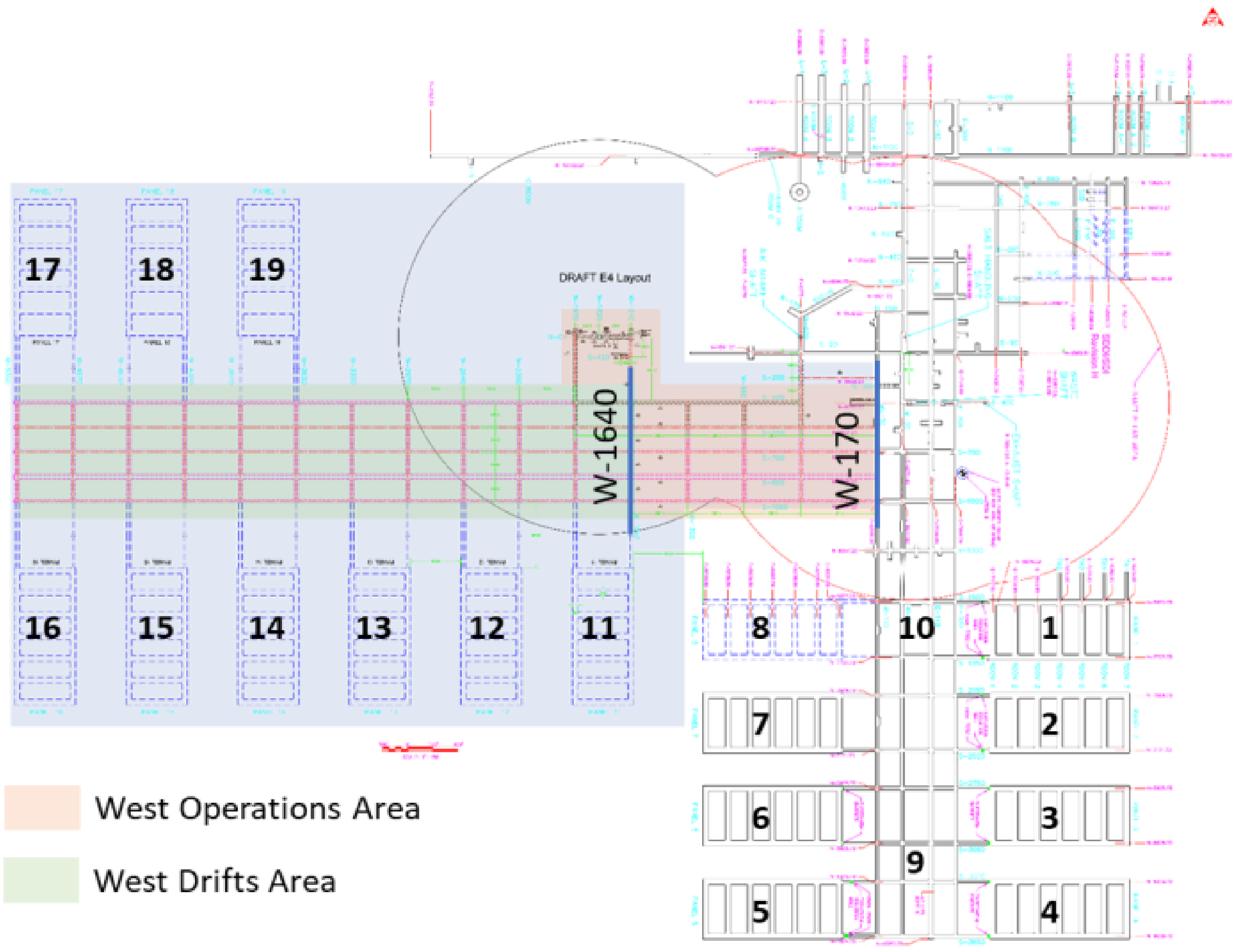
This presentation covers the construction of releases and the results of the Additional Panels Performance Assessment (APPA), as documented in Brunell et al. (2021).

Outline:

- Conceptual Approach to the APPA (AP-185, Hansen, 2020)
- Changes since CRA-2019
- Construction of Releases
- Summary of Results
- Results
  - Salado Flow
  - Cuttings and Cavings
  - Spallings
  - Actinide Mobilization
  - Direct Brine Releases (DBRs)
  - Salado Transport
  - Culebra Releases
  - Sensitivity Analysis
- Conclusions

Conceptual Approach to the Additional Panels PA

- Based on E4 design provided to SNL by NWP (Sjomeling, 2019)
- Conceptual model review (Hansen, 2021)
  - Changes needed to implementation of conceptual models
- FEPs analysis (Kirkes, 2021)
  - No change to FEP screening decisions



Conceptual Approach to the Additional Panels PA

Changes for the APPA

- Modified Salado flow grid
- Modified DBR grid

Detailed discussion to follow in future presentations

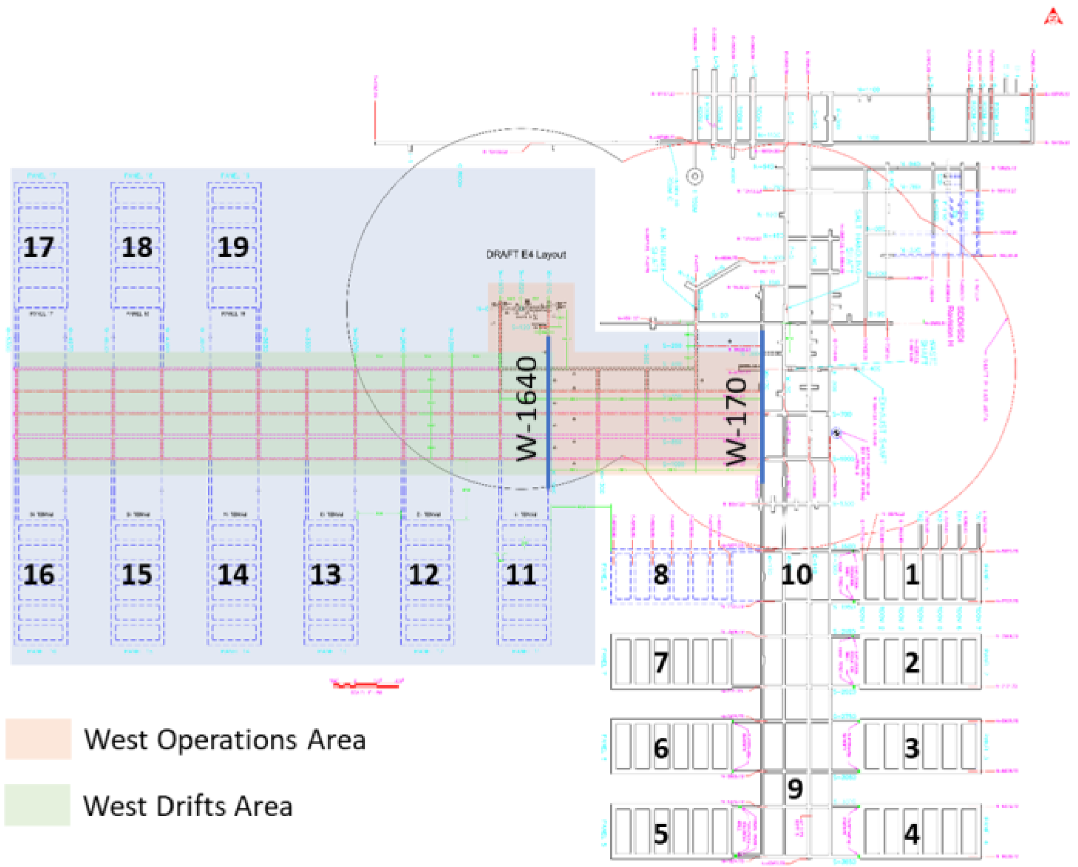
- Updated model input parameters related to repository dimensions
- Updated panel neighboring assignments
- Computational code changes to implement the above

No new uncertain parameters

- Same parameter sampling as the CRA-2019 PA

Other changes since the CRA-2019 PA

- Correction to actinide baseline solubilities[1]



[1] This change resulted from a correction to the thermodynamic database documented in Domski (2020a) and Domski (2020b), and not by the proposed change to the footprint of the WIPP repository.

Repository Parameter Updates

Material	Property	Description	CRA19 Value	APPA Value	Units
REFCON	ABERM	Area of the berm placed over waste panels. Equivalent to the footprint of the waste panels.	628,500	1,268,303	m^2
REFCON	AREA_CH	Area for contact-handled (CH) waste disposal. Combined floor area of the waste panels.	111,500	216,952	m^2
REFCON	FVW	Fraction of repository volume occupied by CH waste. REFCON:VOLCHW* / REFCON:VREPOS.	0.385	0.197	Unitless
REFCON	VREPOS	Excavated storage volume of the repository. Combined volume of waste panels.	438,406.08	819,834.21	m^3
CAVITY_1	PRESSURE	Brine pore pressure. Pressure of the waste panel at time of closure used by BRAGFLO.	128,039	115,610	Pa
CAVITY_2	PRESSURE	Brine pore pressure. Pressure of rest-of-repository at time of closure used by BRAGFLO.	128,039	115,610	Pa

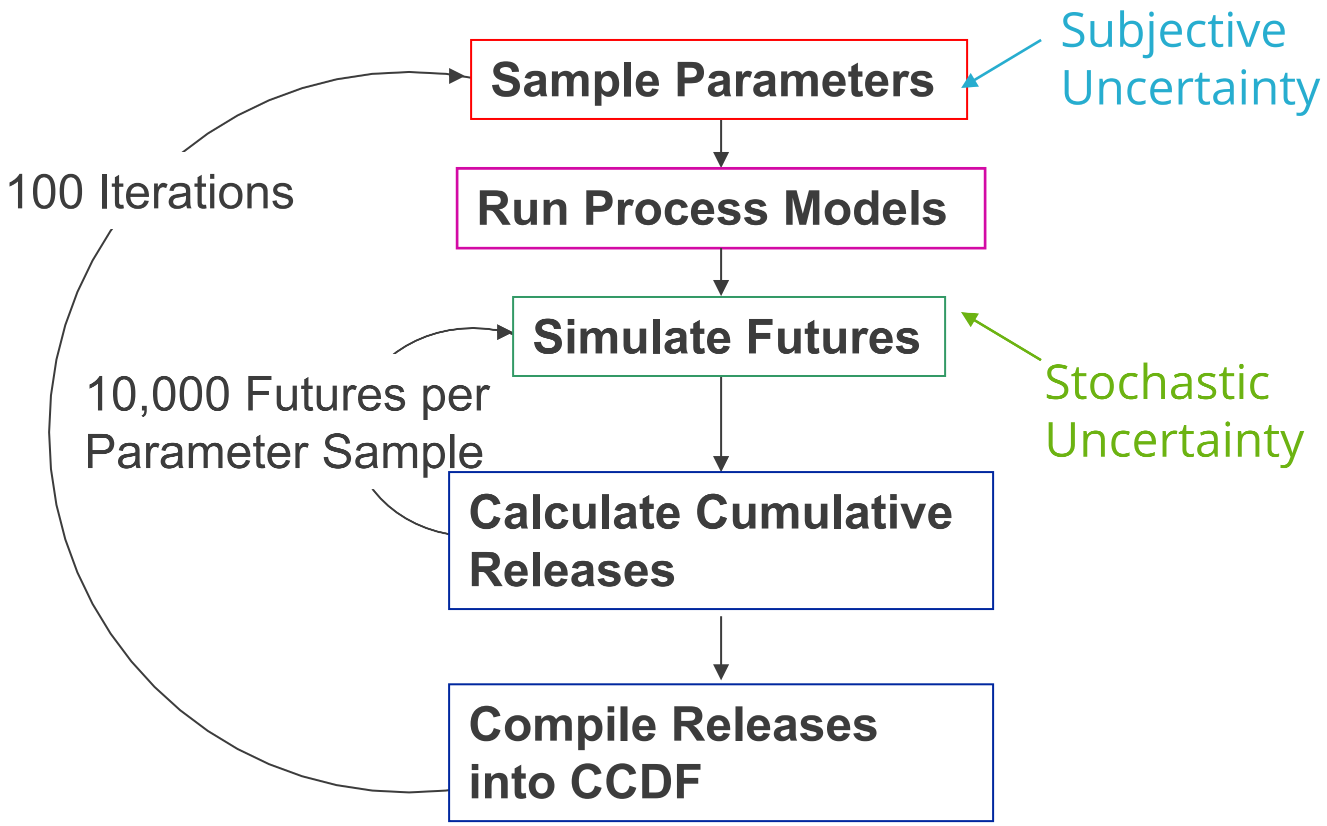
* Parameter REFCON:VOLCHW = 168,500 m^3

Inventory Scaling

- The APPA analysis uses the same inventory as the CRA-2019 PA, which is scaled to the Land Withdrawal Act (LWA) legislated waste capacity of 175,564 m^3.
- The increased waste storage area of the APPA increases the physical volume where waste can be emplaced but does not increase the volume of the waste emplaced in the repository.
- Waste concentrations (radionuclides, steel, CPR) decrease in the APPA as compared to the CRA19.
- Solids releases of CH waste are scaled by the fractional volume of the storage that contains waste (PA Parameter REFCON:FVW). FVW decreases in the APPA (0.197) compared to the CRA19 (0.385).
- The increased storage area will increase the number of borehole intrusion events. For solids releases the increase in intrusions will be counteracted by the decreased FVW value.

