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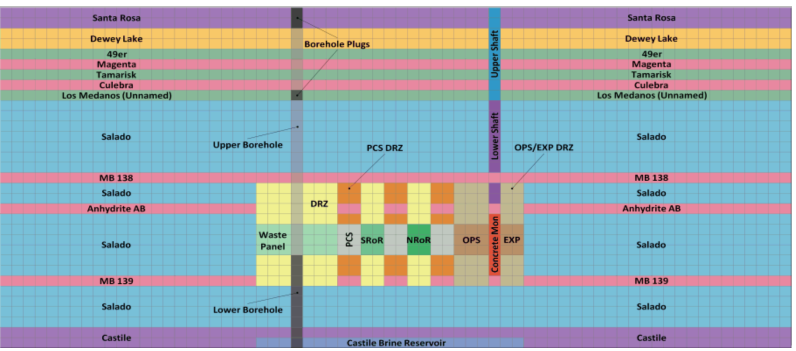

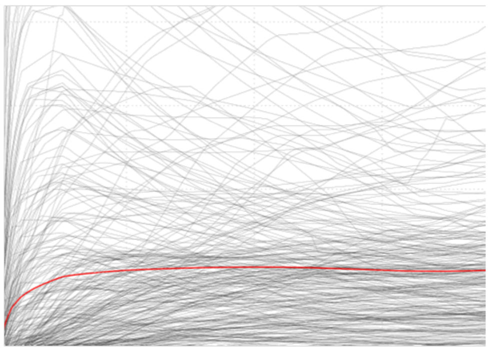

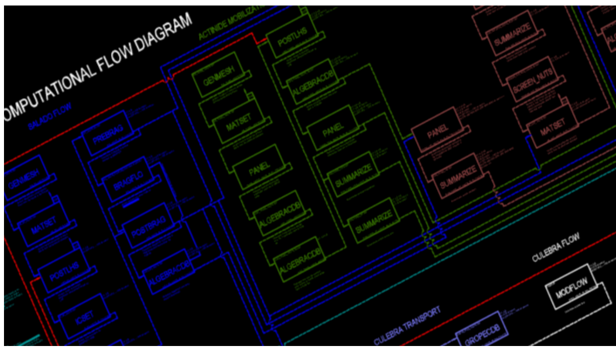

Panel Closure System Sensitivity Study

Presented by:
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Sandia Carlsbad
Performance Assessment Dept.

DOE/EPA Technical Exchange Meeting

September 1, 2016

U.S. DEPARTMENT OF ENERGY   NNSA National Nuclear Security Administration

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Outline

- Background
- Modeling Approach
- Results
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  - Operations/Experimental Area, Rest-of-Repository, and Waste Panel Brine Saturations
  - Operations/Experimental Area Brine and Gas Inflow
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  - Brine and Gas Flows across Northernmost, Middle, and Southernmost Panel Closures
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- Conclusions

Background

- Current PA implementation of Operations (OPS) and Experimental (EXP) cavities uses a constant porosity of 0.18, corresponding to a hydrostatic pressure of 7.8 MPa at 10,000 years based on work by Arguello[a]
  - Past sensitivity analyses used a porosity surface developed for empty rooms to include effects of gas in the void as a restorative force to resist closure
  - FEP DR-3 supported the use of a constant, rather than time-varying, porosity because calculations had shown Performance Assessment (PA) was insensitive to the description of void closure utilized
- The EPA[b] requested a sensitivity study to evaluate the OPS/EXP and associated DRZ at a lower porosity, with increased residual brine and gas saturations, and with two-phase flow properties activated
  - The final EPA OPS/EXP study parameters (CRA14_SEN2) were influenced by a series of initial calculations (CRA14_SEN1) presented to the EPA on 2/2/2016[c]
  - The CRA14_SEN2 final report was transmitted to the EPA on 5/6/2016[d]

[a] Arguello, J.G. 1994, Memorandum to B.M. Butcher, Backfill Sensitivity Study – Creep Closure Behaviors of an "Equivalent" Empty Room at the North End of WIPP Subjected to Gas Generation", Sandia National Laboratories
[b] EPA 2016, Letter correspondence dated 2/29/16 from Tom Peake, EPA, to Russ Patterson, CBFO, Subject: EPA Requested Sensitivity Analysis Parameters, ERMS 565676, Sandia National Laboratories, Carlsbad, NM
[c] Day, B., Zeitler, T., 2016, Non-Waste Area Sensitivity Study, DOE/EPA Technical Exchange Meeting, February 2, 2016, SAND2016-1217PE, Sandia National Laboratories, Carlsbad, NM.
[d] Day, B. 2016. Operations and Experimental Area Sensitivity Study, Sandia National Laboratories, Carlsbad, NM. ERMS 565918.

Background (cont.)

- Current PA implementation of run-of-mine Panel Closure System (PCS) uses a step-down approach to porosity and permeability over the first 200 years based on a planned change request and rulemaking process approved by the EPA[e]
- The EPA[f] requested a sensitivity study to evaluate the PCS and associated DRZ at a lower porosity, with increased residual brine and gas saturations, and with two-phase flow properties activated
  - The implemented PCS study parameters (CRA14_SEN3)[g] were influenced by the OPS/EXP sensitivity study that demonstrated step-changes in porosity and permeability with active capillary pressure results in a diverged solution with nonphysical (negative) pressures in associated model areas[c]
  - The CRA14_SEN3 final report[h] is complete and planned for transmittal to the EPA in the near future

[e] DOE (U.S. Department of Energy). 2011. Panel Closure System Design Planned Change Request to the EPA 40 CFR Part 194 Certification of the Waste Isolation Pilot Plant. DOE/CBFO-11-3479. U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad Field Office. Carlsbad, NM.
[f] EPA 2016, Letter correspondence dated 8/26/16 from Tom Peake, EPA, to Russ Patterson, CBFO, Subject: EPA Requested 2nd Sensitivity Analysis Parameters.
[g] Zeitler, T.R. 2016. Communications between the EPA and the DOE regarding panel closure sensitivity study. Sandia National Laboratories, Carlsbad, NM. ERMS 566571.
[h] Day, B. 2016. Panel Closure System Sensitivity Study, Sandia National Laboratories, Carlsbad, NM.

Modeling Approach

- Perform a full 3-replicate PA evaluation (CRA14_SEN3) utilizing EPA parameters

Experimental and Operations Areas													
Material	Time (yr)	POROSITY	PRMX_LOG PRMY_LOG PRMZ_LOG	COMP_RCK	PORE_DIS	CAP_MOD	PCT_A	PCT_EXP	RELP_MOD	SAT_IBRN	SAT_RBRN	SAT_RGAS
CRA14 (Camphouse 2013)[i]												
CAVITY_3	-5 - 0	1	-10	0	0.7	1	0	0	11	0	0	0
OPS_AREA	0 - 10,000	0.18	-11	0	0.7	1	0	0	11	0	0	0
EXP_AREA	0 - 10,000	0.18	-11	0	0.7	1	0	0	11	0	0	0
CRA14_SEN3 (EPA 2016)[g]												
CAVITY_3	-5 - 0	S_HALITE + 1/2*STDEV	S_HALITE + 1	S_HALITE	0.7	2	0.56	-0.346	4	0.95	0.6	0.398
OPS_AREA	0 - 10,000	S_HALITE + 1/2*STDEV	S_HALITE + 1	S_HALITE	0.7	2	0.56	-0.346	4	0.95	0.6	0.398
EXP_AREA	0 - 10,000	S_HALITE + 1/2*STDEV	S_HALITE + 1	S_HALITE	0.7	2	0.56	-0.346	4	0.95	0.6	0.398

[i] Camphouse, R.C. 2013. Analysis Plan for the 2014 WIPP Compliance Recertification Application Performance Assessment. Sandia National Laboratories, Carlsbad, NM. ERMS 559198.

Modeling Approach (cont.)

Disturbed Rock Zone Adjoining Experimental and Operations Areas													
Material	Time (yr)	POROSITY	PRMX_LOG PRMY_LOG PRMZ_LOG	COMP_RCK	PORE_DIS	CAP_MOD	PCT_A	PCT_EXP	RELP_MOD	SAT_IBRN	SAT_RBRN	SAT_RGAS
CRA14 (Camphouse 2013)[i]												
DRZ_0	-5 - 0	S_HALITE + 0.0029	-17	7.41E-10	0.7	1	0	0	4	1	0	0
DRZ_1	0 - 10,000	S_HALITE + 0.0029	sampled	7.41E-10	0.7	1	0	0	4	N/A	0	0
CRA14_SEN2 (EPA 2016)[g]												
DRZ_OE_0	-5 - 0	S_HALITE	S_HALITE	S_HALITE	0.7	2	0.56	-0.346	4	0.95	0.6	0.398
DRZ_OE_1	0 - 10,000	S_HALITE	S_HALITE	S_HALITE	0.7	2	0.56	-0.346	4	0.95	0.6	0.398

Modeling Approach (cont.)

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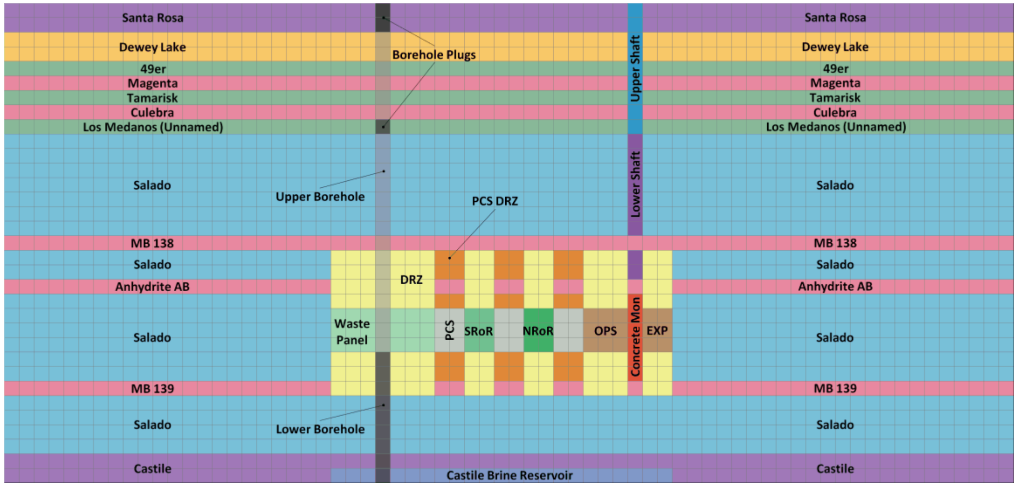
Panel Closures												
Material	Time (yr)	POROSITY	PRMX_LOG PRMY_LOG PRMZ_LOG	COMP_RCK	PORE_DIS	CAP_MOD	PCT_A	PCT_EXP	RELP_MOD	SAT_IBRN	SAT_RBRN S_{ROMBR}	SAT_RGAS S_{ROMGR}
CRA14 (Camphouse 2013)[i]												
CAVITY_4	-5 - 0	1	-10	0	0.7	1	0	0	11	0	0	0
PCS_T1	0 - 100	Sampled [0.066 to 0.187] Uniform	Sampled [-20.84 to -12.00] Uniform	8E-11	Sampled [0.11 to 8.10] Cumulative	1	0	0	4	NA	Sampled [0.0 to 0.6] Cumulative	Sampled [0.0 to 0.4] Uniform
PCS_T2	100 - 200	Sampled [0.025 to 0.075] Uniform	-18.6	8E-11	Sampled [0.11 to 8.10] Cumulative	1	0	0	4	NA	Sampled [0.0 to 0.6] Cumulative	Sampled [0.0 to 0.4] Uniform
PCS_T3	200 - 10,000	Sampled [0.001 to 0.0519] Uniform	-19.1	8E-11	Sampled [0.11 to 8.10] Cumulative	1	0	0	4	NA	Sampled [0.0 to 0.6] Cumulative	Sampled [0.0 to 0.4] Uniform
CRA14_SEN3 (EPA 2016)[g]												
CAVITY_5	-5 - 0	S_HALITE	S_HALITE	S_HALITE	0.7	2	0.56	-0.346	4	0.95	Sampled [0.5 to 0.65] Uniform	$(1-S_{ROMBR})*0.8$
PCS_T1	0 - 10,000	S_HALITE	S_HALITE	S_HALITE	0.7	2	0.56	-0.346	4	0.95	Sampled [0.5 to 0.65] Uniform	$(1-S_{ROMBR})*0.8$

Modeling Approach (cont.)