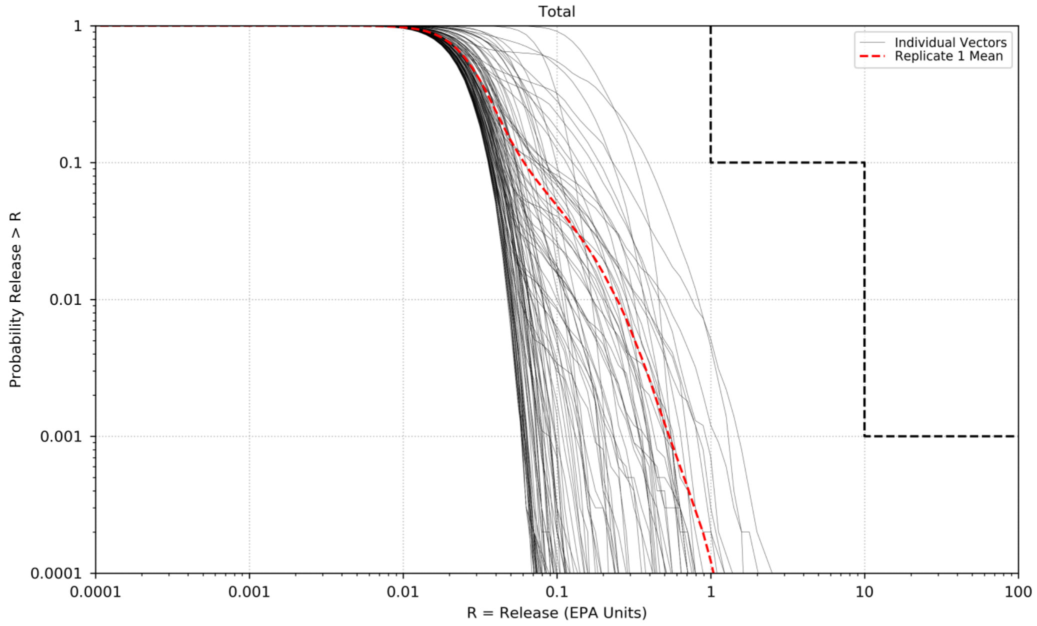
CCDFs of releases - overview

- A CCDF defines the probability that cumulative normalized releases will exceed a given level
- One complementary cumulative distribution function (CCDF) is constructed for each set of sampled parameter values
- Each future comprises a sequence of random borehole intrusions and a random time of complete mining
- Cumulative releases for each future are assembled from results from other WIPP PA codes



APPA Total Releases

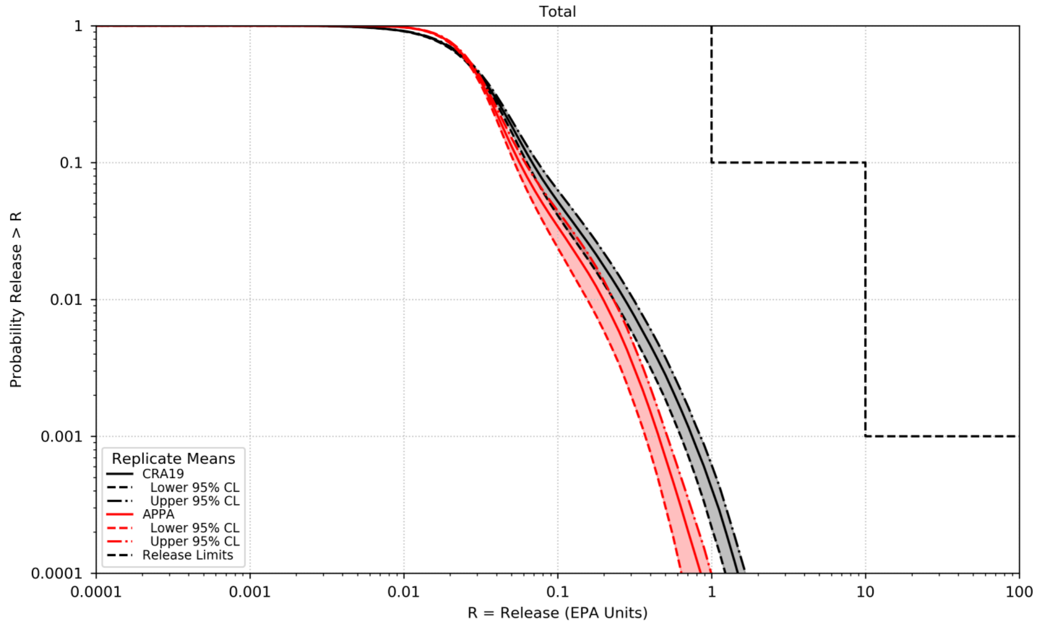
APPA Total Releases, Replicate 1



100 CCDFs, each constructed from 10,000 data points (futures)

Replicated three times (independent parameter samples) to compute a confidence interval for the mean CCDF

CRA-2019 vs. APPA Total Releases

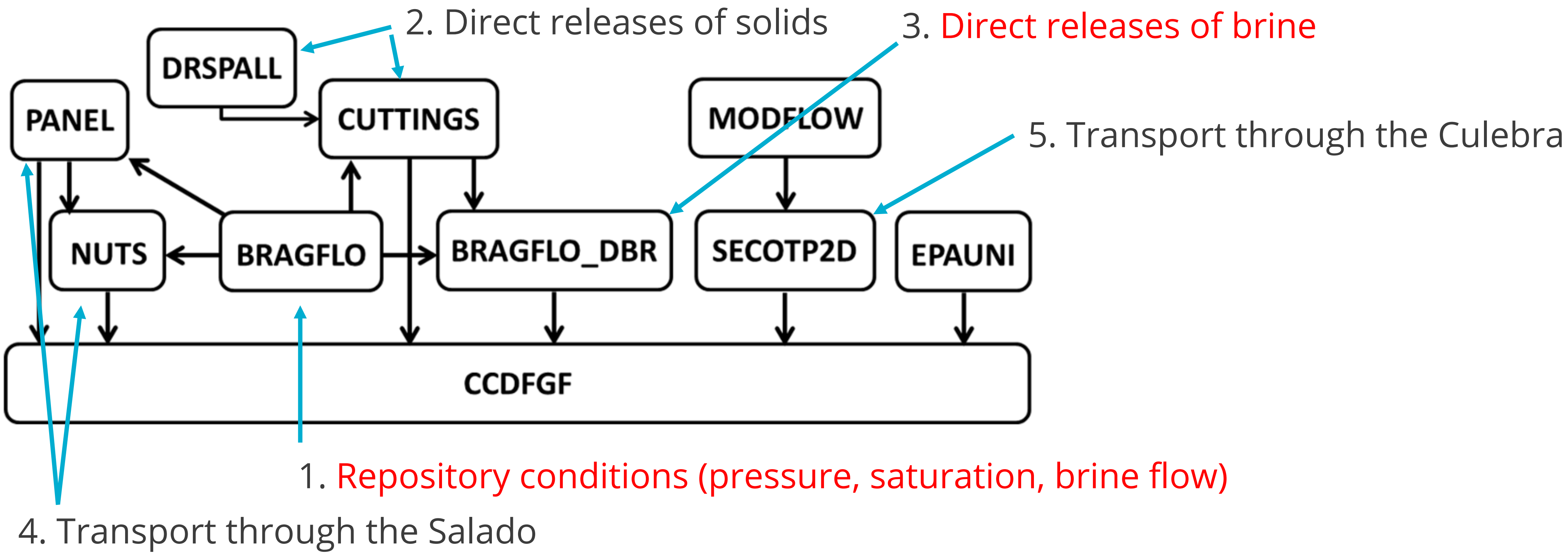


Mean CCDFs

WIPP compliance is based on the mean CCDF over 3 replicates. An individual CCDF is NOT relevant for compliance

CCDFs – Constructing Releases

- Computationally too intensive to explicitly model each future’s sequence of random intrusions
- Model representative scenarios, shift and interpolate on scenario results to determine releases from each intrusion and future.



Intrusion Types and BRAGFLO Scenario Definitions

Intrusion Type	Description
E1	Borehole intrusion encounters brine pocket.
E2	Borehole intrusion does not encounter brine pocket.
E1E2	Multiple intrusions occur, at least one is an E1 intrusion.

BRAGFLO Scenarios	Description
S1-BF	Undisturbed Repository
S2-BF	E1 intrusion at 350 years
S3-BF	E1 intrusion at 1,000 years
S4-BF	E2 intrusion at 350 years
S5-BF	E2 intrusion at 1,000 years
S6-BF	E2 intrusion at 1,000 years; E1 intrusion at 2,000 years.

BRAGFLO-DBR scenarios

Scenario	Description
S1-DBR	Initially undisturbed repository (i.e., E0 conditions). Intrusion into lower, middle, upper, or other waste panel at 100; 350; 1,000; 3,000; 5,000; or 10,000 years: 24 combinations.
S2-DBR	Initial E1 intrusion at 350 years followed by a second intrusion into the same, connected, adjacent, or nonadjacent waste panel at 550; 750; 2,000; 4,000; or 10,000 years: 20 combinations.
S3-DBR	Initial E1 intrusion at 1,000 years followed by a second intrusion into the same, connected, adjacent, or nonadjacent waste panel at 1,200; 1,400; 3,000; 5,000; or 10,000 years: 20 combinations.
S4-DBR	Initial E2 intrusion at 350 years followed by a second intrusion into the same, connected, adjacent, or nonadjacent waste panel at 550; 750; 2,000; 4,000; or 10,000 years: 20 combinations.
S5-DBR	Initial E2 intrusion at 1,000 years followed by a second intrusion into the same, connected, adjacent, or nonadjacent waste panel at 1,200; 1,400; 3,000; 5,000; or 10,000 years: 20 combinations.

- Five of the BRAGLFO Salado Flow model scenarios, S1-BF to S5-BF, are used to set the initial conditions for the DBR calculations at the time of intrusion.
- DBR calculations map the resulting BRAGFLO pressure and saturation conditions at a suite of intrusion times onto the DBR model grid and simulate flow to the intrusion.
- 104 possible combinations of scenario, location, and intrusion time. With 3 replicates of 100 vectors, there are a total of 31,200 DBR simulations.

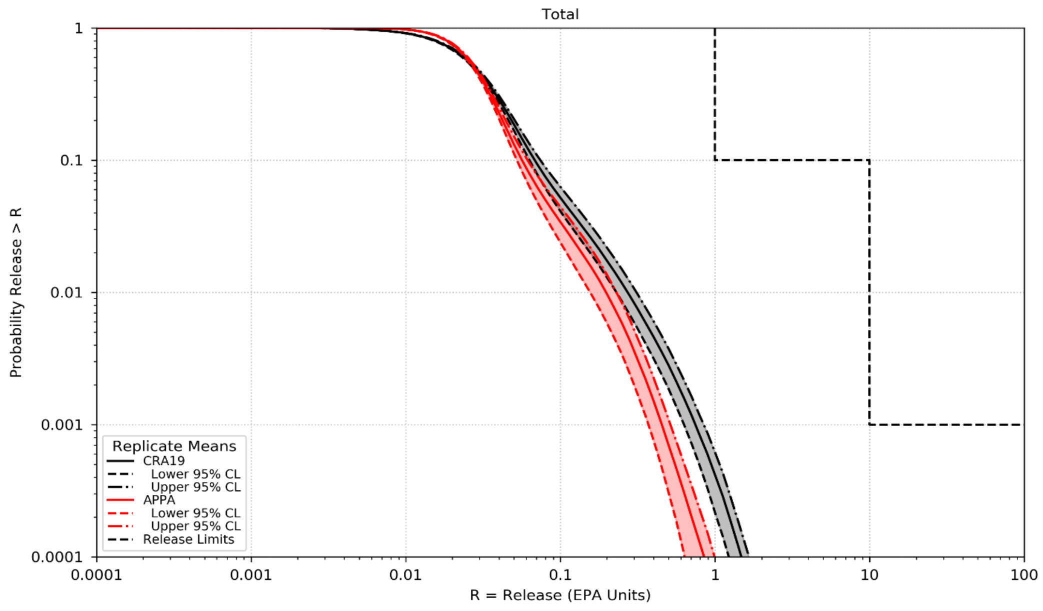
Summary of Results

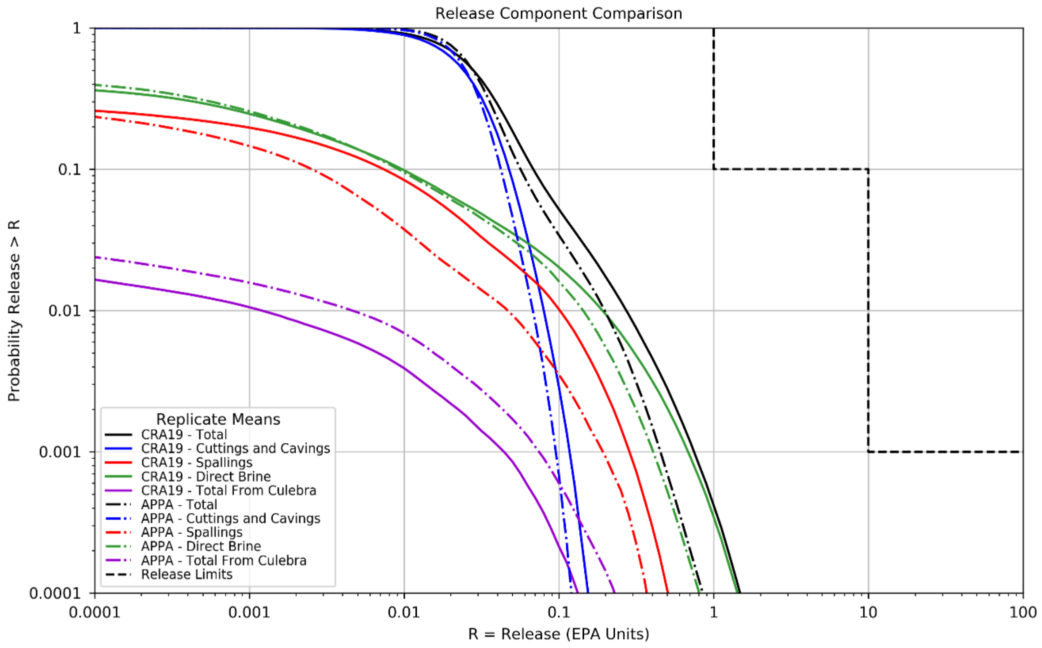
Overall Results:

- Increased at highest probabilities
- Decreased at lower probabilities
- Decreased at both compliance points

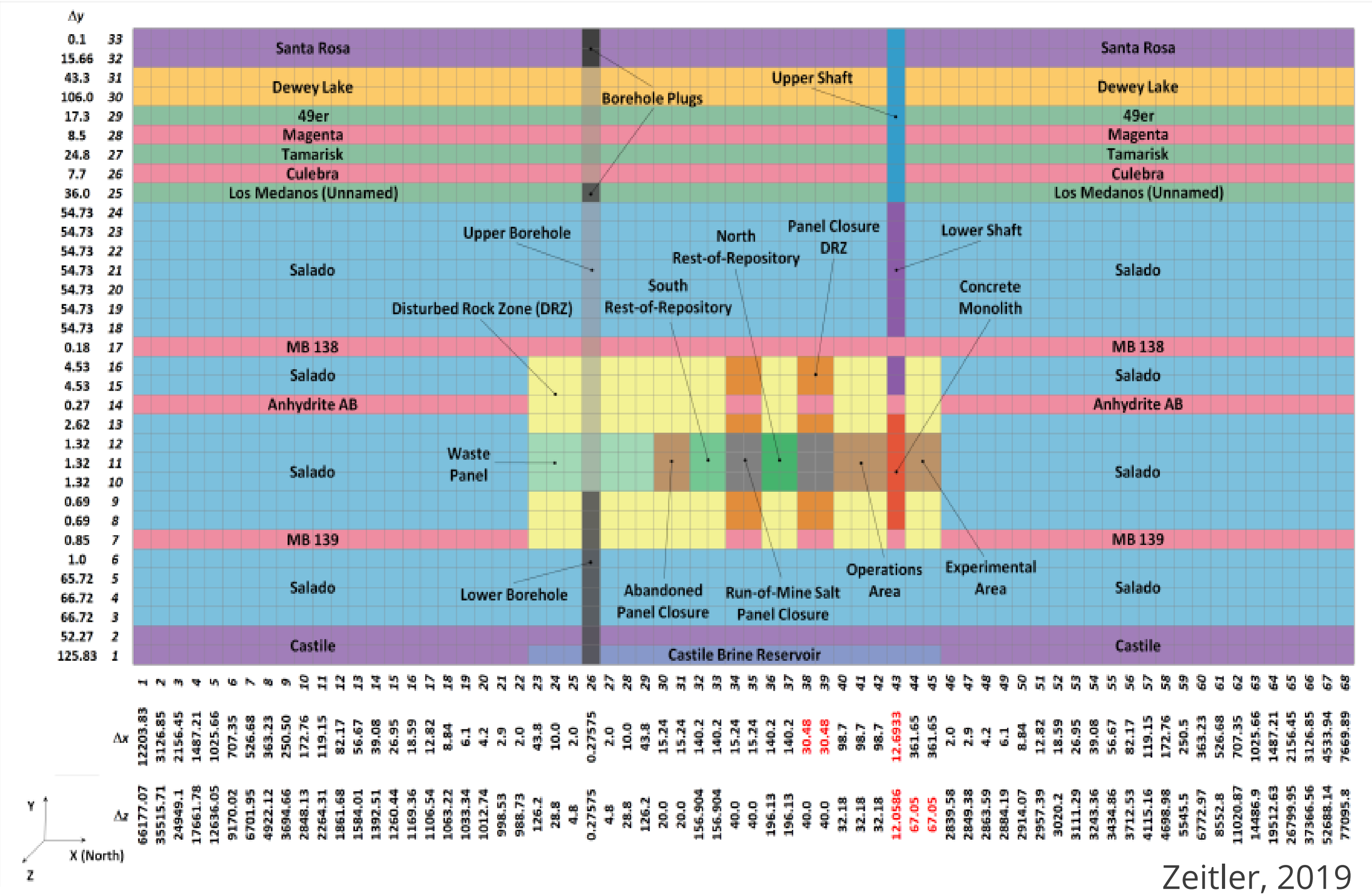
Total Releases by Release Mechanism:

- Cuttings and cavings dominate at high probabilities
- DBRs dominate at low probabilities
- Culebra releases increased at all probabilities
- Releases generally decreased for all other release mechanisms.





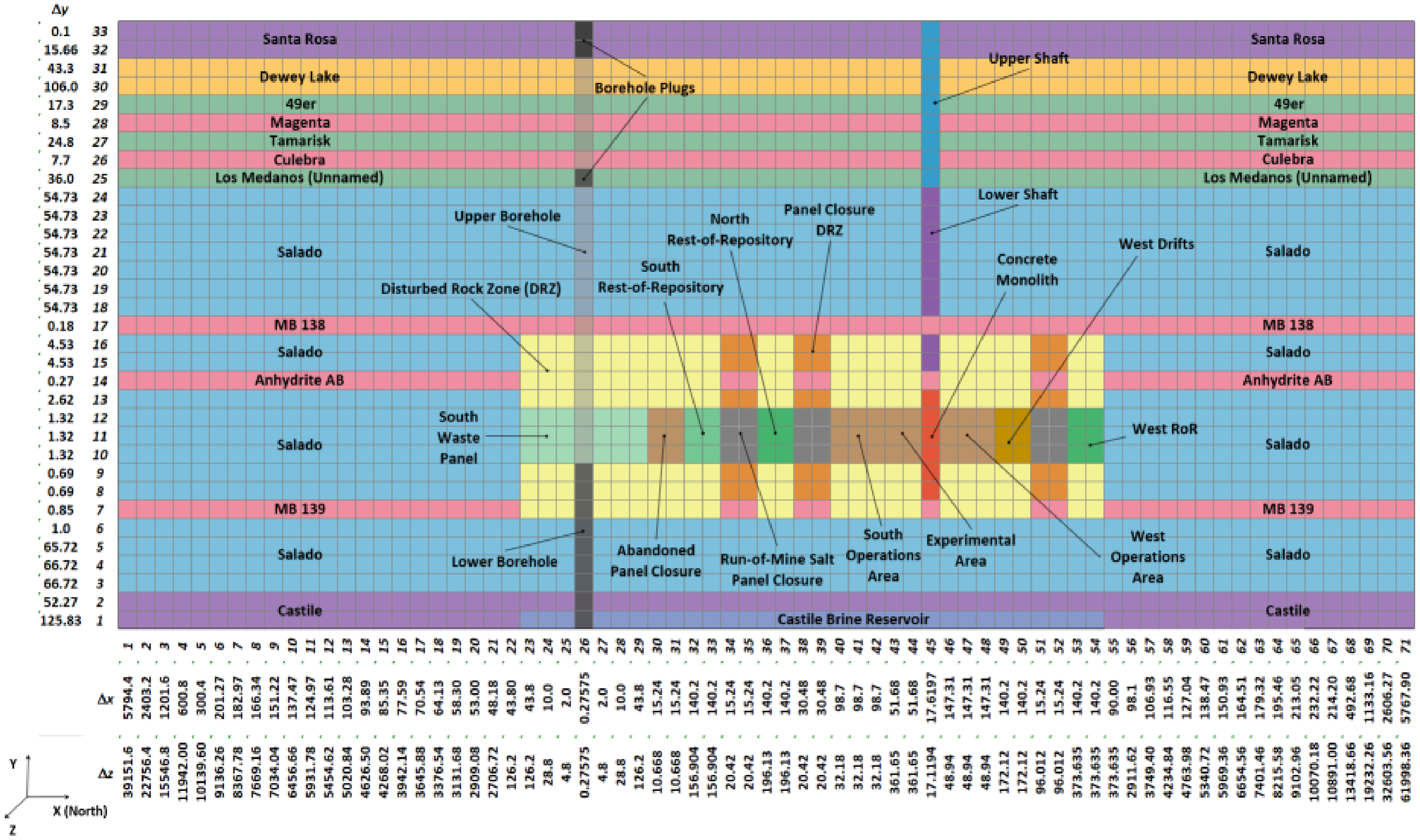
CRA19 BRAGFLO Grid



Zeitler, 2019

- Single combined shaft (5 shafts modeled).
- Single representative intrusion.
- Abandoned panel closures between the Waste Panel (WP) and South Rest-of-Repository (SRoR).

APPA BRAGFLO Grid

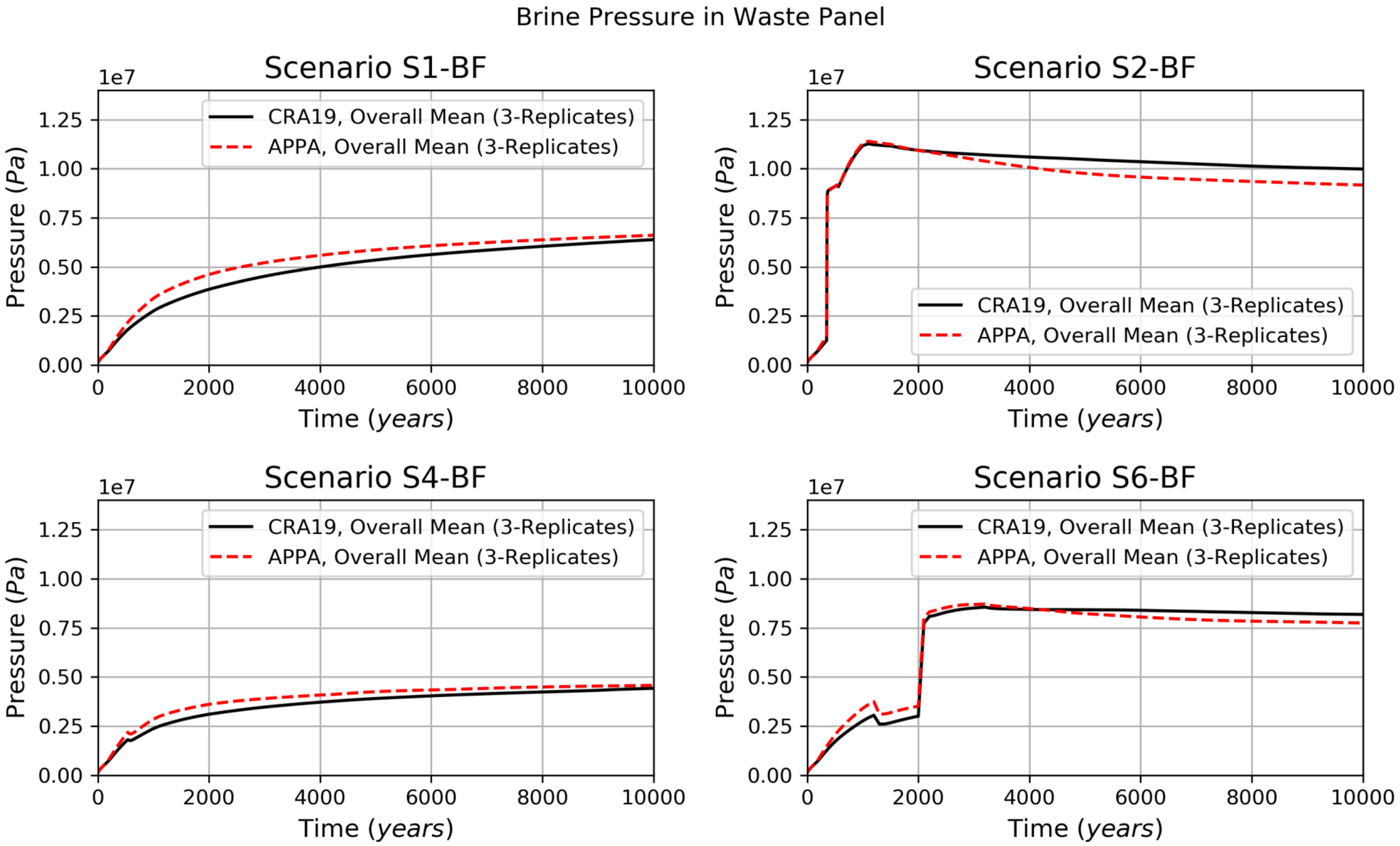


Salado Flow results for the APPA are documented in King (2021b).

Salado Flow grid development and results will be discussed in detail in future presentations.

- New regions:
  - West Rest-of-Repository (RoR)
  - West Drifts
  - West Operations Area
- Shaft relocated between experimental area and West Operations area.
- Additional panel closure added between West RoR and West Drifts.
- Experimental area and grid flaring recalculated.