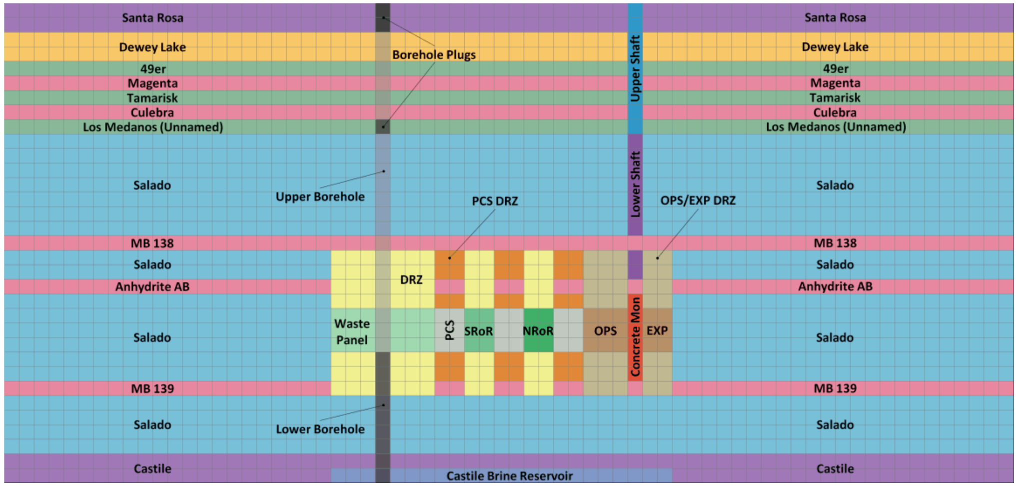
Disturbed Rock Zone Adjoining Panel Closures												
Material	Time (yr)	POROSITY	PRMX_LOG PRMY_LOG PRMZ_LOG	COMP_RCK	PORE_DIS	CAP_MOD	PCT_A	PCT_EXP	RELP_MOD	SAT_IBRN	SAT_RBRN S_{DRZBR}	SAT_RGAS S_{DRZGR}
CRA14 (Camphouse 2013)[i]												
DRZ_0	-5 - 0	S_HALITE + 0.0029	-17	7.41E-10	0.7	1	0	0	4	1	0	0
DRZ_1	0 - 200	S_HALITE + 0.0029	Sampled [-19.40 to -12.50] Uniform	7.41E-10	0.7	1	0	0	4	N/A	0	0
DRZ_PCS	200 - 10,000	S_HALITE + 0.0029	Sampled [-20.699 to -17.00] Triangular	7.41E-10	0.7	1	0	0	4	NA	0	0
CRA14_SEN3 (EPA 2016)[g]												
DRZ_PC_0	-5 - 0	S_HALITE	S_HALITE	S_HALITE	0.7	2	0.56	-0.346	4	0.95	S_{ROMBR}	S_{ROMGR}
DRZ_PC_1	0 - 10,000	S_HALITE	S_HALITE	S_HALITE	0.7	2	0.56	-0.346	4	0.95	S_{ROMBR}	S_{ROMGR}

Modeling Approach (cont.)

- BRAGFLO Grids



CRA14

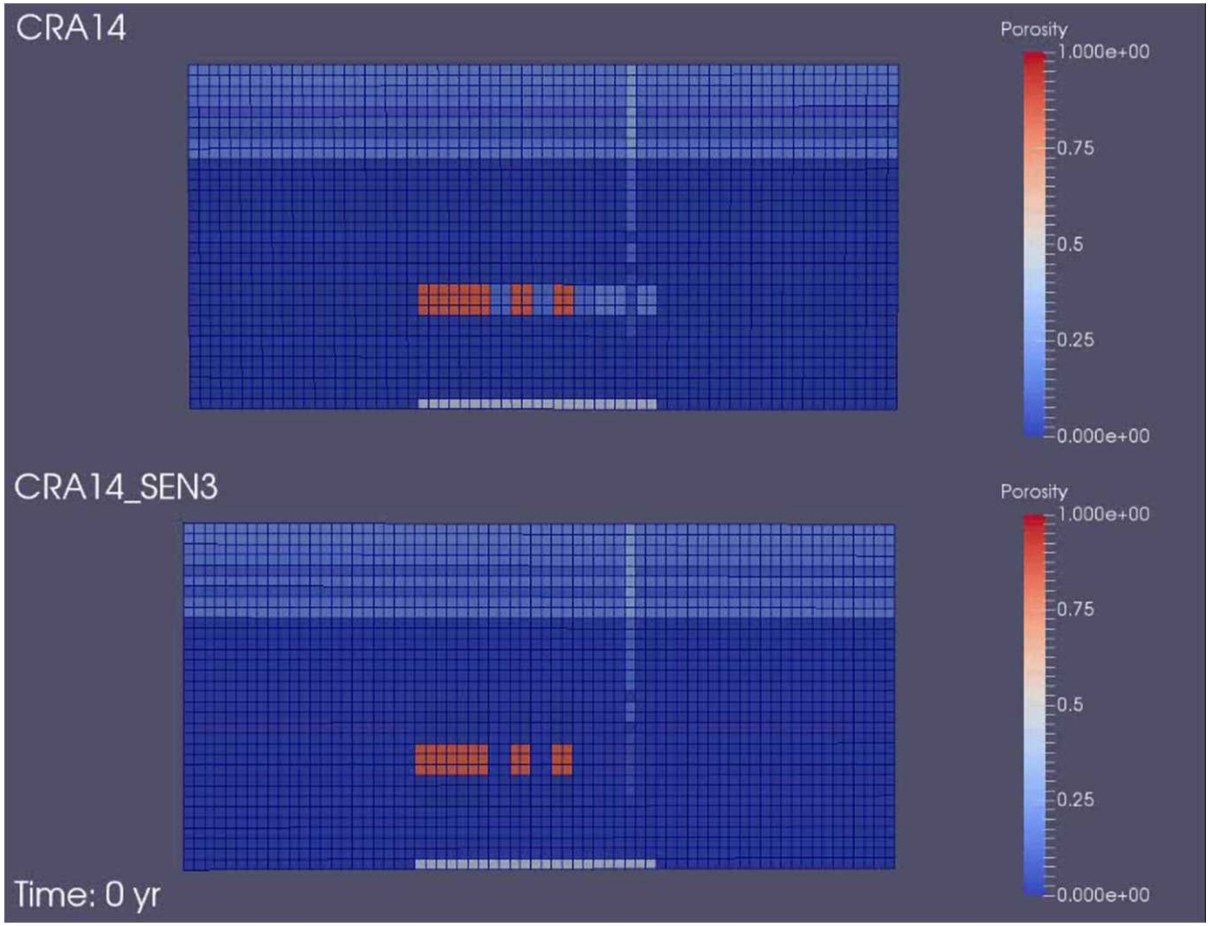


CRA14_SEN3

Results

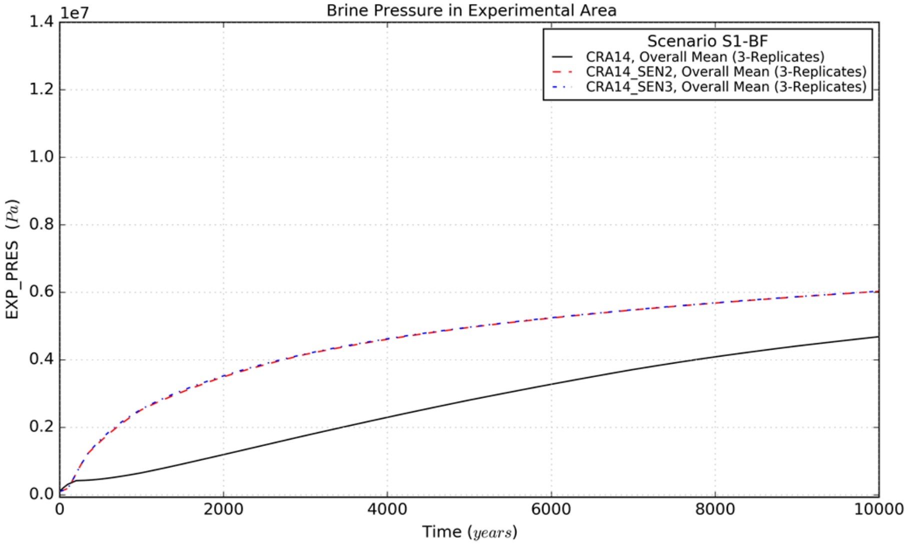
- CRA14
- CRA14_SEN2 – ϕ reduced, k reduced, k_r nonlinear, C_p nonzero, s_r increased in OPS/EXP
- CRA14_SEN3 – ϕ reduced, k reduced, k_r nonlinear, C_p nonzero, s_r increased in OPS/EXP + PCS

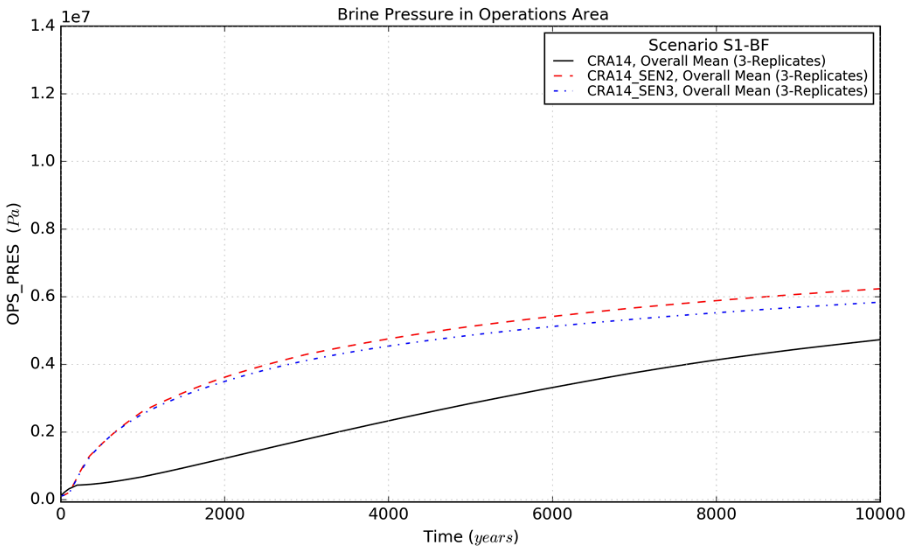
Results are presented for the CRA14_SEN3 study in comparison with the CRA14 PA (and the CRA14_SEN2 sensitivity study, where applicable)



OPS/EXP Pressures – Scenario 1

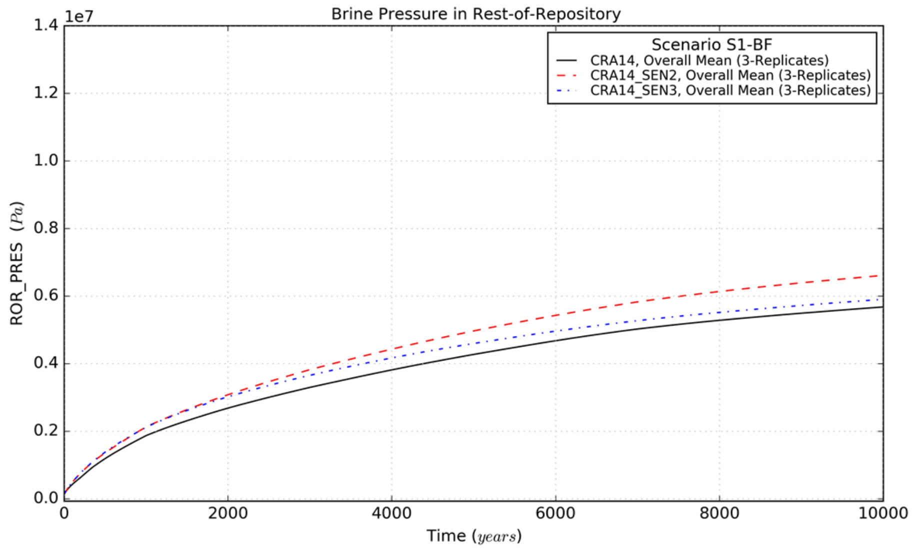
- Increase in pressure results from a decrease in porosity and permeability, increase in initial and residual brine saturations, increase in residual gas saturations, and application of capillary-pressure effects on relative permeability which collectively decreases pore volume and brine and gas flows within OPS/EXP and across the northernmost PCS
- Scenario 1 EXP_PRES Function Average
  - CRA14 - 2.67E+06
  - CRA14_SEN2 - 4.53E+06
    - Increase = 70% over CRA14
  - CRA14_SEN3 - 4.54E+06
    - Increase = 70% over CRA14
- Scenario 1 OPS_PRES Function Average
  - CRA14 - 2.70E+06
  - CRA14_SEN2 - 4.69E+06
    - Increase = 74% over CRA14
  - CRA14_SEN3 - 4.45E+06
    - Increase = 65% over CRA14
- Scenarios 2 thru 6 follow similar trends

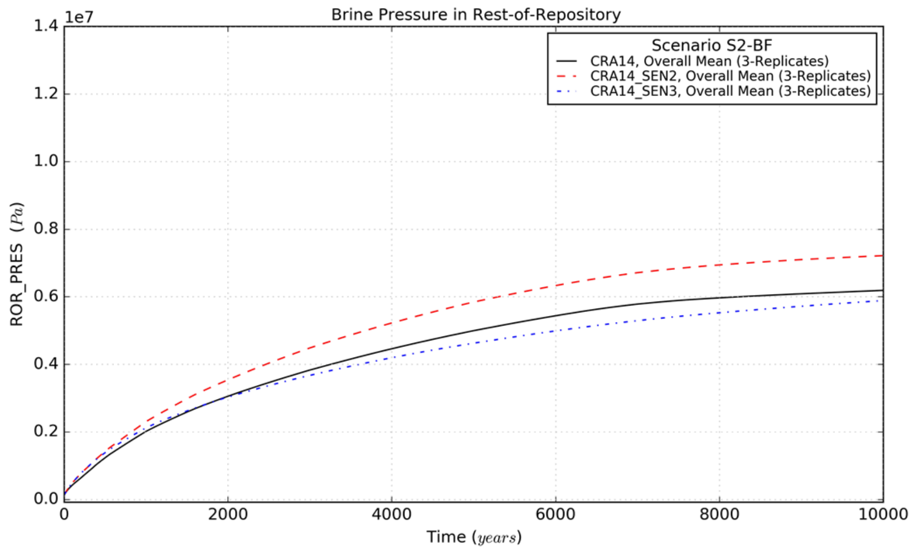




ROR Pressures – Scenarios 1,2

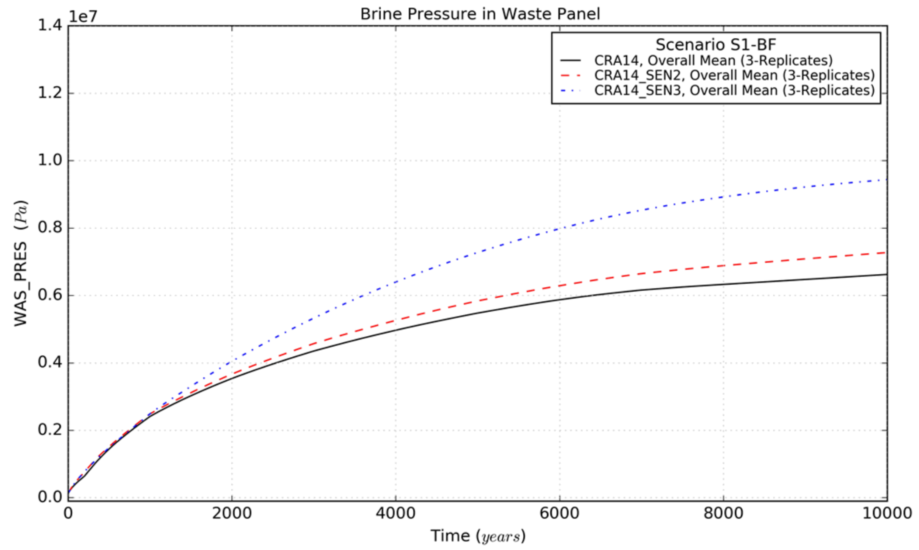
- Pressure change results from reduced brine and gas flows from the Waste panel across the PCS and reduced gas flows across the PCS and northward to the OPS/EXP areas
- Scenario 1 ROR_PRES Function Average
  - CRA14 - 3.95E+06
  - CRA14_SEN2 - 4.58E+06
    - Increase = 16% over CRA14
  - CRA14_SEN3 - 4.23E+06
    - Increase = 7% over CRA14
- Scenario 2 ROR_PRES Function Average
  - CRA14 - 4.50E+06
  - CRA14_SEN2 - 5.24E+06
    - Increase = 16% over CRA14
  - CRA14_SEN3 - 4.25E+06
    - Decrease = 6% under CRA14
- Scenarios 3 thru 6 follow similar trends based on intrusion type

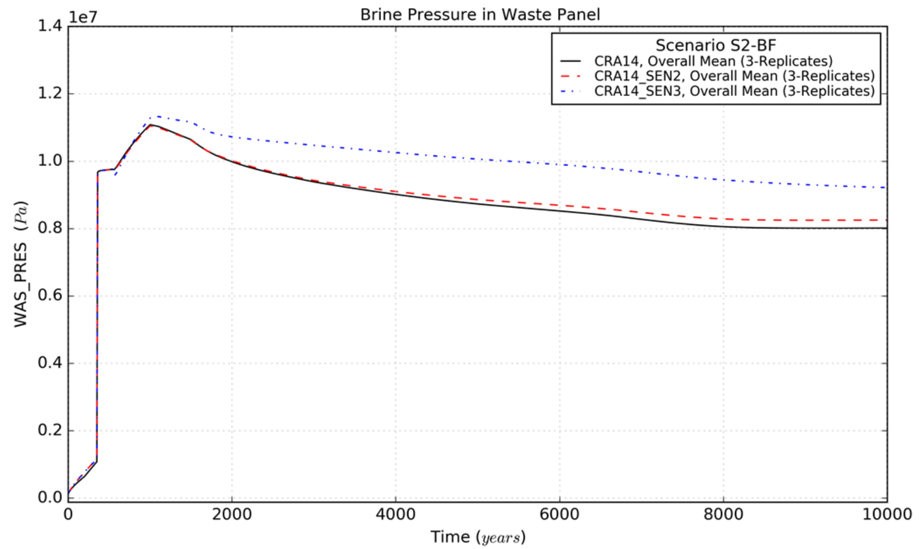




Waste Panel Pressures – Scenarios 1,2

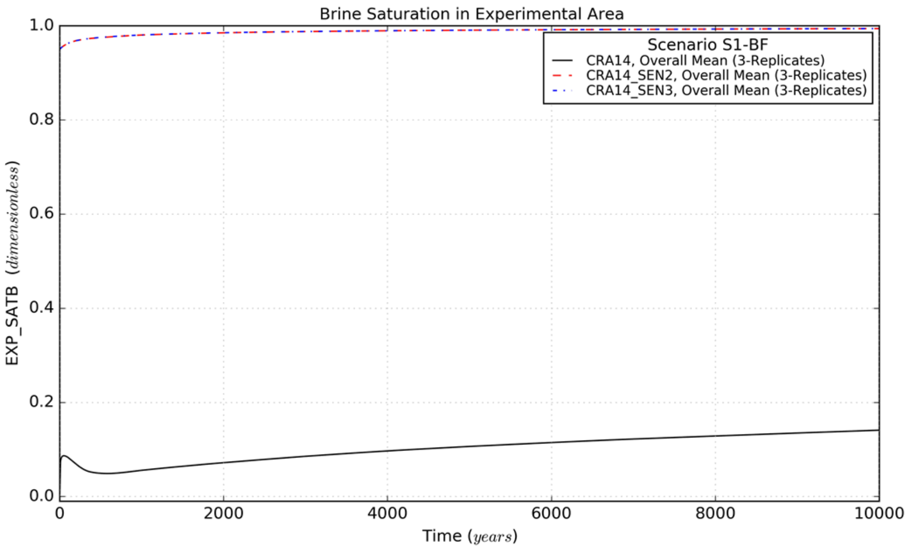
- Increase in pressure results from reduced brine and gas flows from the Waste panel across the PCS and reduced gas flows across the PCS and northward to the OPS/EXP areas
- Scenario 1 WAS_PRES Function Average
  - CRA14 - 4.92E+06
  - CRA14_SEN2 - 5.27E+06
    - Increase = 7% over CRA14
  - CRA14_SEN3 - 6.53E+06
    - Increase = 33% over CRA14
- Scenario 2 WAS_PRES Function Average
  - CRA14 - 8.64E+06
  - CRA14_SEN2 - 8.76E+06
    - Increase = 1% over CRA14
  - CRA14_SEN3 - 9.70E+06
    - Increase = 12% over CRA14
- Scenarios 3 thru 6 follow similar trends