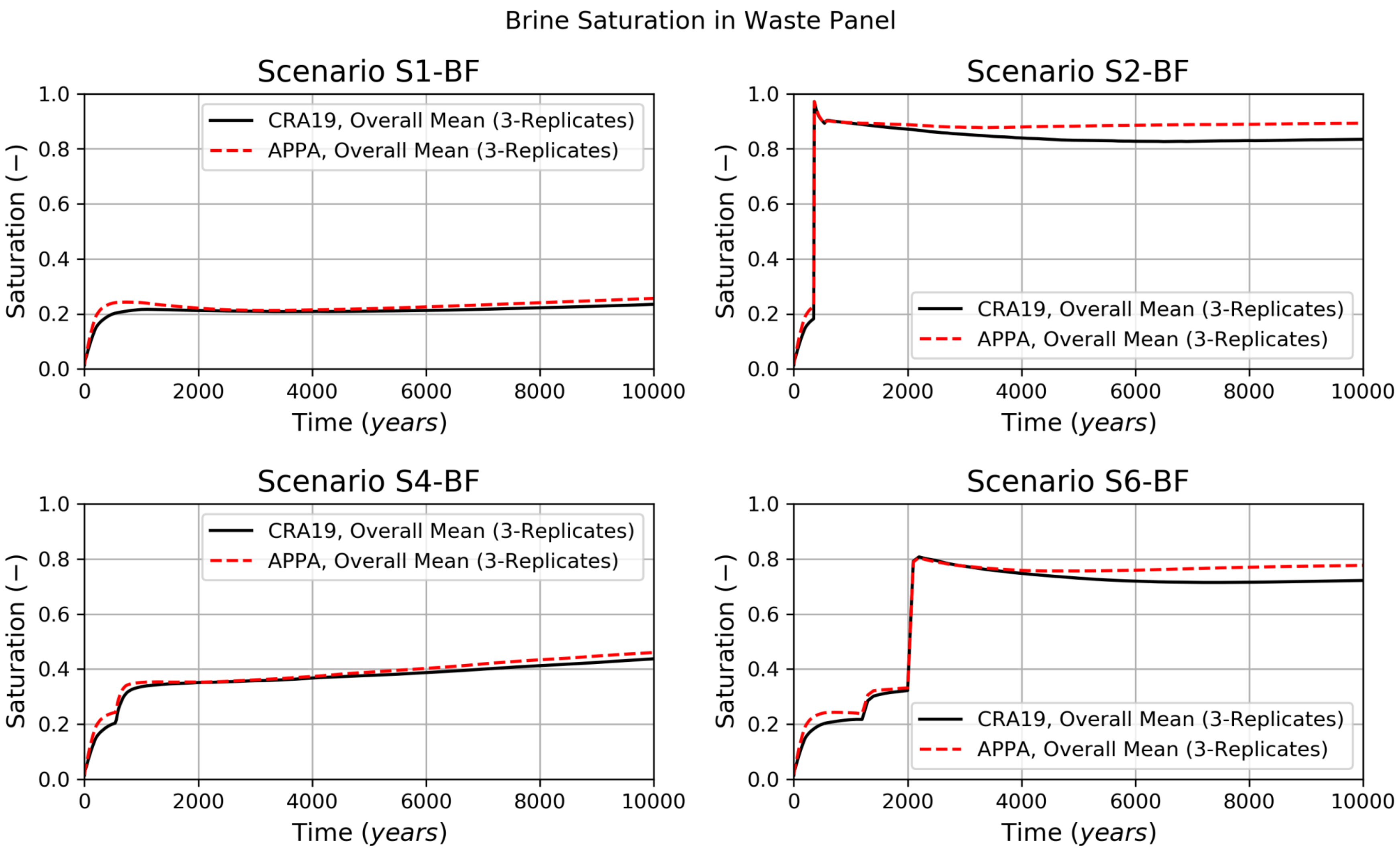
Salado Flow Results – Mean Brine Pressure



Mean brine pressure in the waste panel is shown.

- Mean brine pressures have not drastically changed.
- In cases with an E1 intrusion (S2, S3, and S6), mean brine pressures are slightly decreased.
- In cases without an E1 intrusion (S1, S4, and S5), mean brine pressures are slightly increased.

Salado Flow Results – Mean Brine Saturation



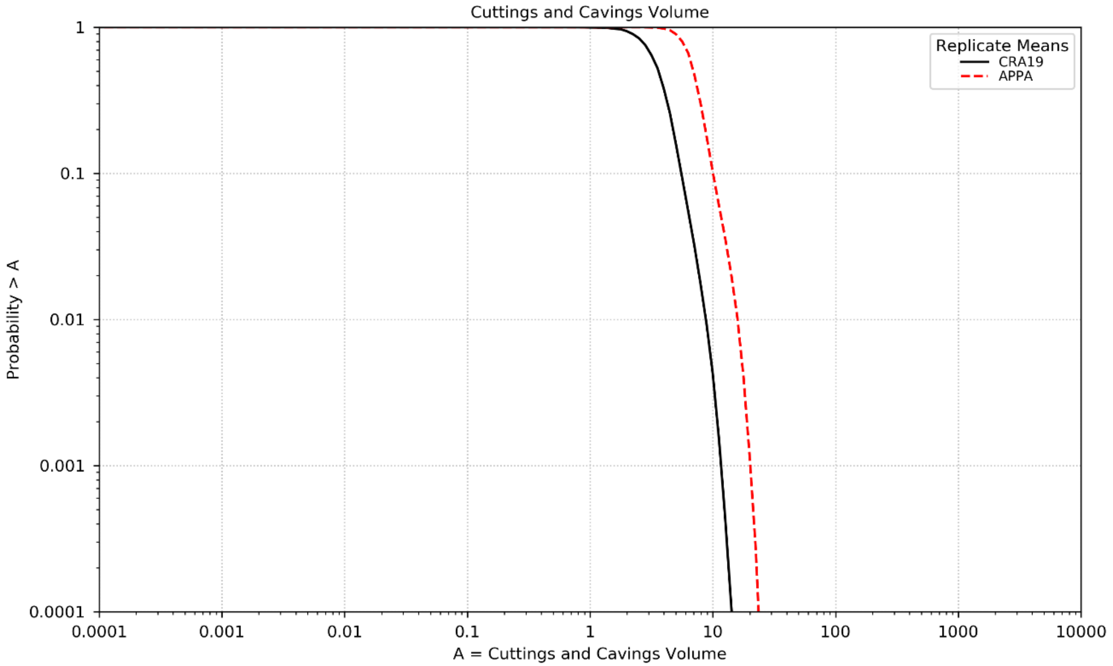
Mean brine saturation in the waste panel is shown.

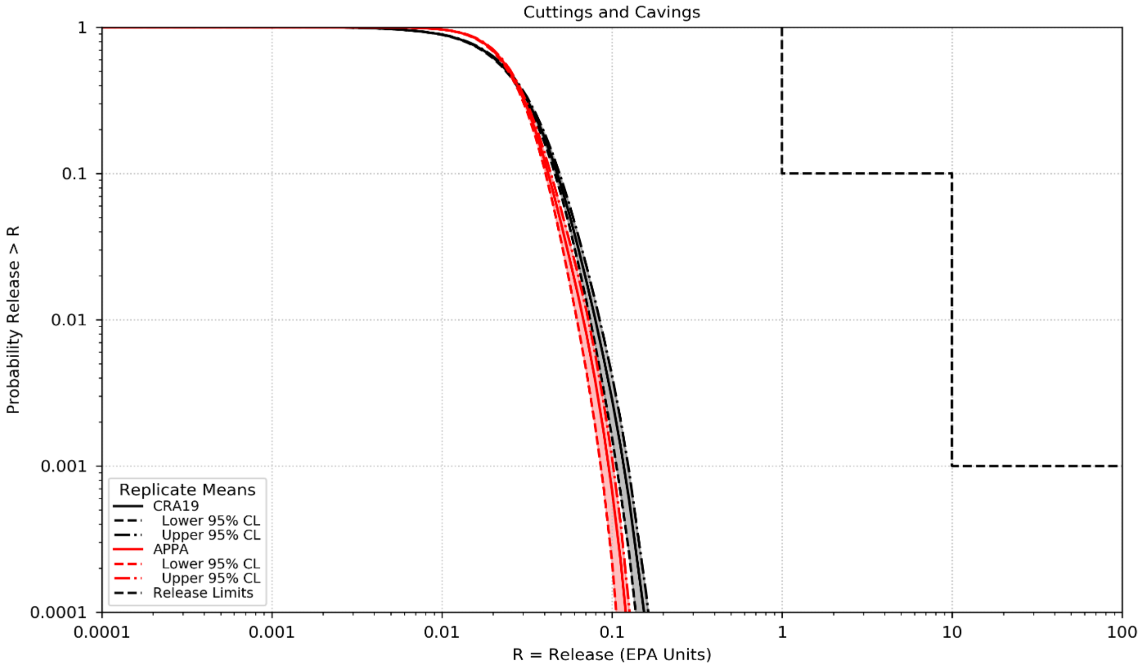
- Mean brine saturations are slightly increased in the APPA.
- The increased repository area increased the DRZ.
- Results in increased communication with the Salado formation.
- Allows more brine to flow into the repository.

Cuttings and Cavings

- Cuttings and cavings parameters are the same between CRA-2019 and APPA.
- Cuttings and cavings areas are identical, waste concentrations are similar but not identical due to the increased frequency of boreholes resulting in a different selection of waste streams for each future

- Extracted volumes increased due to increased number of boreholes
  - Extracted volumes are scaled by FVW to obtain volume of CH waste[1]
- Mean releases are similar
  - Releases have slightly decreased at both compliance points



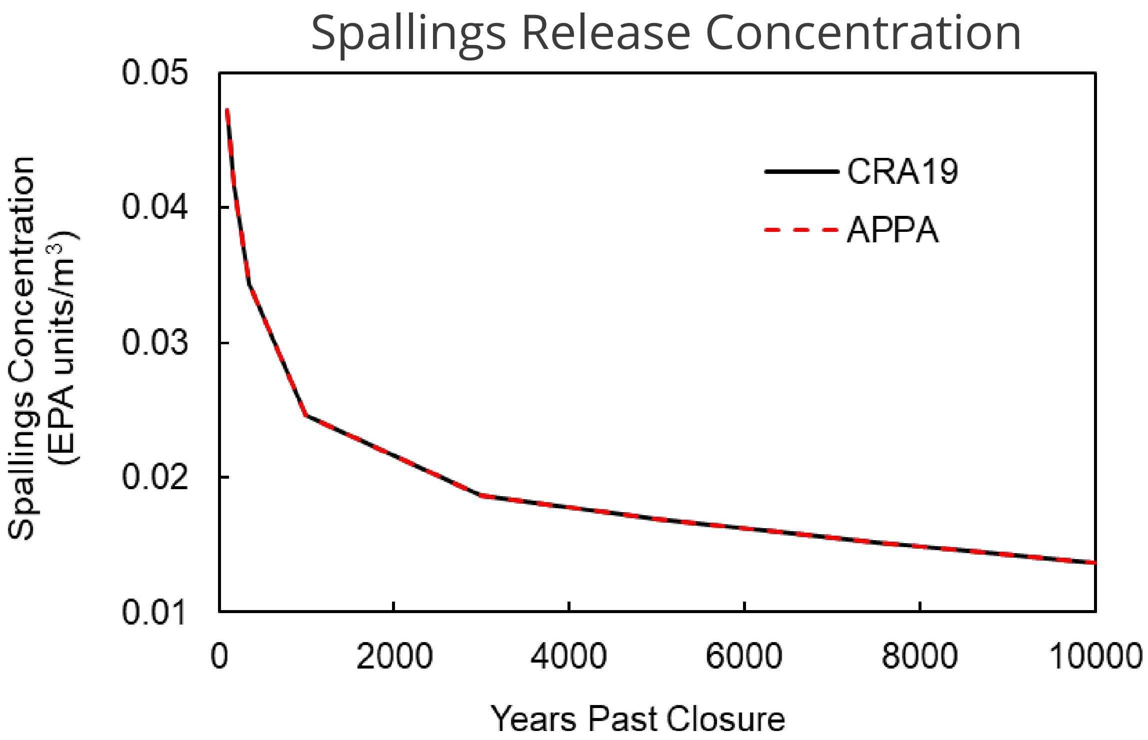


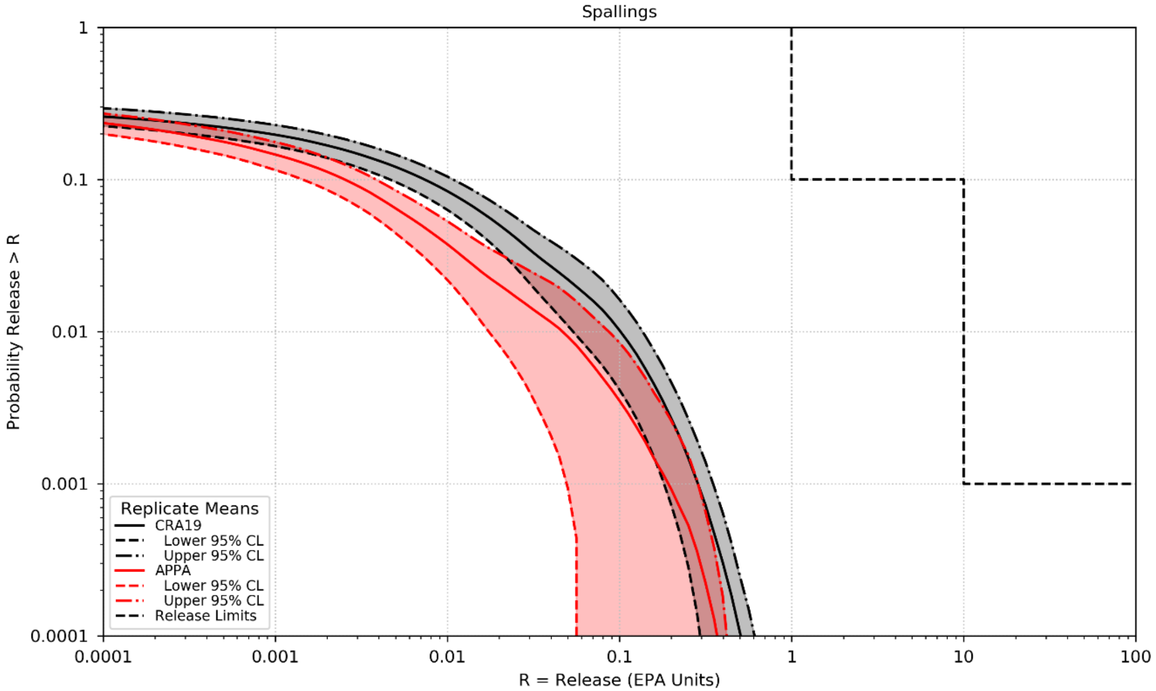
[1] RH waste is scaled by the parameter REFCON:FVRW, which is unchanged from CRA19

Spallings

- Spallings volumes are similar
- Average waste stream activity concentrations are identical

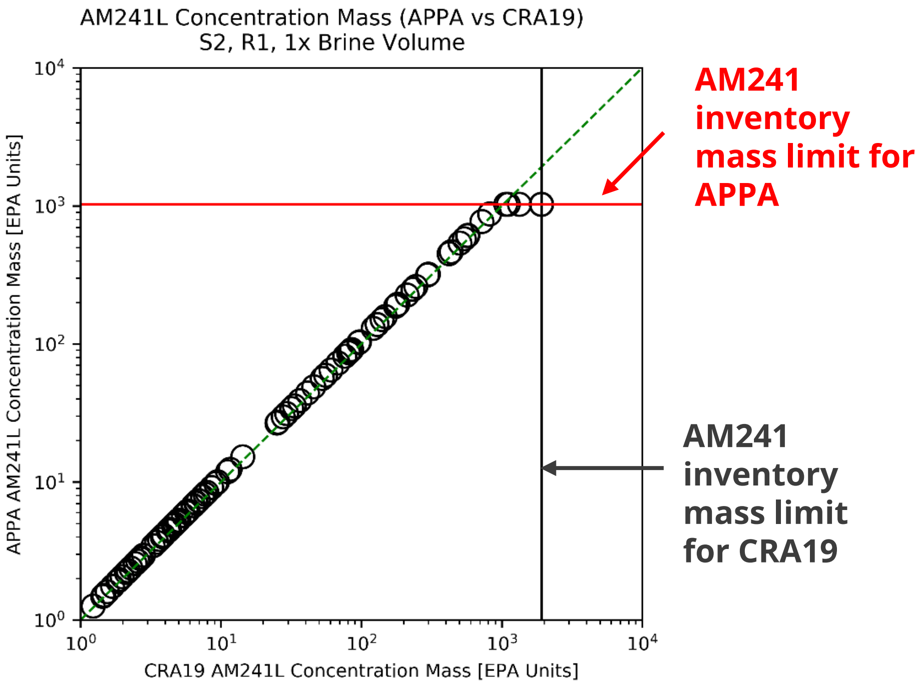
- Spalled volumes scaled by FVW
- Mean releases are decreased at all probabilities

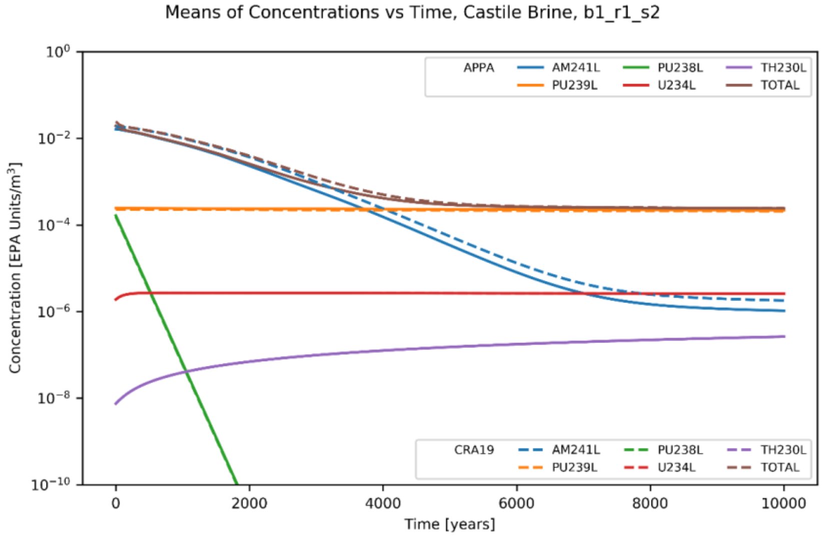


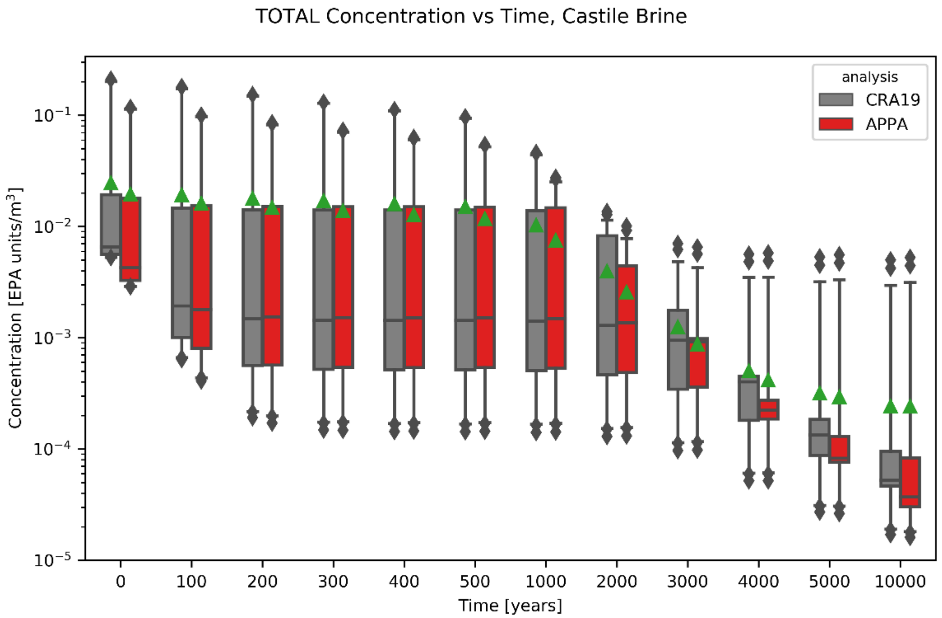


Actinide Mobilization

Actinide Mobilization is documented in Kim, 2021.





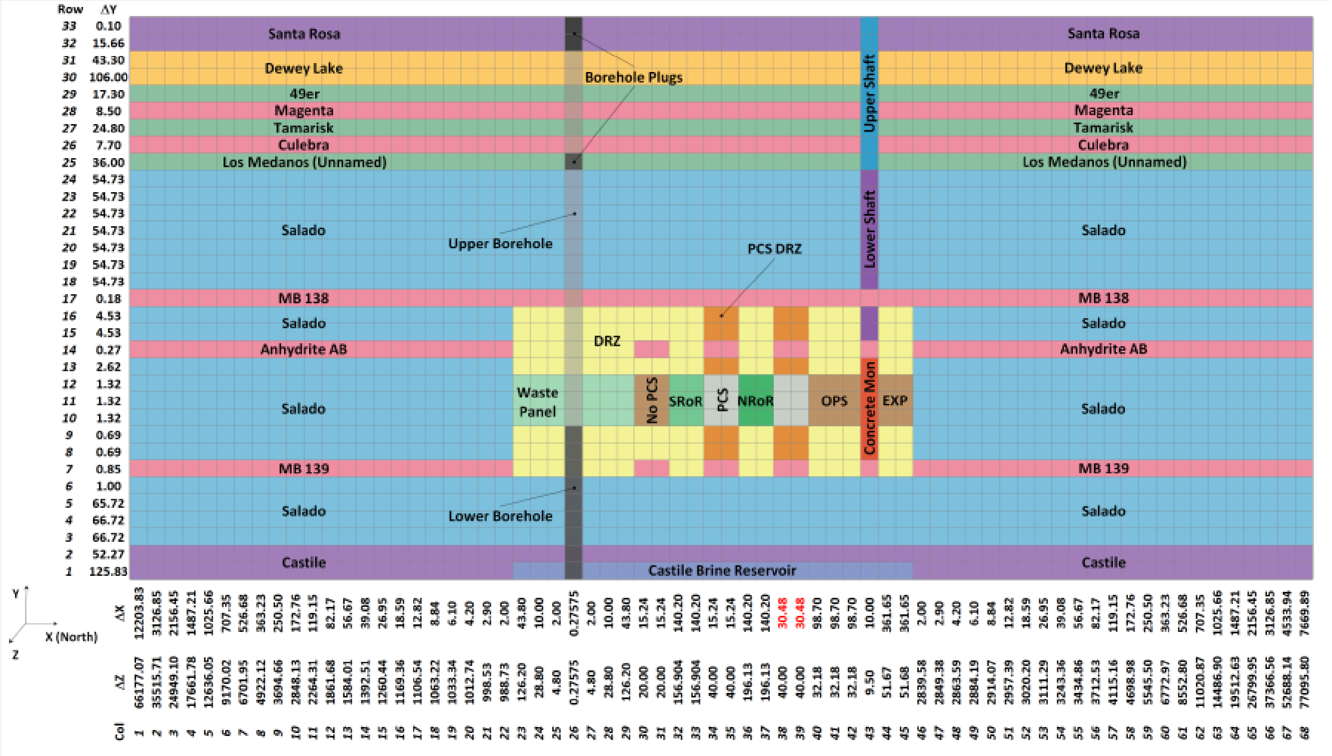


Maximum mobile mass (in EPA Units) of AM241L (replicate 1 scenario 2 with 1× brine volume) in APPA vs CRA19.

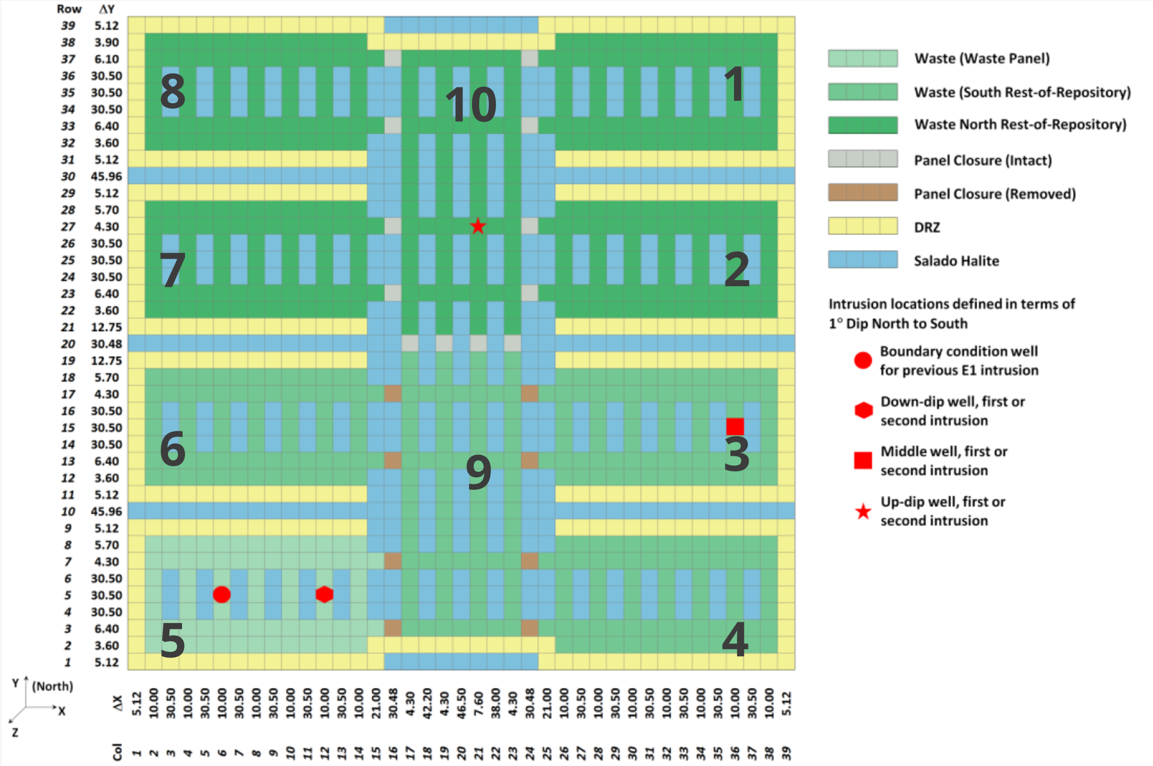
Inventory in a panel area is decreased due to the increased repository volume. This decreases the inventory mass available for mobilization, resulting in a decrease in the mean instantaneous concentration of individual and lumped radionuclides with +III oxidation state.