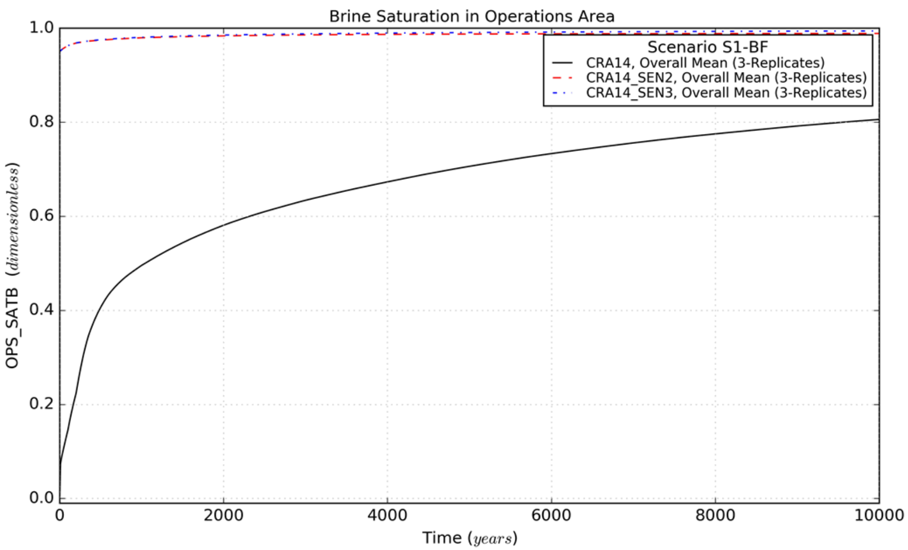




OPS/EXP Saturations – Scenario 1

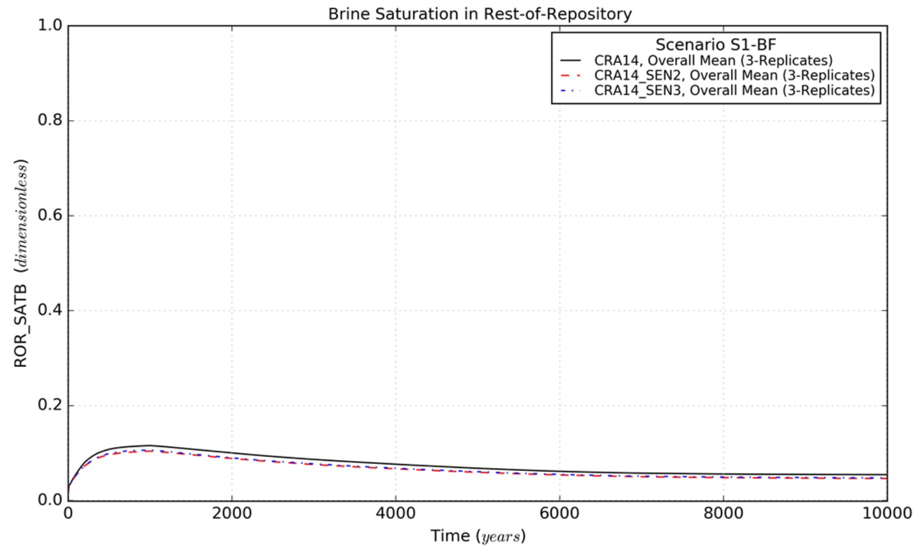
- Increase in brine saturation results from an increased initial saturation and modified parameters that restrict brine flow within the greatly reduced pore volumes in OPS/EXP
- Scenario 1 EXP_SATB Function Average
  - CRA14 - 1.02E-01
  - CRA14_SEN2 - 9.89E-01
    - Increase = 870% over CRA14
  - CRA14_SEN3 - 9.89E-01
    - Increase = 870% over CRA14
- Scenario 1 OPS_SATB Function Average
  - CRA14 - 6.67E-01
  - CRA14_SEN2 - 9.86E-01
    - Increase = 48% over CRA14
  - CRA14_SEN3 - 9.89E-01
    - Increase = 48% over CRA14
- Scenarios 2 thru 6 follow similar trends
- Note that saturations are increased but total brine volumes are essentially unchanged in EXP and reduced in OPS

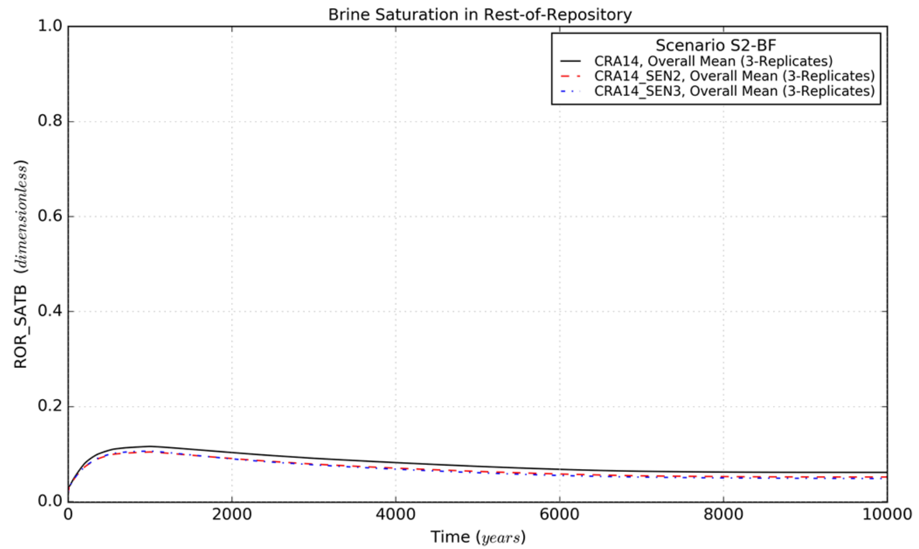




RoR Saturations – Scenarios 1,2

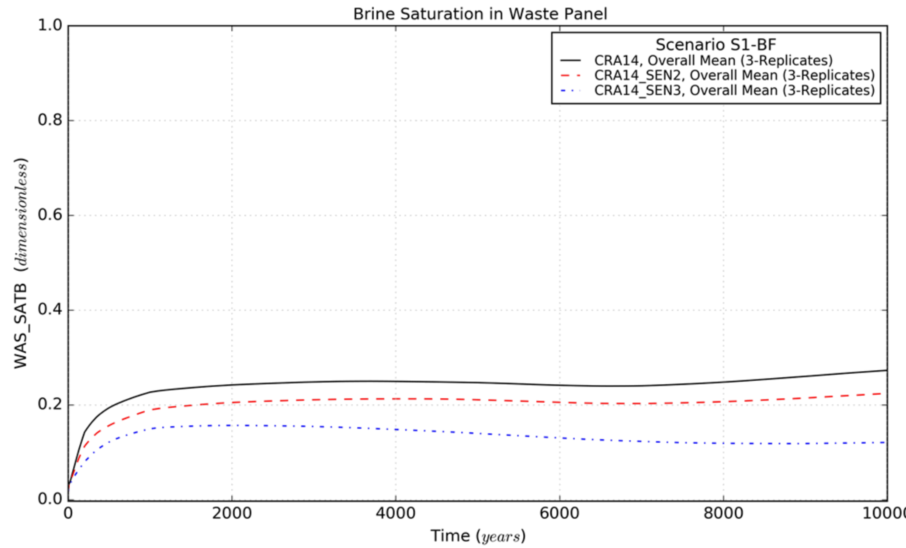
- Reduced brine saturation results from an increased pressure within the rest-of-repository
- Scenario 1 WAS_SATB Function Average
  - CRA14 - 7.44E-02
  - CRA14_SEN2 - 6.54E-02
    - Decrease = 14% under CRA14
  - CRA14_SEN3 - 6.67E-02
    - Decrease = 12% under CRA14
- Scenario 2 WAS_SATB Function Average
  - CRA14 - 7.93E-02
  - CRA14_SEN2 - 6.87E-02
    - Decrease = 15% under CRA14
  - CRA14_SEN3 - 6.69E-02
    - Decrease = 19% under CRA14
- Scenarios 3 thru 6 follow similar trends

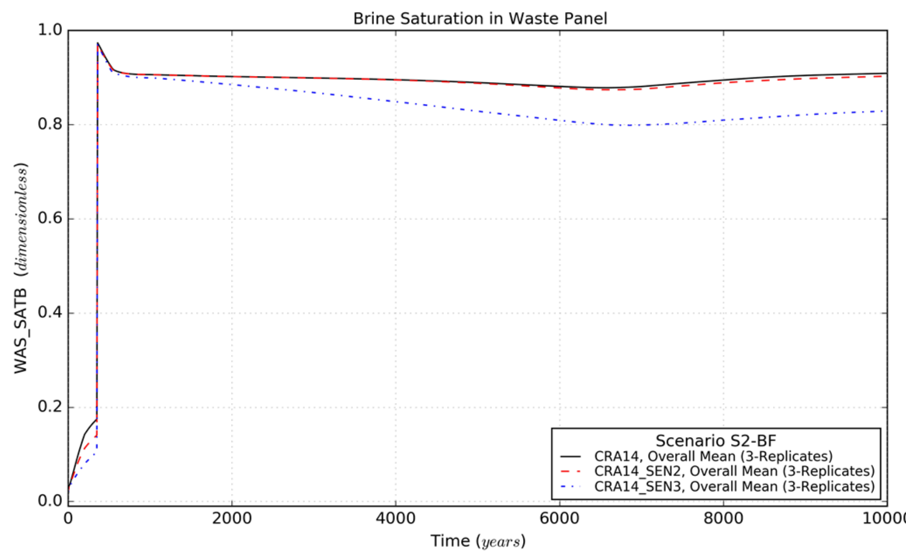




Waste Panel Saturations – Scenarios 1,2

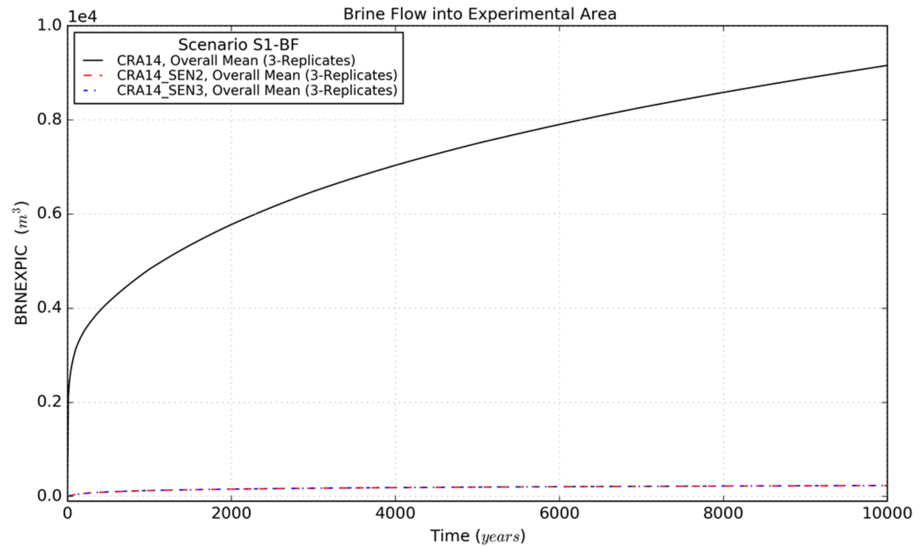
- Reduced brine saturation results from an increased pressure within the waste panel
- Scenario 1 WAS_SATB Function Average
  - CRA14 - 2.40E-01
  - CRA14_SEN2 - 2.02E-01
    - Decrease = 19% under CRA14
  - CRA14_SEN3 - 1.34E-01
    - Decrease = 79% under CRA14
- Scenario 2 WAS_SATB Function Average
  - CRA14 - 8.69E-01
  - CRA14_SEN2 - 8.66E-01
    - Decrease = 1% under CRA14
  - CRA14_SEN3 - 8.15E-01
    - Decrease = 7% under CRA14
- Scenarios 3 thru 6 follow similar trends