CRA19 BRAGFLO DBR Grid

Salado Flow Grid



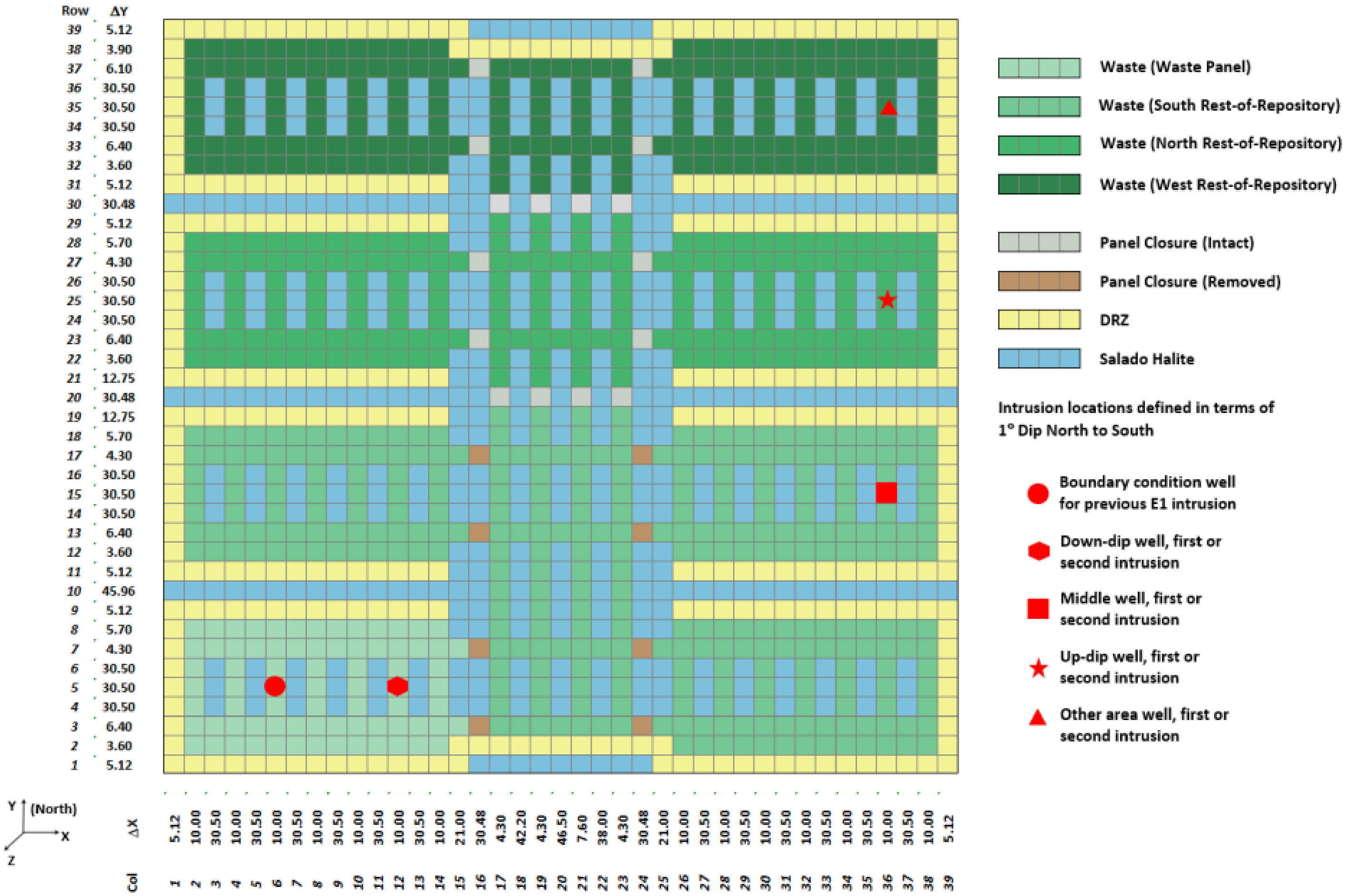
DBR Grid



Zeitler, 2019

Waste Panel – Lower – Panel 5
South Rest-of-Repository (SRoR) – Middle – Panels 3, 4, 6, and 9
North Rest-of-Repository (NRoR) – Upper – Panels 1, 2, 7, 8, and 10

APPA BRAGFLO DBR grid



Waste Panel – Lower
South Rest-of-Repository (SRoR) – Middle
North Rest-of-Repository (NRoR) – Upper
West Rest-of-Repository (WRoR) – Other

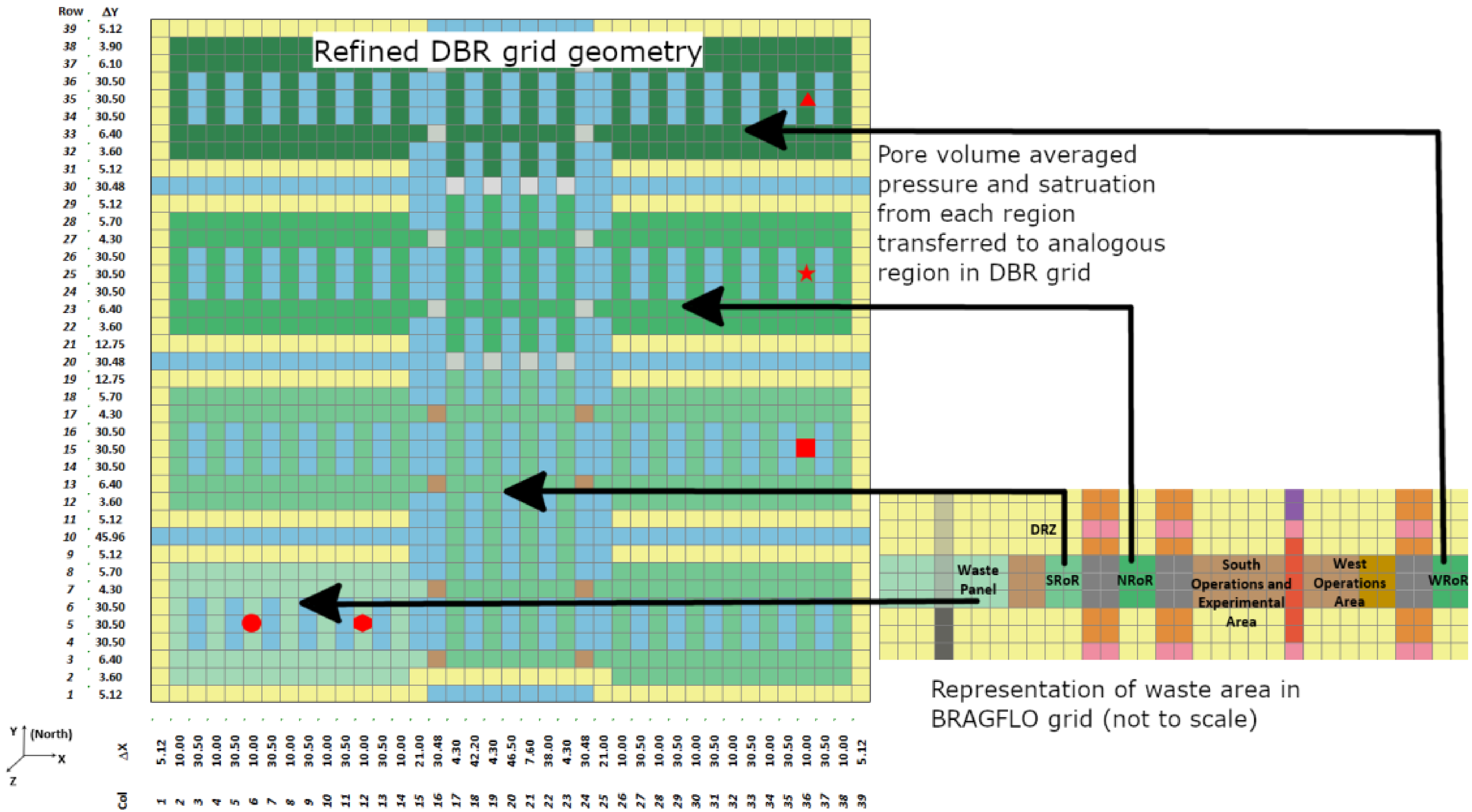
DBR results for the APPA are documented in King (2021a).

DBR grid development and results will be discussed in detail during a future presentation.

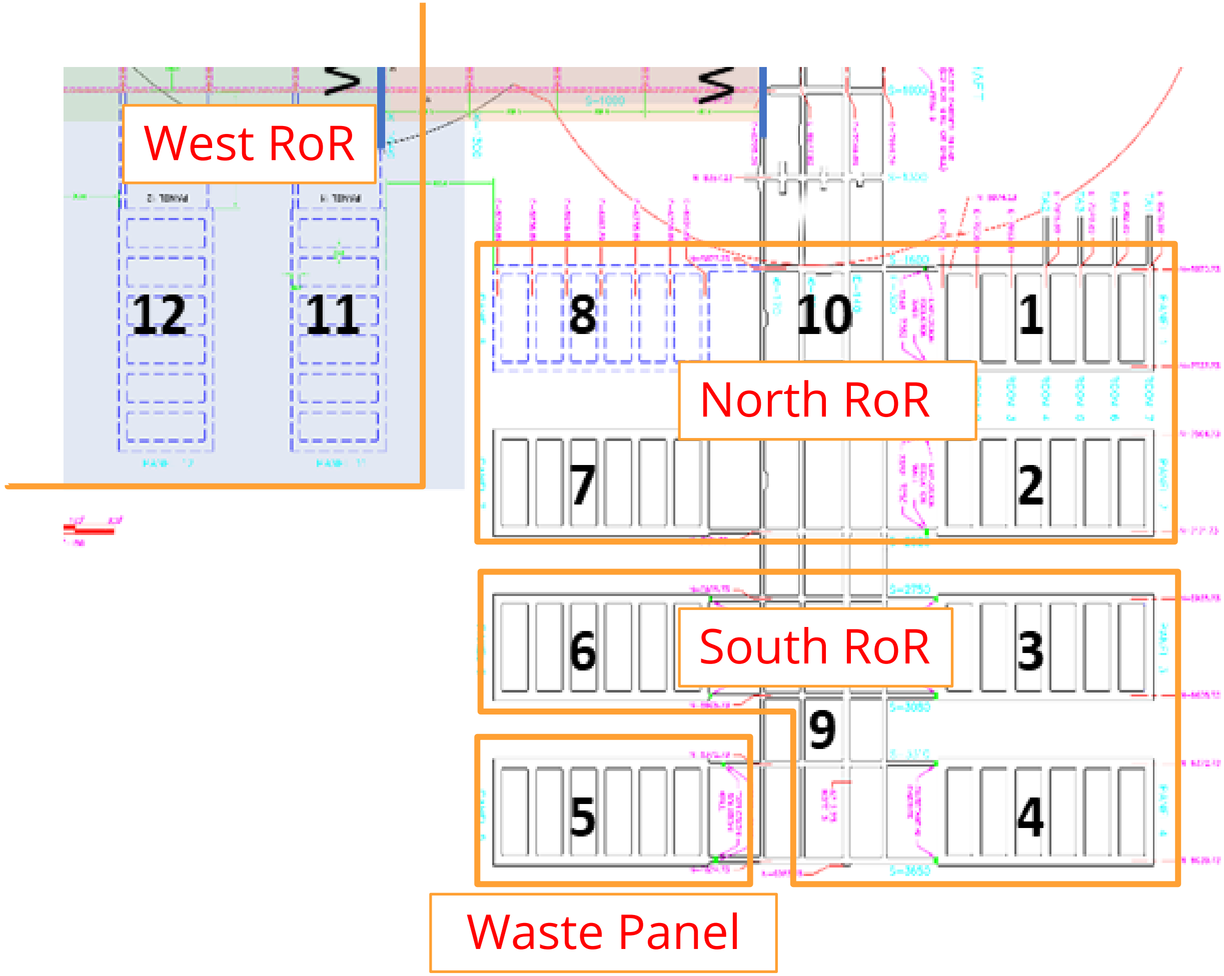
To accommodate modeling intrusions into the new West waste panel

- North RoR in the DBR simulation grid has been cut in half.
- Up-dip North RoR intrusion modeled in the lower portion of the North RoR.
- Other-Area WRoR intrusions modeled in the upper portion of the North RoR.

Salado Flow volume-averaged brine pressure and saturation transfer for DBR initial conditions



Panel Neighbor Relationships



- Panels are assigned a relationship to every other panel based on their physical location in the repository.
- DBR and Spallings scenarios represent:
  - Lower: Waste Panel
  - Middle: South Rest-of-Repository
  - Upper: North Rest-of-Repository
  - Other: West Rest-of-Repository
- These modeled intrusions map to intrusions into each of the other panels based on the distance between the initial intrusion and the subsequent intrusion.

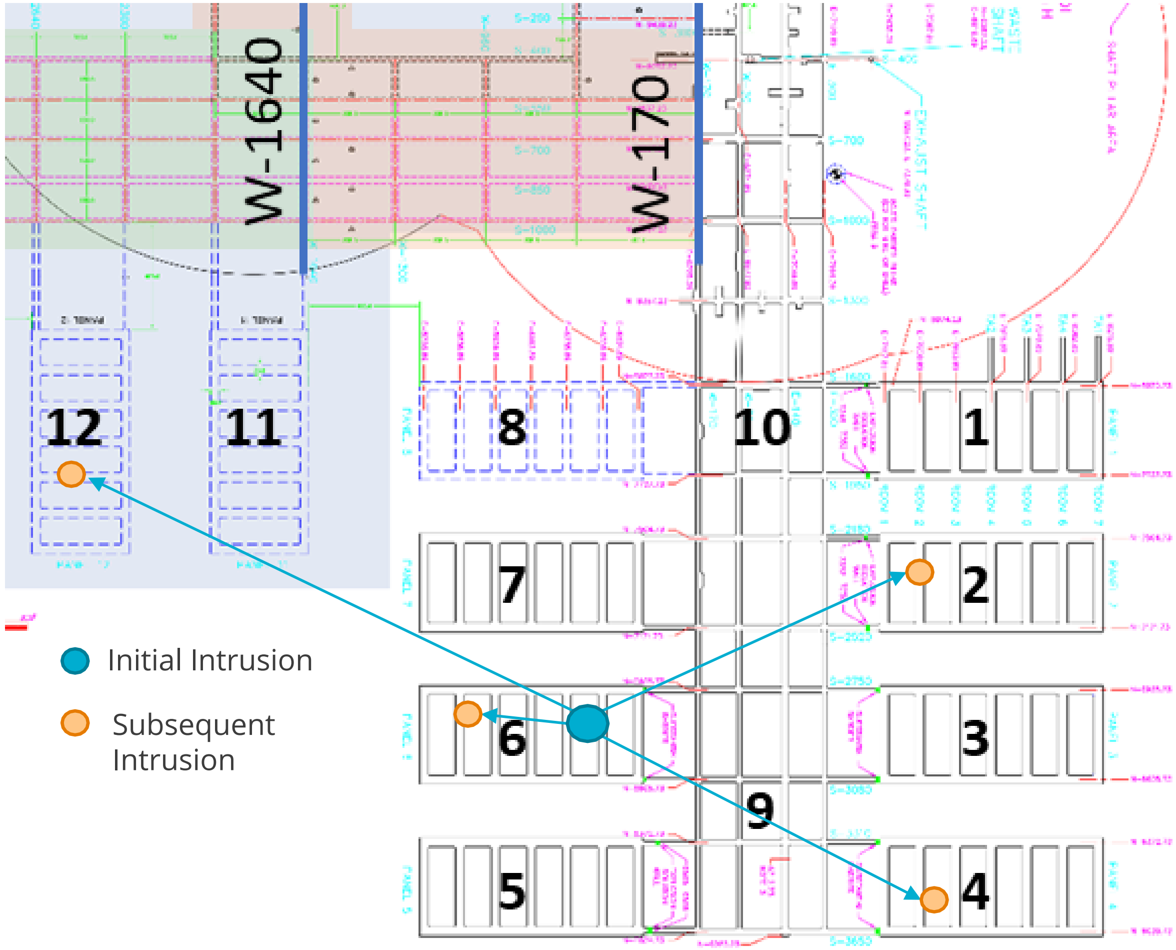
Panel Neighbor Relationships

To illustrate, assume an initial intrusion into Panel 6.

Consider the following subsequent intrusions:

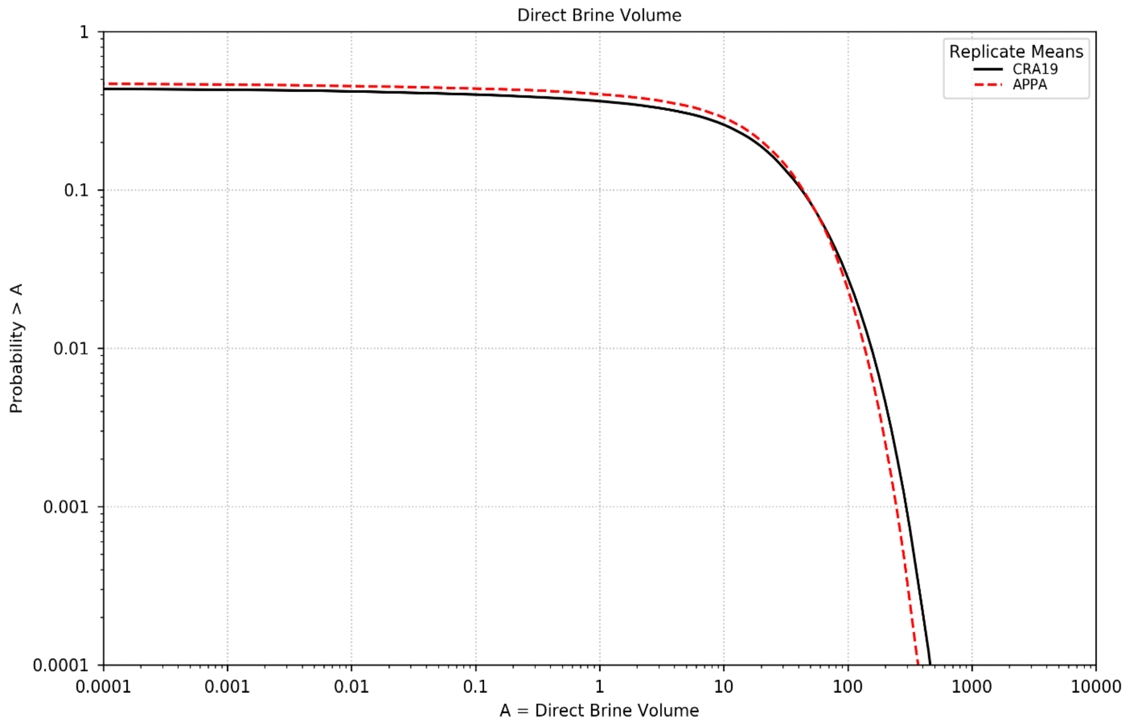
- Into Panel 6: is the "Same" panel using results from the "Lower" DBR and spallings models.
- Into Panel 4: is "Connected" to Panel 6 (no panel closures between Panels 4 and 6) using the "Middle" DBR and spallings results.
- Into Panel 2: is "Adjacent" to Panel 6 (same area but separated by at least one panel closure) using the "Upper" DBR and spallings results.
- Into Panel 12: is "Non-adjacent" to Panel 6 (different repository area) using the "Other" DBR and spallings results.

See Table 5 in AP-185 for a list of panel neighboring relationships (Hansen, 2020).

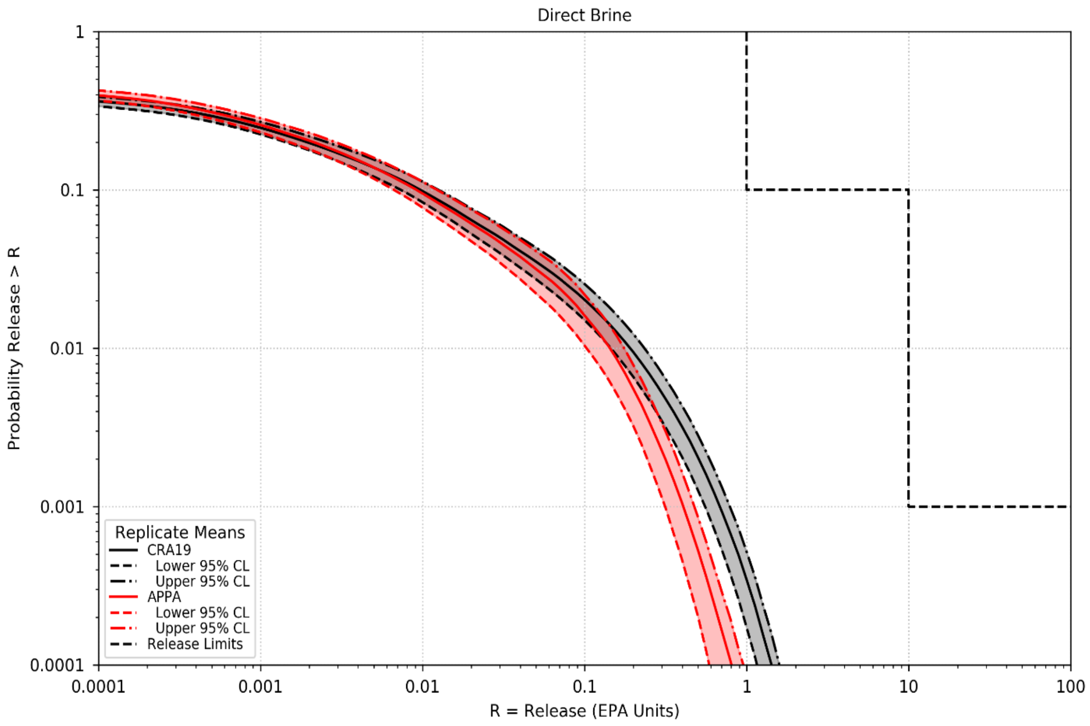


Direct Brine Releases

- DBR Volumes increased at high probabilities, decreased at low probabilities
- Concentrations of lumped radionuclides in brine are similar

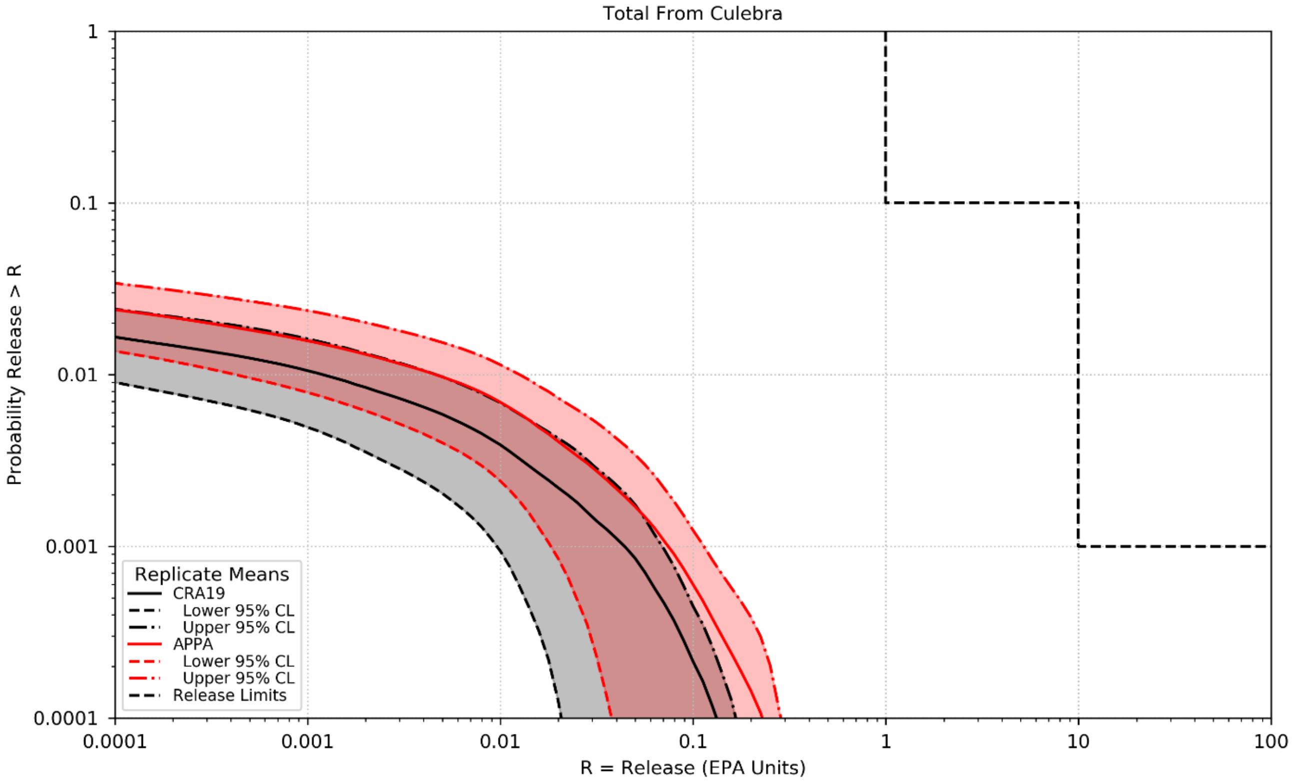


- Releases increased at high probability and decreased at low probability
- Releases decrease at both compliance points



Culebra Releases

- Cumulative releases through the Culebra are increased as compared to the CRA-2019 PA
- Concentrations of lumped radionuclides in brine are similar
- Cumulative releases to the Culebra are increased due to the increased number of boreholes



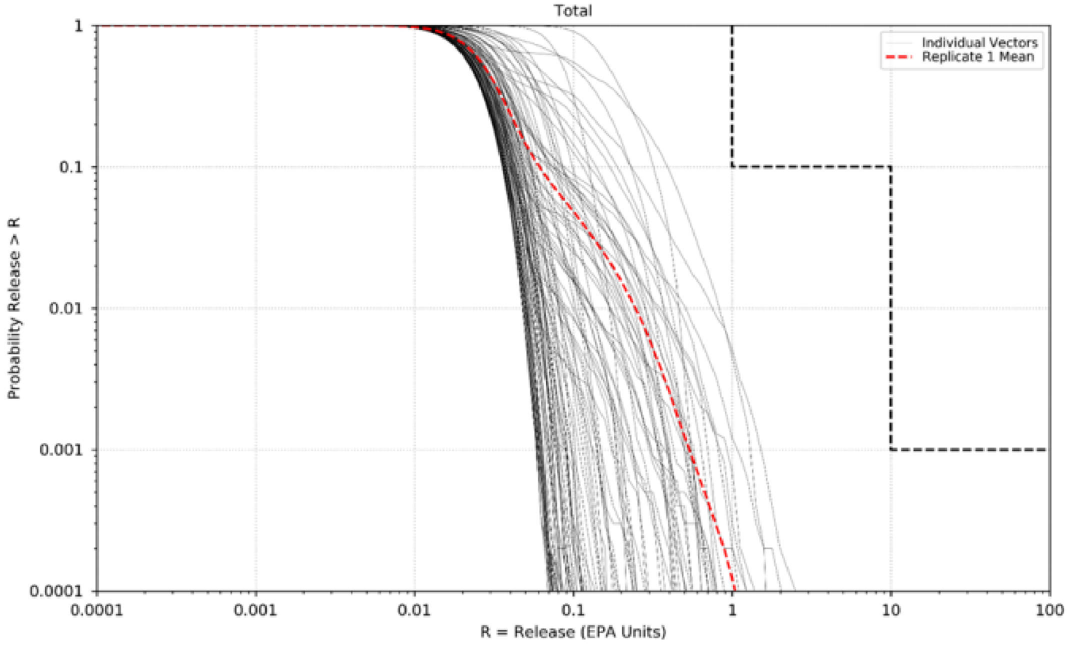
Sensitivity Analysis

Stepwise ranked regression is used to identify parameters having influence on mean total releases (mean of each of 100 CCDFs of total release).