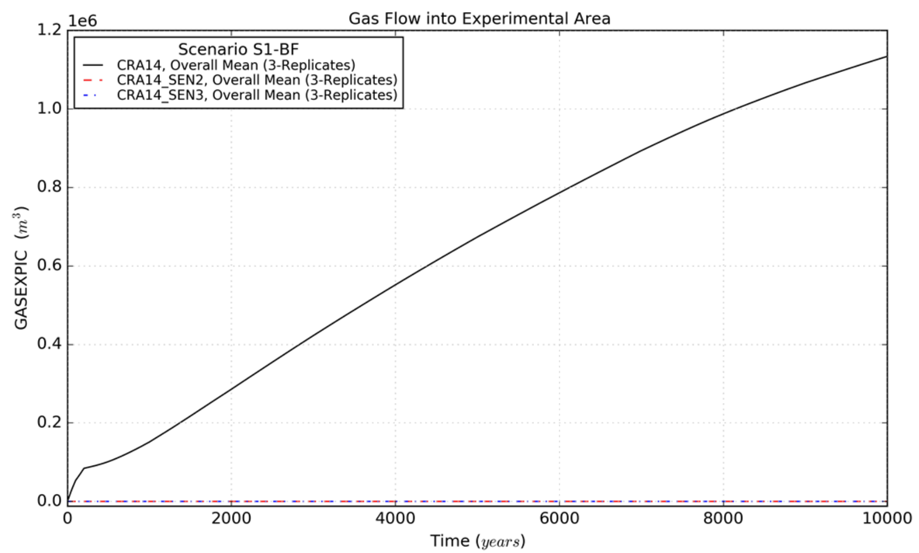




OPS/EXP Brine/Gas Inflow – Scenario 1

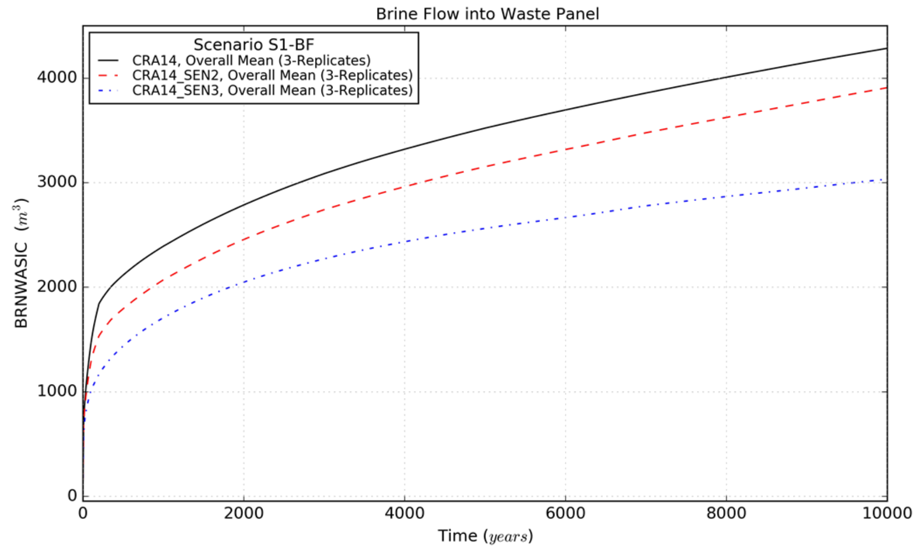
- Significant decrease in brine and gas inflow results from modified parameters that restrict brine and gas flow within the greatly reduced pore volumes in OPS/EXP
- Scenario 1 BRNEXPIC Function Average
  - CRA14 - 7.15E+03
  - CRA14_SEN2 - 1.86E+02
    - Decrease = 38X under CRA14
  - CRA14_SEN3 - 1.86E+02
    - Decrease = 38X under CRA14
- Scenario 1 GASEXPIC Function Average
  - CRA14 - 6.42E+05
  - CRA14_SEN2 - 0
    - Decrease = Infinite
  - CRA14_SEN3 - 0
    - Decrease = Infinite
- Gas flow into OPS is significantly reduced for Scenario 1 under CRA14_SEN2 and is entirely eliminated for Scenario 1 under CRA14_SEN3
- Brine and gas inflow for OPS/EXP Scenarios 2 thru 6 follow similar trends

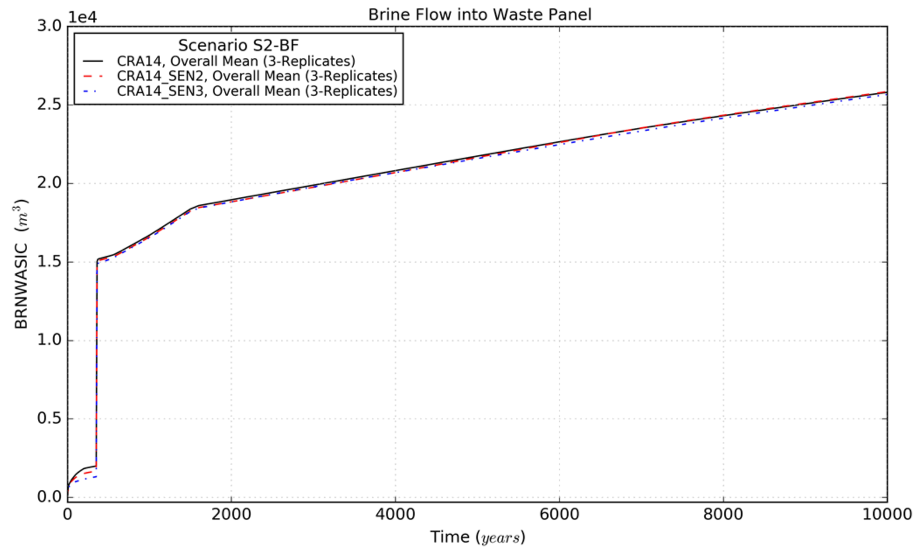




Waste Panel Brine Inflow – Scenarios 1,2

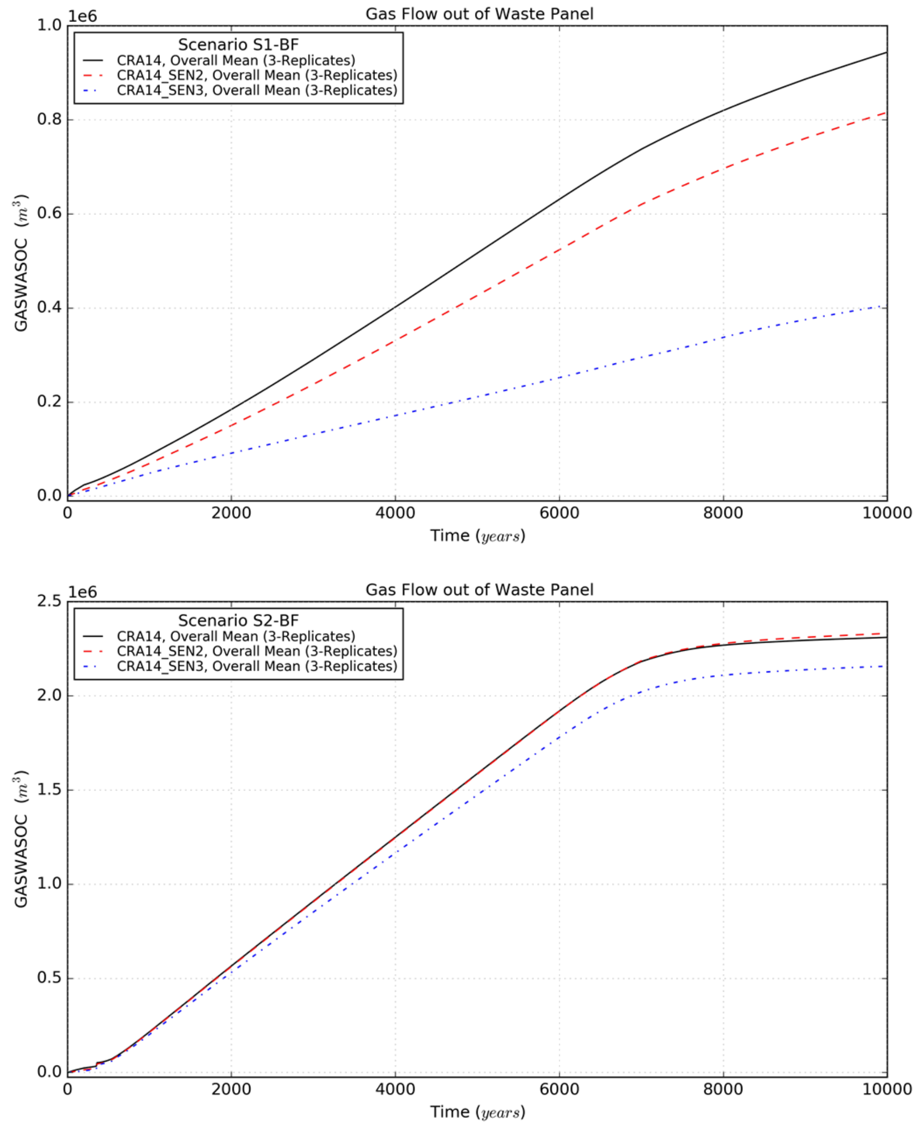
- Reduced brine inflow results from an increased pressure within the waste panel and reduced flow across PCS
- Scenario 1 BRNWASIC Function Average
  - CRA14 - 3.38E+03
  - CRA14_SEN2 - 3.02E+03
    - Decrease = 12% under CRA14
  - CRA14_SEN3 - 2.44E+03
    - Decrease = 39% under CRA14
- Scenario 2 BRNWASIC Function Average
  - CRA14 - 2.09E+04
  - CRA14_SEN2 - 2.09E+04
    - Decrease = 0% under CRA14
  - CRA14_SEN3 – 2.08E+04
    - Decrease = 0% under CRA14
- Magnitude of inflow reduction is significantly less for scenarios with Castile brine intrusions
- Scenarios 3 thru 6 follow similar trends





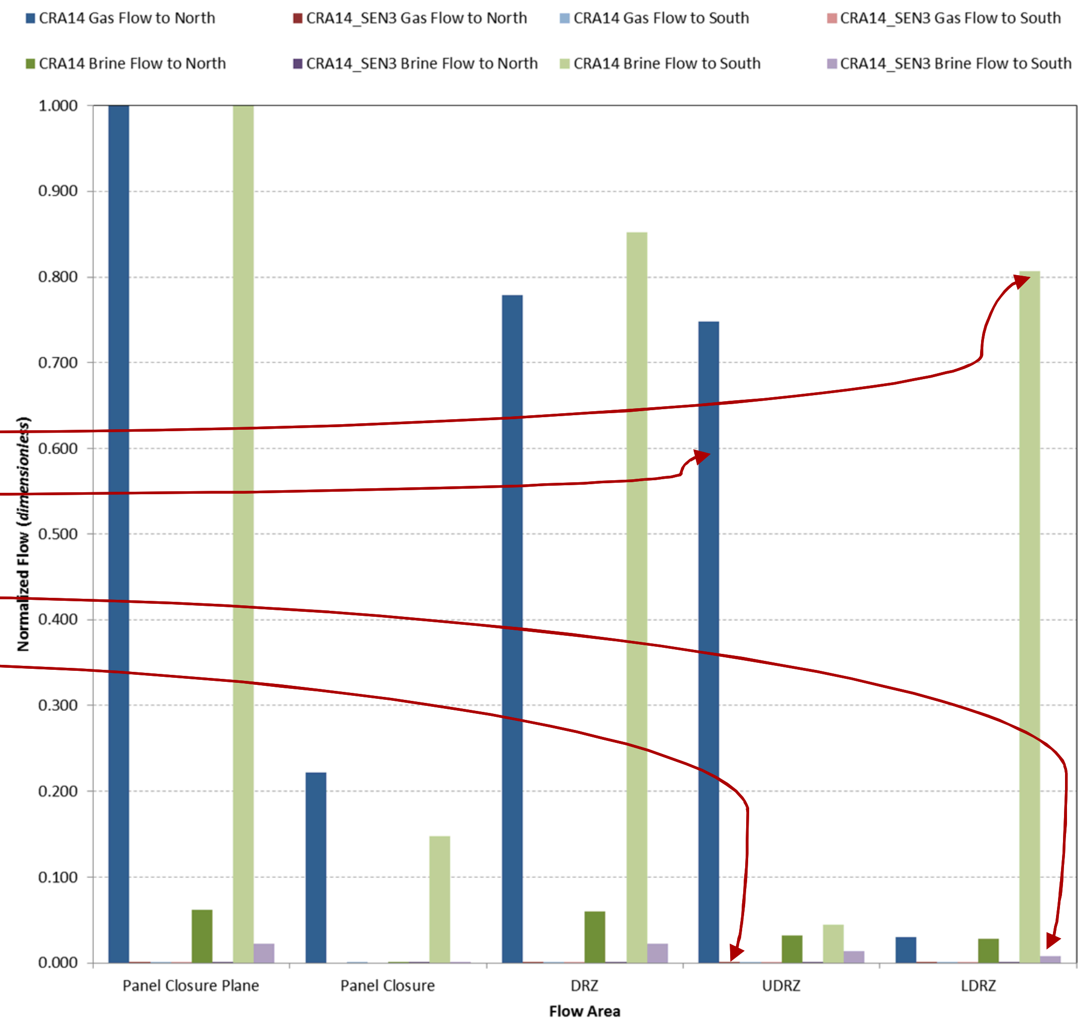
Waste Panel Gas Outflow – Scenarios 1,2

- Reduced gas outflow results from reduced flow across PCS
- Scenario 1 GASWASOC Function Average
  - CRA14 - 5.03E+05
  - CRA14_SEN2 - 4.23E+05
    - Decrease = 12% under CRA14
  - CRA14_SEN3 - 2.12E+05
    - Decrease = 39% under CRA14
- Scenario 2 GASWASOC Function Average
  - CRA14 - 1.44E+06
  - CRA14_SEN2 - 1.44E+06
    - Decrease = 0% under CRA14
  - CRA14_SEN3 - 1.34E+06
    - Decrease = 8% under CRA14
- Magnitude of inflow reduction is significantly less for scenarios with Castile brine intrusions
- Scenarios 3 thru 6 follow similar trends



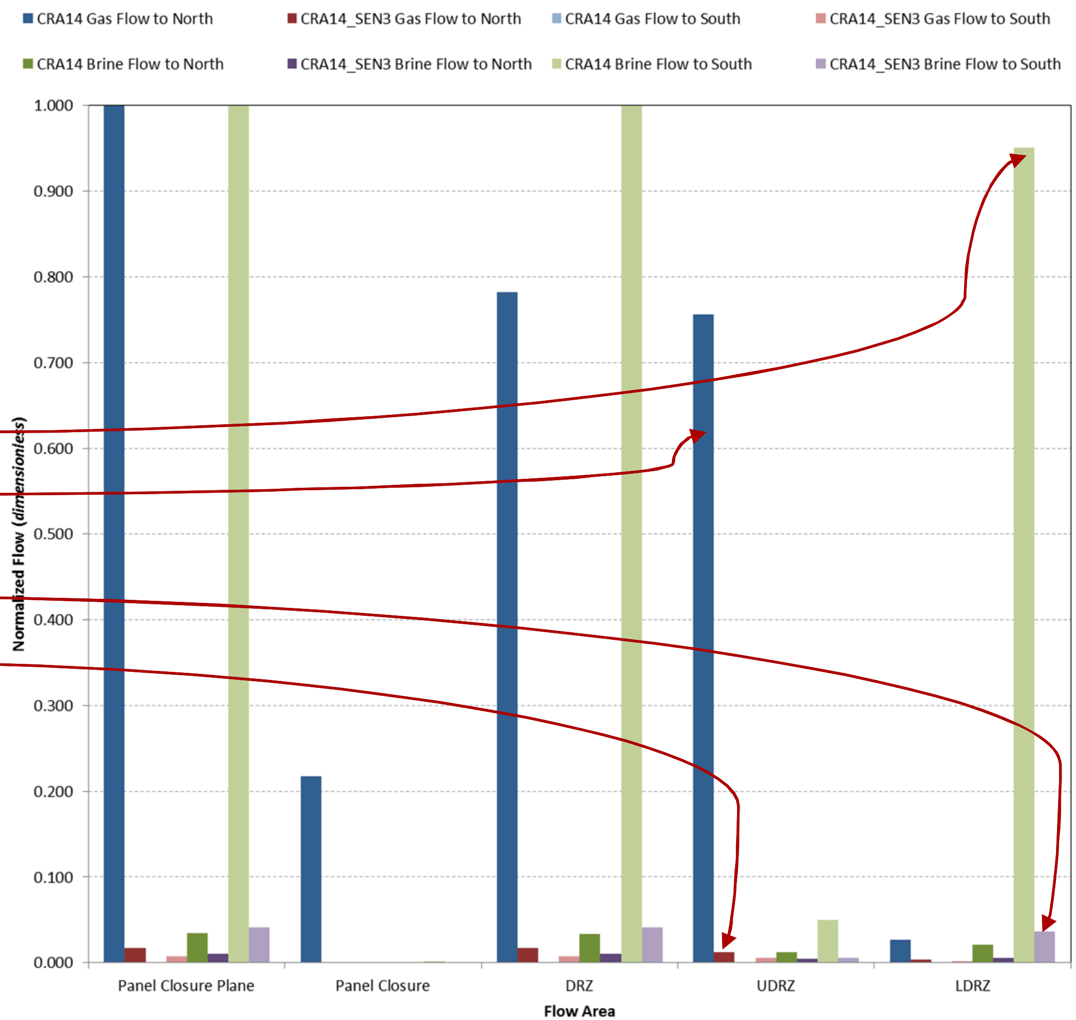
Brine/Gas Flow Across Northernmost Panel Closure – Scenario 1

- Evaluated for north and south flows across:
  - entire panel closure plane (panel closure plus upper and lower DRZ)
  - panel closure
  - panel closure DRZ (upper and lower DRZ)
  - upper DRZ
  - lower DRZ
- Normalized by the maximum gas and brine flow in either direction across the full planes
- CRA14
  - Brine flows predominantly south with 80% through the lower DRZ
  - Gas flows predominantly north with 75% through the upper DRZ
- CRA14_SEN3
  - Brine flow is <3% of CRA14; flows south and within lower DRZ
  - Gas flow is essentially zero
- Scenarios 2 through 6 follow similar trends



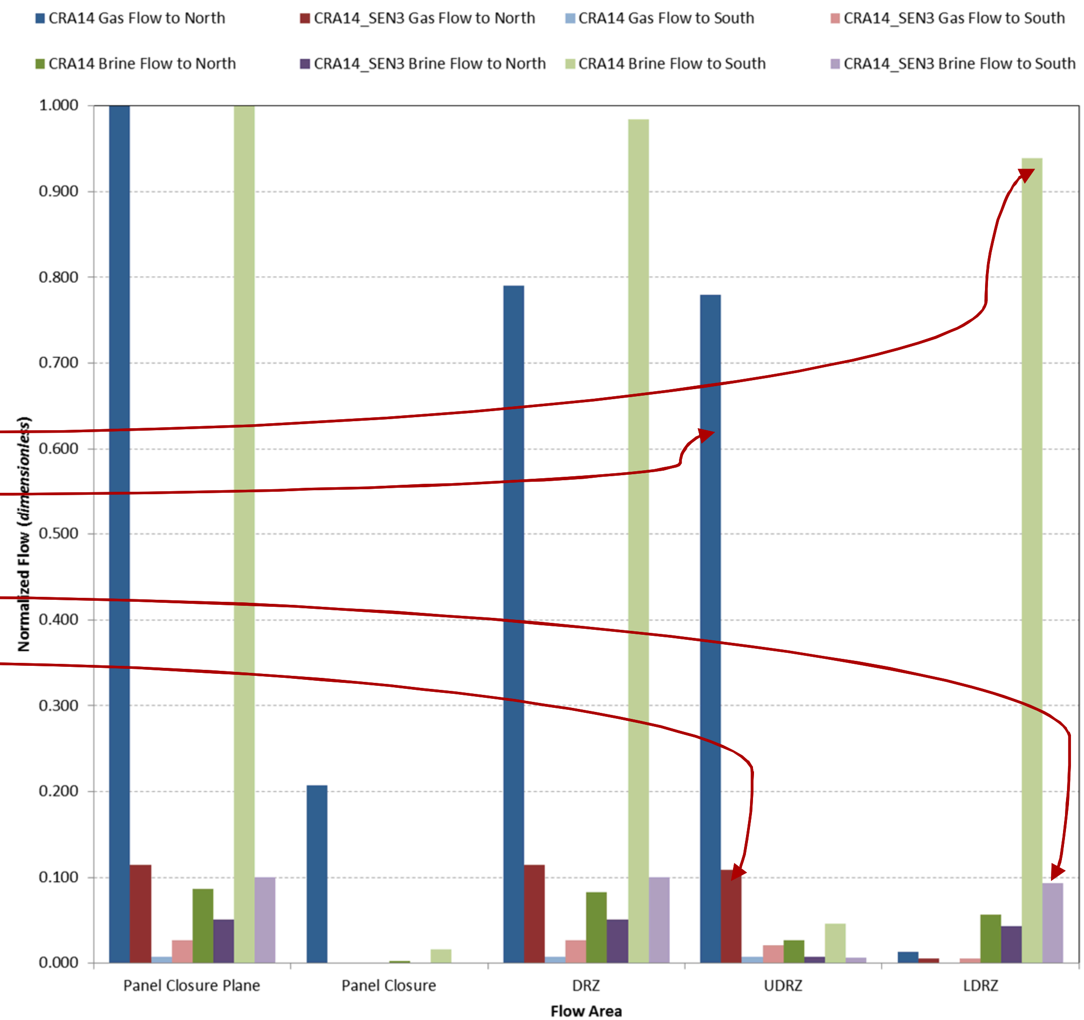
Brine/Gas Flow Across Middle Panel Closure – Scenario 1