- Table shows only parameters with $\Delta R^2 > 0.05$ (the difference in R^2 between the current step and the previous step).
- SOLMOD3:SOLVAR is the uncertainty in solubility of actinides in +III state. Affects concentrations in DBR releases.
- BOREHOLE:TAUFAIL is the shear strength of waste. Affects cavings releases.
- CASTILER:PRESSURE is the initial pressure in the Castile brine reservoir. Affects total volume of brine that enters the repository through a borehole into the Castile, which in turn affects repository pressure, etc.
- BH_SAND:PRMX_LOG is the (logarithm) permeability of the material filling a borehole over the long term. Affects brine flow primarily from the Castile reservoir.

The cumulative R^2 is relatively low because total releases are summed over all processes, reducing the strength of the relationship with many parameters.

	CRA19			APPA		
Step [a]	Variable [b]	R[2c]	SRRC [d]	Variable [b]	R[2c]	SRRC [d]
Replicate 1						
1	SOLMOD3:SOLVAR	0.23	0.51	SOLMOD3:SOLVAR	0.18	0.45
2	BOREHOLE:TAUFAIL	0.35	-0.35	BOREHOLE:TAUFAIL	0.32	-0.39
3	CASTILER:PRESSURE	0.44	0.31	CASTILER:PRESSURE	0.45	0.36
4	BH_SAND:PRMX_LOG	0.5	-0.27			
[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		



Sensitivity Analysis – Cuttings and Cavings

Sensitivity analysis determines the relative importance of the sampled parameters (epistemic uncertainty) in the uncertainty in releases.

Does not account for uncertainty in future events (aleatory uncertainty).

- BOREHOLE:TAUFAIL is the shear strength of the waste. Affects cavings release areas.
- BOREHOLE:DOMEGA is the angular velocity of the drill string. Affects cavings release areas.

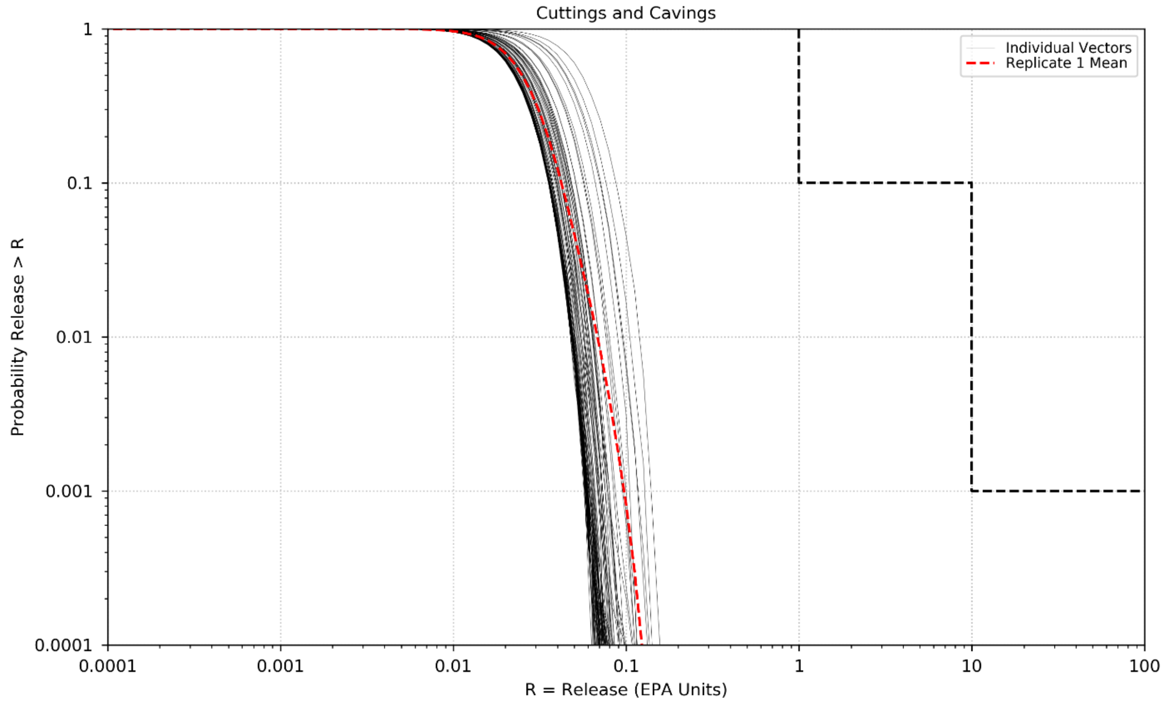
	CRA19			APPA		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable [b]	R^2 [c]	SRRC [d]
Replicate 1						
1	BOREHOLE:TAUFAIL	0.59	-0.76	BOREHOLE:TAUFAIL	0.63	-0.80
2	BOREHOLE:DOMEGA	0.66	0.27	BOREHOLE:DOMEGA	0.69	0.23

[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

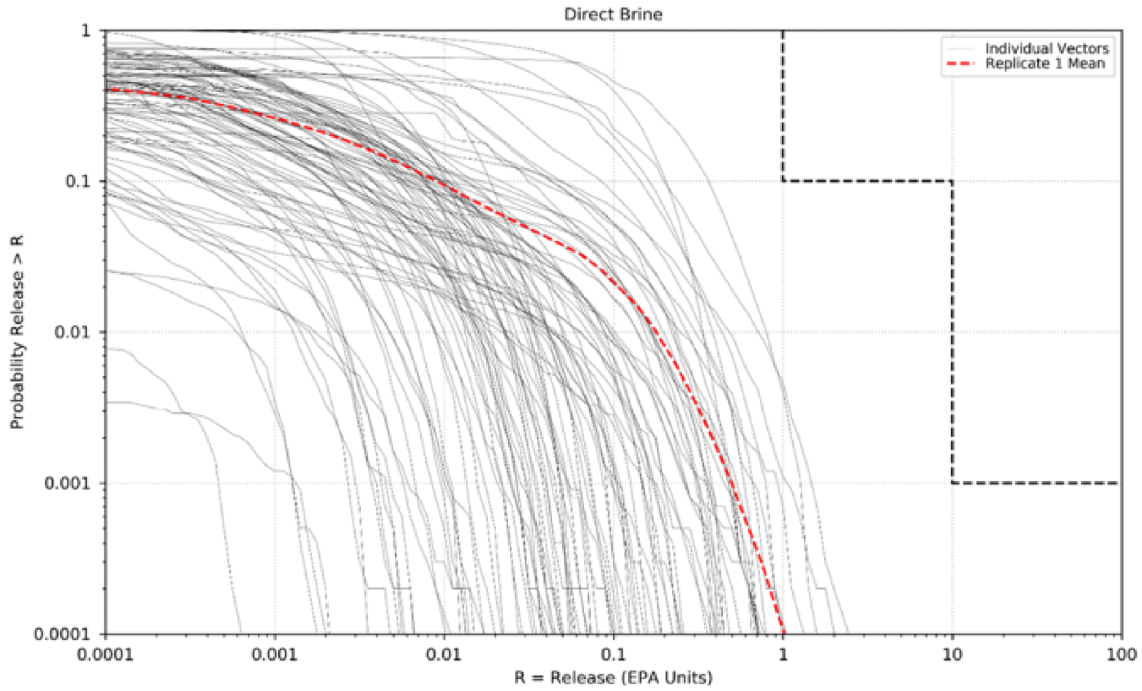
[d] Standardized Rank Regression Coefficient



Sensitivity Analysis – DBR releases

- $SOLMOD3:SOLVAR$ is the uncertainty in solubility of actinides in +III state. Affects concentrations in DBR releases.
- CASTILER:PRESSURE is the initial pressure in the Castile brine reservoir. Affects total volume of brine that enters the repository through a borehole into the Castile, which in turn affects repository pressure, etc.
- STEEL:CORRMCO2 is the inundated steel corrosion rate without CO_2 present. Affects gas generation rate from the corrosion of steel, which affects repository pressure.
- WAS_AREA:SAT_RBRN is the residual brine saturation of the waste and waste panel.

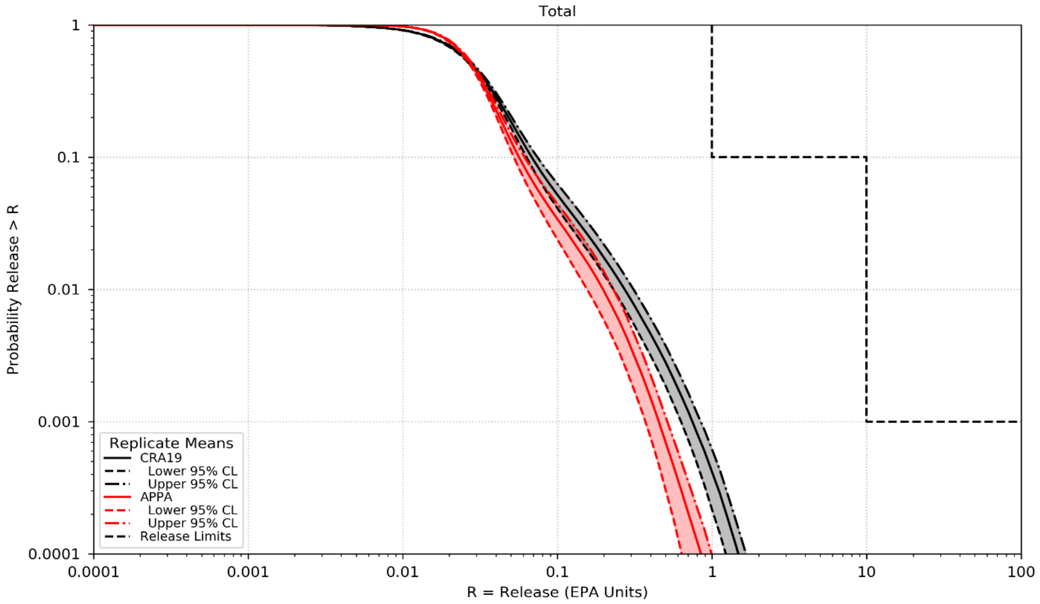
	CRA19			APPA		
Step [a]	Variable [b]	R^2 [c]	SRRC [d]	Variable [b]	R^2 [c]	SRRC [d]
Replicate 1						
1	SOLMOD3:SOLVAR	0.39	0.63	SOLMOD3:SOLVAR	0.36	0.60
2	CASTILER:PRESSURE	0.57	0.43	CASTILER:PRESSURE	0.54	0.42
3	STEEL:CORRMCO2	0.64	-0.25	WAS_AREA:SAT_RBRN	0.58	-0.19
[a] Steps in stepwise regression 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		



Conclusions

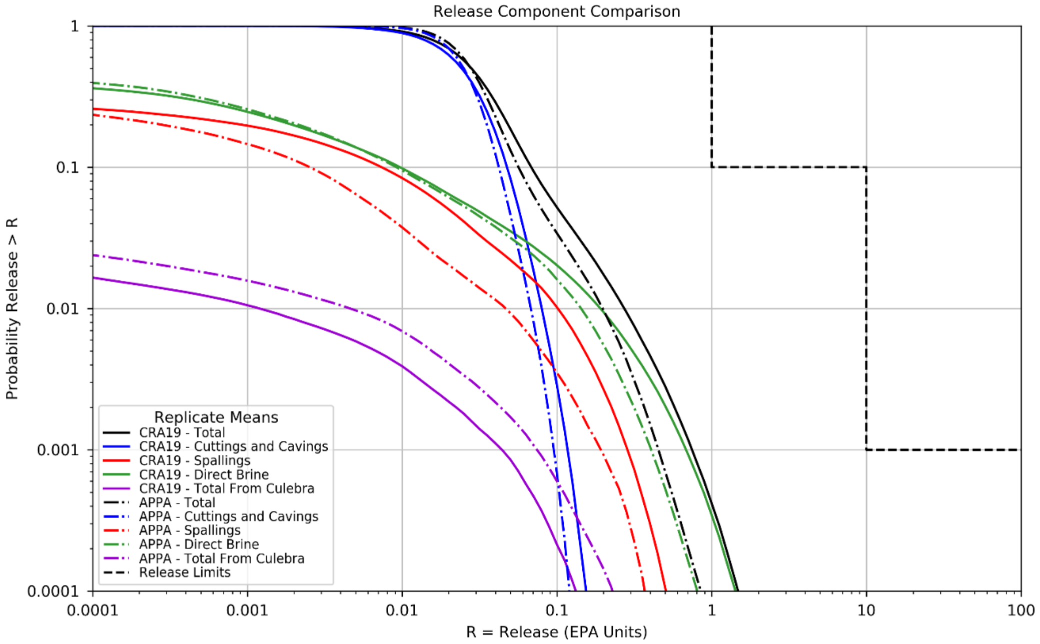
Overall Results:

- Increased at highest probabilities
- Decreased at lower probabilities
- Decreased at both compliance points



Total Releases by Release Mechanism:

- Cuttings and cavings dominate at high probabilities
- DBRs dominate at low probabilities
- From-Culebra releases increased at all probabilities
- Releases generally decreased for all other release mechanisms.



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