- Evaluated for north and south flows across:
  - entire panel closure plane (panel closure plus upper and lower DRZ)
  - panel closure
  - panel closure DRZ (upper and lower DRZ)
  - upper DRZ
  - lower DRZ
- Normalized by the maximum gas and brine flow in either direction across the full planes
- CRA14
  - Brine flows predominantly south with 95% through the lower DRZ
  - Gas flows predominantly north with 76% through the upper DRZ
- CRA14_SEN3
  - Brine flow is <5% of CRA14; flows south and within lower DRZ
  - Gas flow is <2% of CRA14; flows north and within upper DRZ
- Scenarios 2 through 6 follow similar trends



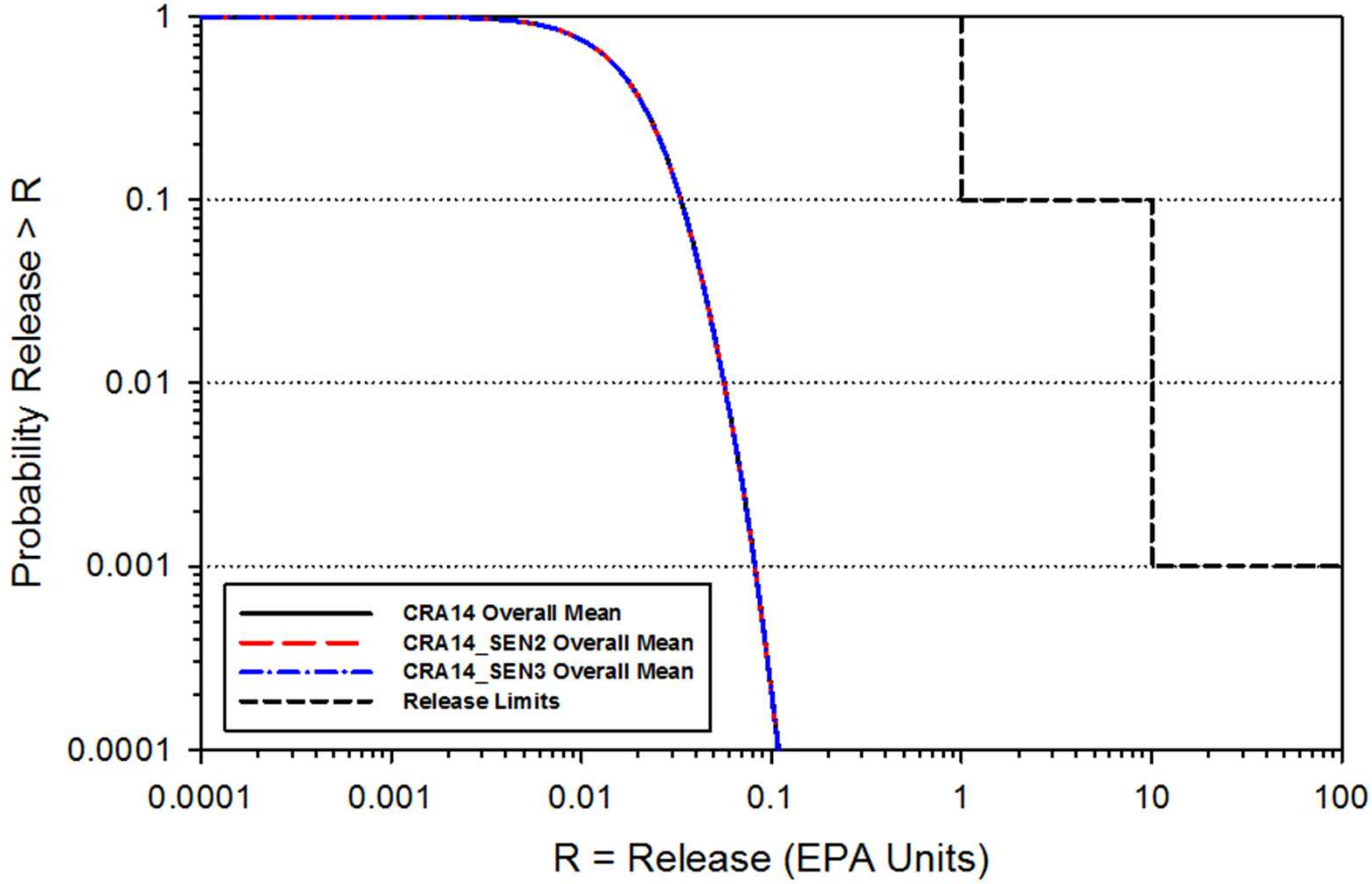
Brine/Gas Flow Across Southernmost Panel Closure – Scenario 1

- Evaluated for north and south flows across:
  - entire panel closure plane (panel closure plus upper and lower DRZ)
  - panel closure
  - panel closure DRZ (upper and lower DRZ)
  - upper DRZ
  - lower DRZ
- Normalized by the maximum gas and brine flow in either direction across the full planes
- CRA14
  - Brine flows predominantly south with 94% through the lower DRZ
  - Gas flows predominantly north with 78% through the upper DRZ
- CRA14_SEN3
  - Brine flow is <10% of CRA14; flows south and within lower DRZ
  - Gas flow is <12% of CRA14; flows north and within upper DRZ
- Scenarios 2 through 6 follow similar trends



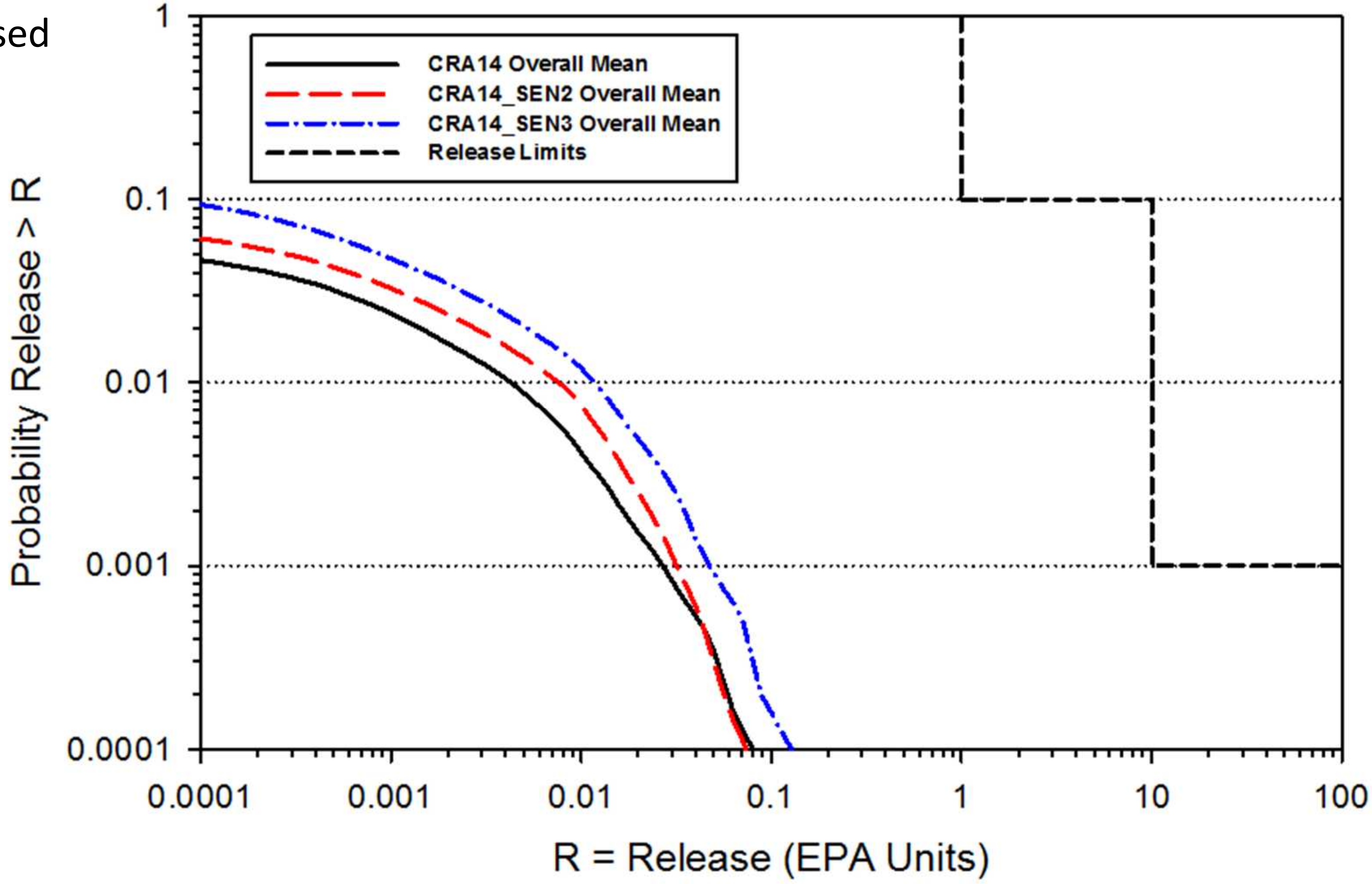
Cuttings and Cavings Releases

- Overall Mean CCDFs (3-replicate)
- No change, as expected



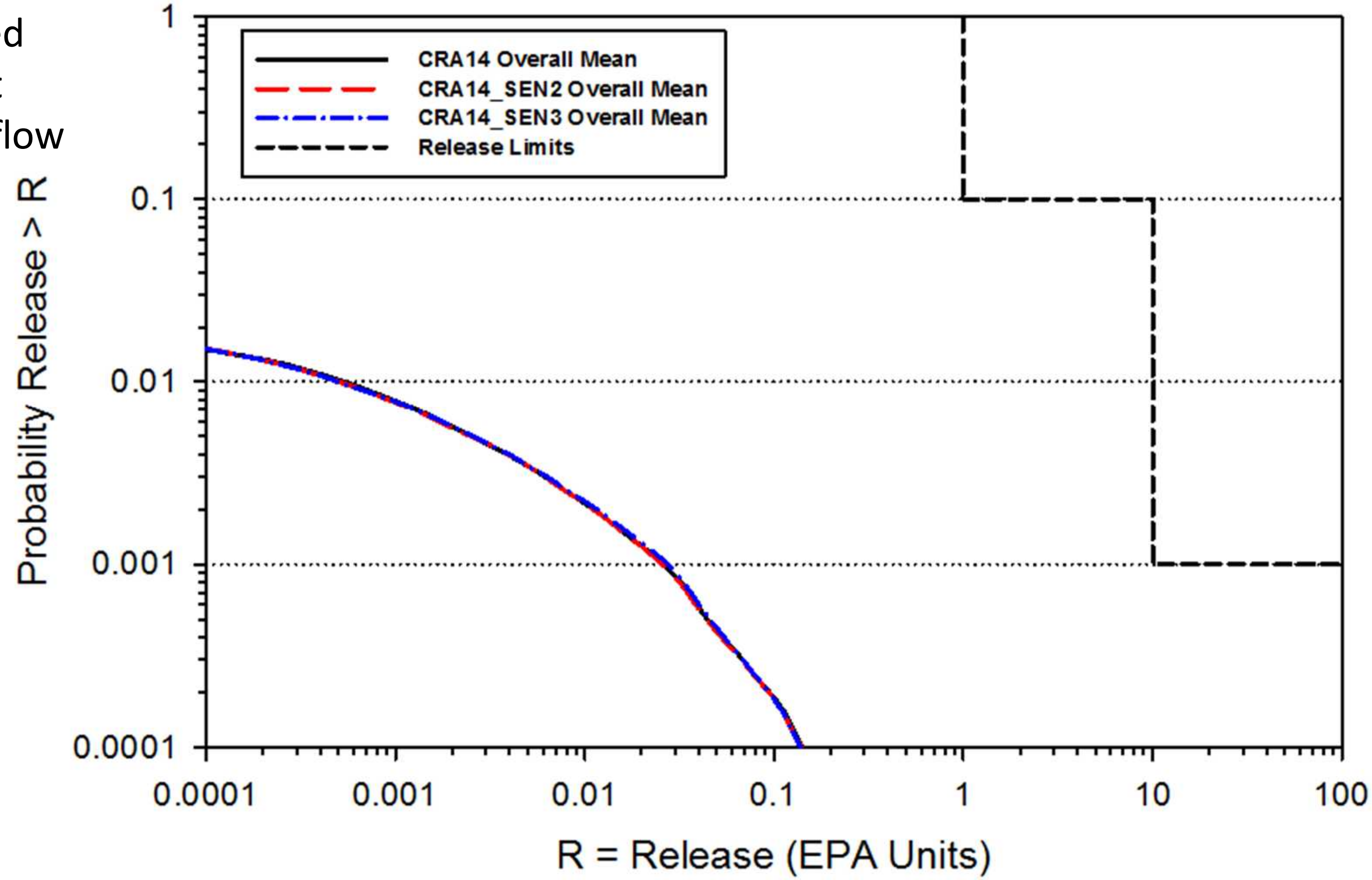
Spallings Releases

- Overall Mean CCDFs (3-replicate)
- Marginally increased due to increased pressure in waste areas



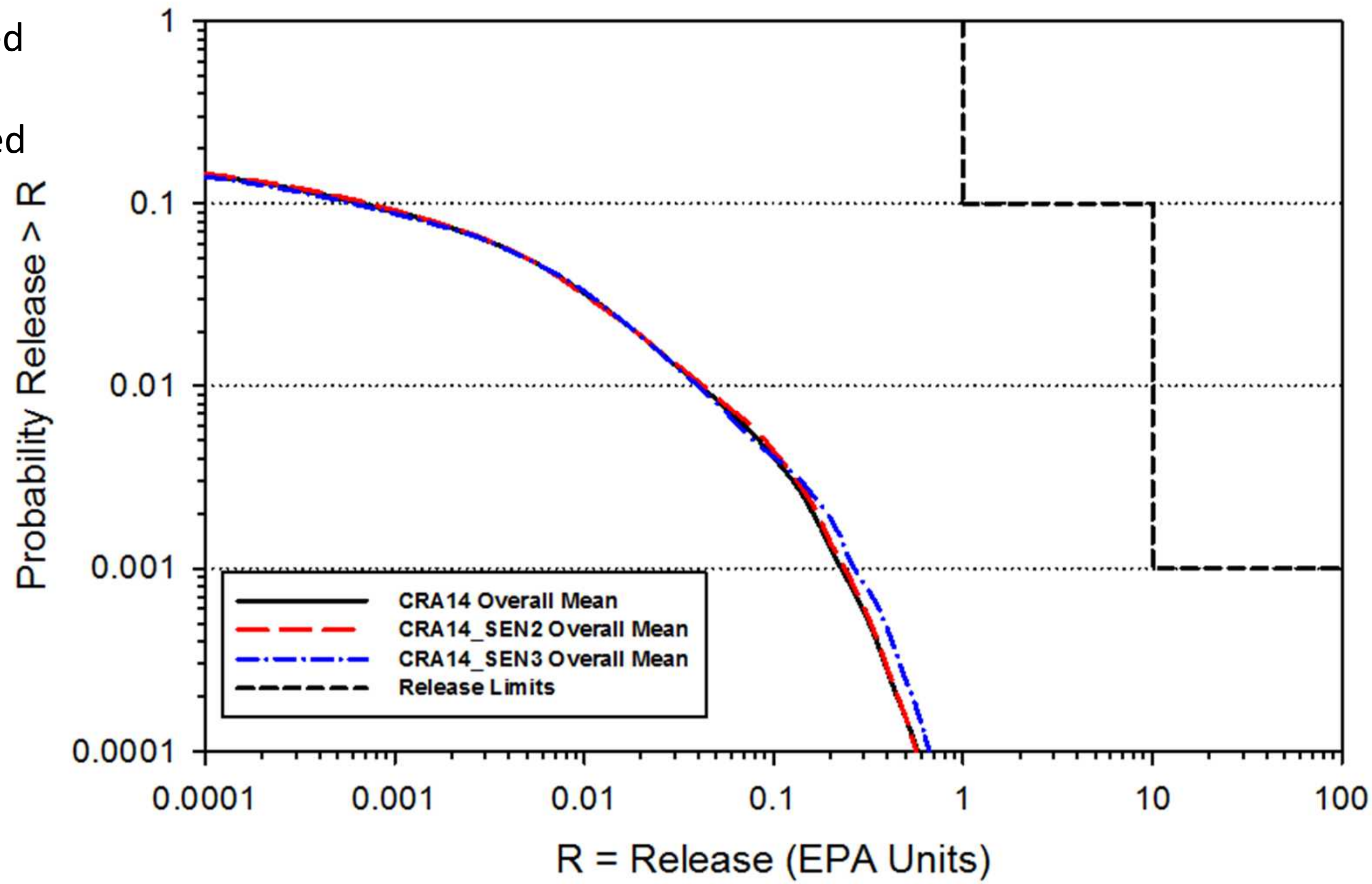
From Culebra Releases

- Overall Mean CCDFs (3-replicate)
- Negligibly changed due to equivalent amount of brine flow up the borehole



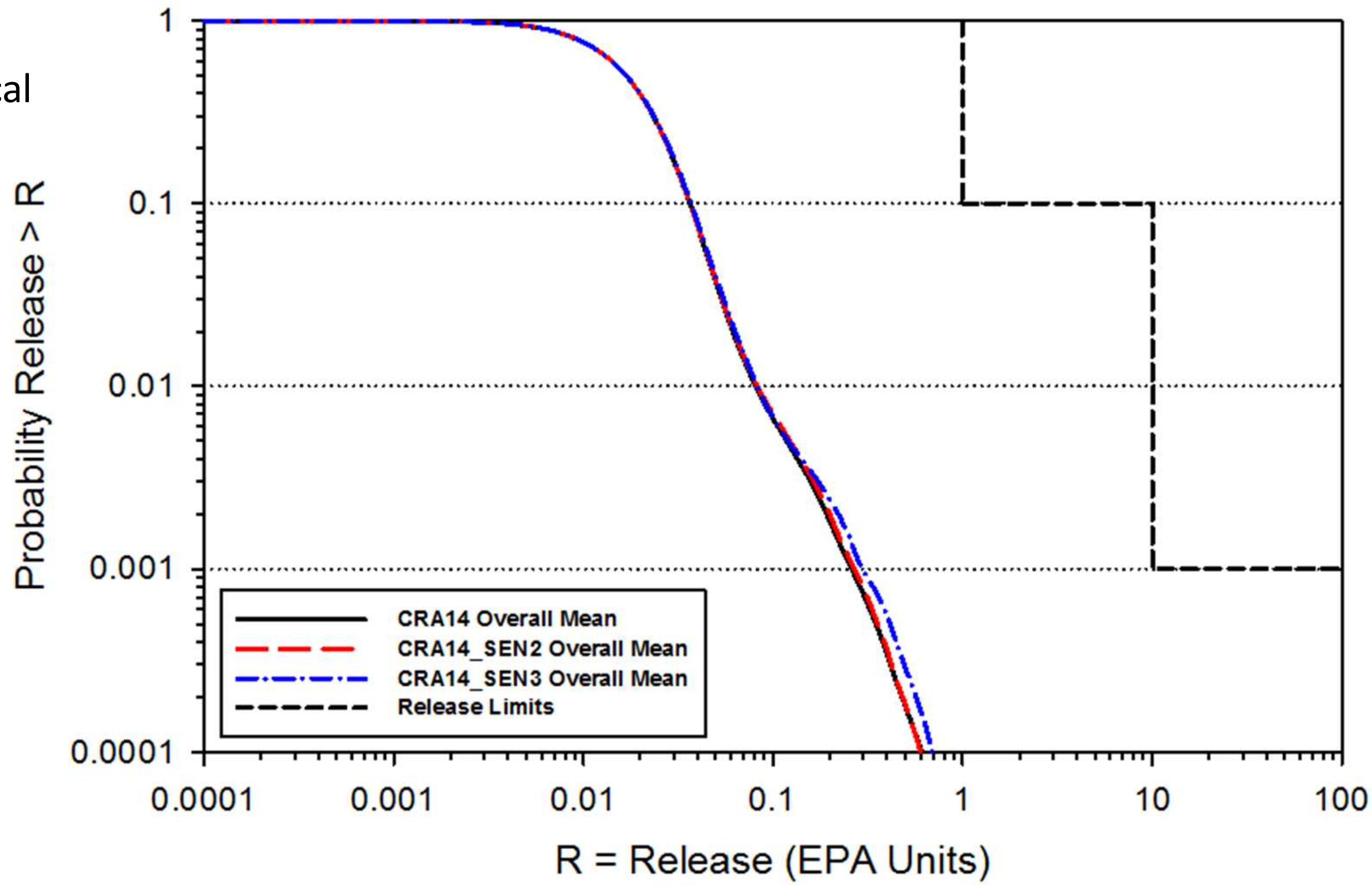
Direct Brine Releases

- Overall Mean CCDFs (3-replicate)
- Minimally changed due to trade-off between increased waste panel pressures and reduced waste panel saturations



Total Releases

- Overall Mean CCDFs (3-replicate)
- 0.1 Probability essentially identical
- 0.001 Probability minimally increased by 15% for CRA14_SEN3



Conclusions

- The modeling assumptions associated with the operations and experimental areas of the repository and the panel closure system have only a small effect on the prediction of total releases from the repository such that the results from the sensitivity studies support the reasonableness, computational efficiency/stability, and adequacy of the current (CRA14) model to demonstrate compliance with the regulatory limits